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An Improvement of Hand Press Machine by Design for Manufacturing and Assembly (DFMA) Methodology

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ABSTRACT
This research consists of the analysis of hand press machine selected using the Design for Manufacturing and Assembly (DFMA) method. DFMA is a method that combines both Design for Manufacturing (DFM) and Design for Assembly (DFA) techniques. It has the purpose to make improvements on the existing product by implementing DFMA to reduce number of components, time, and cost. The combination of hand press machine and a die cutting tool has been an effective tool to produce and replicate identical designs in the shortest time. The main objective of this research is to develop a Hand Press Machine that exhibits superior design efficiency and reduced manufacturing costs compared to the original design. To achieve this, the chosen existing model, the WUTA Pro Leather Cutting Machine, was remodelled using SolidWorks 2022 software. The original design of the Hand Press Machine had a design efficiency of 25.89%. However, the improved design achieved a significantly higher design efficiency of 36.56%, representing an increase of 10.67%. To attain this improvement, four modifications were implemented. One notable achievement in the improved design was a reduction in the total number of parts. The original design comprised 52 parts, whereas the improved design successfully reduced this to 34 parts, resulting in a reduction of 18 parts. The cost analysis, based on total absorption cost, revealed that the manufacturing cost of the original design was estimated at $362.01 for 18 manufactured parts. In contrast, the improved design was able to achieve a cost reduction, with an estimated manufacturing cost of around $339.16 for 16 manufactured parts. This indicates a cost reduction of $22.85 between the two models.
Keywords: DFMA, DFM, DFA, DFA Worksheet, SolidWorks Costing, Cost Analysis, Hand Press Machine.

1 INTRODUCTION

The concept of Design for Manufacturing and Assembly (DFMA) is now widely adopted in industry. It aims to achieve a product design that is easy to manufacture and assemble. The DFMA methodology relies on the collaboration between product designers and manufacturing engineers. Their effort is to optimize the product's design for ease of assembly while minimizing production costs. By implementing DFMA methodology, businesses can improve their competitiveness by creating products that are easier to manufacture and assemble while reducing costs and enhancing customer satisfaction.

A company called Boothroyd Dewhurst, Inc. (BDI) develops software systems for the globally recognised and approved "Design for Manufacture and Assembly" (DFMA). In the middle of the 1960s, Dr. Geoffrey Boothroyd and Dr. Peter Dewhurst, the pioneers of BDI, began developing DFMA techniques. U.S. National Science Foundation-funded collaborative research on the design for automatic feeding and insertion conducted at the University of Massachusetts in 1977 served as the foundation for the development of the DFMA approach.(Curtis, 2006).

The findings of this research were initially presented as a handbook in 1980, and Dr. K. G. Swift put together a UK version of the handbook for the Salford University Industrial Centre. A personal computer programme for DFA was launched by BDI in 1982, and an updated release of the handbook was issued in 1983 based on the lessons learnt during the execution of DFA in industry. Roughly ten years after it was first introduced, variations of the BDI DFA approach started to emerge, concentrating on the assembly for specific component types such Printed Circuit Boards (PCB) (Curtis, 2006).

Since 1985, Boothroyd Dewhurst and a colleague of his, Dr. Winston Knight have broadened the scope of BDI DFA's capabilities to incorporate "Design for Manufacture (DFM)" issues, which comprise structured techniques for early cost-estimating of parts along with associated tooling. Machined components, injection-moulded parts, sheet metal stampings, die castings, and powdered metal parts costs estimation methods and software have been developed and rendered commercially by BDI (Curtis, 2006).

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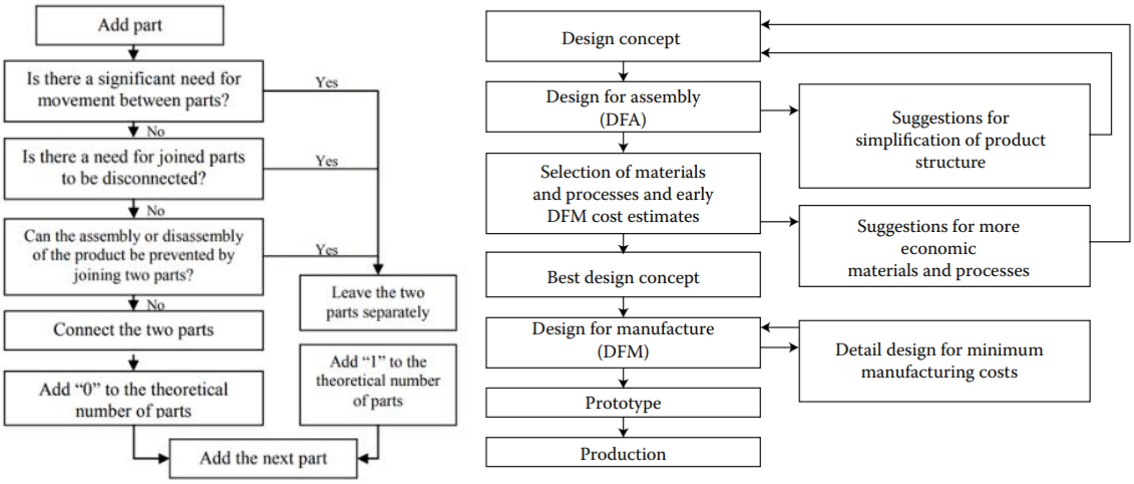


(a) (b)

Figure 1: (a) Component Elimination Scheme and (b) Steps Taken in DFMA

Hand press machines have evolved gradually over time. Materials were initially formed by hand using hammers. Eventually, big, and heavy hammers were used to press thick metal workpieces or vast amounts of material at once. Then, for operating the big steam hammers, steam power and windmills were used. Workers had to manually hammer metal by hand to change the shape of materials before the machine press was invented. After that, it lost its physical effectiveness and was unable to be used to alter the shape of massive or large-sized materials. The steam hammer, often referred to as a drop hammer, was invented in the middle of the nineteenth century.(Enjeti et al., 2022)

Die cutting is a mass production technique that involves cutting or shaping materials like paper and chipboard using a die with sharp edges. The process involves creating precise patterns, streamlining the production process, and allowing shoemakers to replicate and standardize shoe sole sizes. Die cutting has evolved over time, revolutionizing various sectors, and allowing for intricate designs. The efficiency and speed of die cutting are influenced by factors such as stroke speed, feeding approach, and die cutting machine type. It is a versatile and asset that can be used for both low and high-volume production.(Tripathi, 2021)

This study aims to achieve three objectives. The first objective is to compare and analyse the hand press machines available in the market using DFMA as the basis for evaluation. Second, this study aims to improve the design efficiency of hand press machine by implementing DFMA principle. The last aim is to determine the total reduction of cost to manufacture and assembly of hand press machine using SolidWorks software and cost analysis.

2 Methodology

2.1 Design for Manufacturing and Assembly

Design for Manufacturing and Assembly (DFMA) optimizes product design for efficient production and assembly by combining DFA and DFM principles. It reduces costs, streamlines assembly, and minimizes the number of parts.(Battaïa et al., 2018) DFMA is applied in various sectors and enhances overall productivity.(Rankohi et al., 2022) It can be used to develop new products or improve existing ones.(Nasyitah Mohammad et al., 2020) DFMA can also be integrated with sustainable design principles to achieve environmental sustainability by reducing material costs, assembly time, and the product's environmental impact. Implementing DFMA offers advantages such as cost reduction, improved efficiency, and better product quality.(Gao et al., 2018; Rankohi et al., 2022; Trinder, 2018) However, DFMA may require additional time and resources during the design phase and may limit design creativity.(Gao et al., 2018; Trinder, 2018)

The objective is to create a product that can be produced easily and economically. The core of any design for manufacturing system is a collection of design principles or guidelines that are arranged to aid the designer in reducing cost and difficulty during manufacturing process.(Chang et al., 1998)

The guidelines for DFMA are as listed below:

1. Reduce the number of parts.
2. Create a modular design.
3. Use standard components.
4. Design parts with multiple function.
5. Design for easy fabrication.
6. Avoid using separate fasteners.
7. Minimize assembly directions.
8. Increase compliance.
9. Minimize handling.

2.2 Design for Manufacturing

DFM focuses on optimizing product design for efficient manufacturing by considering factors such as material selection, part size, shape, and tolerances. (Reforiandi & Arief, 2021) Its aim is to lower manufacturing costs and time without compromising product quality. DFM ensures that the product is compatible with the intended manufacturing processes, resulting in efficient production. By designing products that can be easily manufactured, DFM enables manufacturers to streamline their operations and achieve cost savings.

2.2.1 SolidWorks Costing

SolidWorks is a widely used CAD software that includes the feature of SolidWorks Costing. This feature helps users assess the cost implications of their designs(Prasetya & Khaerudini, 2021) by providing estimates of manufacturing costs for parts and assemblies, specifically for sheet metal and machined components. It considers design choices, material selection, and manufacturing processes to optimize designs for cost efficiency. Users can analyse the economic feasibility of their designs and make modifications to meet cost targets using cost estimates based on labour, materials, and production processes. SolidWorks Costing is a valuable tool for making informed decisions and developing cost-effective design solutions.(Eustache et al., 2020)

2.3 Design for Assembly

DFA focuses on optimizing product design for efficient assembly by considering factors such as part count, part orientation, and fastener selection.(Johnson & Sanket, 2022) Its goal is to lower the cost and time of assembly by developing products that are easy to put together. DFA ensures that the product design is compatible with the intended assembly processes, resulting in streamlined assembly operations. By designing products with simplicity and ease of assembly in mind, DFA enables manufacturers to reduce assembly costs and improve overall efficiency.

The table below is showing an example of design for manual assembly worksheet. This table has normally been used together with the Manual Handling table and the Manual Insertion table. Each column in the table works differently as they are for recording different data.

Table 1: Design for Manual Assembly Worksheet

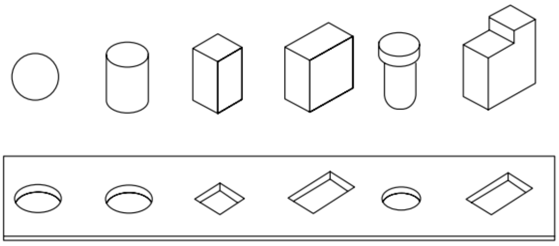
0	C1	C2	C3	C4	C5	C6	C7	C8	C9
Name of part	Part ID	No. of operations carried out consecutively	Manual handling code	Manual handling time per part	Manual insertion code	Manual insertion time per part	Operation time C2(C4 + C6)	Total angle of symmetry (α+β), deg(°)	Estimation for theoretical minimum parts
			Total =				TM		NM

There are three equations that can be applied to the DFA Worksheet. The equations are used to calculate the operation time, total manual assembly time, and design efficiency. Elements that are used in the equations are number of operations(N_0), manual handling time per part (T_h), manual insertion time per part (T_i), total handling time(T_t), total insertion time(T_s), theoretical minimum number of parts(NM), and total manual assembly time(TM).

$$Operation\ time, T_0 = N_0[T_h + T_i] \tag{1}$$

$$Total\ manual\ assembly\ time, TM = T_t + T_s \tag{2}$$

$$Design\ efficiency, DE = \frac{3NM}{TM} \tag{3}$$



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

Figure 2: Alpha (α) and Beta (β) Rotational Symmetric for Parts

(a)

MANUAL HANDLING-ESTIMATED TIMES (s)

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					Parts present handling difficulties (1)				
		Thickness >2 mm			Thickness ≤2 mm		Thickness >2 mm			Thickness ≤2 mm	
		Size >15 mm	6 mm ≤ size >15 mm	Size <6 mm	Size >6 mm	Size ≤6 mm	Size >15 mm	6 mm ≤ size ≤15 mm	Size <6 mm	Size >6 mm	Size ≤6 mm
		0	1	2	3	4	5	6	7	8	9
(α+β) < 360°	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
360° ≤ (α+β) < 540°	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
540° ≤ (α+β) < 720°	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
(α+β) = 720°	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

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 need standard tools other than tweezers	Parts need special tools for grasping and manipulation
			Parts can be manipulated without optical magnification				Parts require optical magnification for manipulation					
			Parts are easy to grasp and manipulate		Parts present handling difficulties (1)		Parts are easy to grasp and manipulate		Parts present handling difficulties (1)			
			Thickness >0.25 mm	Thickness ≤0.25 mm	Thickness >0.25 mm	Thickness ≤0.25 mm	Thickness >0.25 mm	Thickness ≤0.25 mm	Thickness >0.25 mm	Thickness ≤0.25 mm		
			0	1	2	3	4	5	6	7	8	9
α ≤ 180°	0 ≤ β ≤ 180°	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
α ≤ 180°	β = 360°	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8
α = 360°	α ≤ β ≤ 180°	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
α = 360°	β = 360°	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

Two hands for manipulation

		Parts present no additional handling difficulties					Parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)				
		α ≤ 180°			α = 360°		α ≤ 180°			α = 360°	
		Size >15 mm	6 mm≤ size ≤15 mm	Size <6 mm	Size >6 mm	Size ≤6 mm	Size >15 mm	6 mm≤ size ≤15 mm	Size <6 mm	Size >6 mm	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

Two hands or assistance required for large size

		Parts can be handled by one person without mechanical assistance									Two persons or mechanical assistance required for parts manipulation
		Parts do not severely nest or tangle and are not flexible								Parts severely nest or tangle or are flexible (2)	
		Part weight < 10 lb				Parts are heavy (>10 lb)					
		Parts are easy to grasp and manipulate		Parts present other handling difficulties (1)		Parts are easy to grasp and manipulate		Parts present other handling difficulties (1)			
		α ≤ 180°	α = 360°	α ≤ 180°	α = 360°	α ≤ 180°	α = 360°	α ≤ 180°	α = 360°		
		0	1	2	3	4	5	6	7	8	9
Two hands, two persons or mechanical assistance required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

(b)

MANUAL INSERTION-ESTIMATED TIMES (s)

Key:
- Part added but not secured
- Part secured immediately
- Separate operation

Addition of any part (1) where neither the part itself nor any other part is finally secured immediately		Alter assembly no holding down required to maintain orientation and location (3)				Holding down required during subsequent processes to maintain orientation at location (3)			
		Easy to align and position during assembly (4)		Not easy to align or position during assembly		Easy to align and position during assembly (4)		Not easy to align or position during assembly	
		No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	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
Part and associated tool (including hands) cannot easily reach the desired location: 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

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.)		Plastic deformation immediately after insertion: Plastic bending or torsion			Plastic deformation immediately after insertion: Riveting or similar operation			Screw tightening immediately after insertion	
		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)	Easy to align and position during assembly (4)	Not easy to align or position during assembly: No resistance to insertion	Not easy to align or position during assembly: Resistance to insertion (5)	Easy to align and position during assembly (4)	Not easy to align or position during assembly: No resistance to insertion	Not easy to align or position during assembly: Resistance to insertion (5)	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 accessor restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
Part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: Due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

		Mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				Non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				Non-fastening processes	
		None or localized plastic deformation			Bulk plastic deformation (large proportion of part is plastically deformed during fastening)	Metallurgical processes: No additional material required (e.g. resistance, friction welding, etc.)	Metallurgical processes: Additional material required: Soldering processes	Metallurgical processes: Additional material required: Weld/braze processes	Chemical processes (e.g. adhesive bonding, etc.)	Manipulation of parts or sub-assembly (e.g. orienting, fittings or adjustment of part(s). etc.)	Other processes (e.g. liquid insertion, etc.)
		Bending or similar process	Riveting or similar processes	Screw tightening or other processes							
		0	1	2	3	4	5	6	7	8	8
Assembly processes where all solid parts are in place	9	4	7	5	12	7	8	12	12	9	12

Figure 3: (a) Manual Handling Table (b) Manual Insertion Table

2.4 Cost Analysis

Cost analysis is a method used to assess the feasibility and profitability of a project or decision by evaluating its costs. It involves identifying and analysing all costs associated with the project, product, or service to understand their impact on the overall cost.(Posner, 2000)

2.4.1 Absorption Cost Analysis

Absorption cost analysis, also known as full costing, is a valuable method used to calculate the total cost of manufacturing a product. This approach takes into account all manufacturing costs, including both variable and fixed expenses, when determining the expenses associated with producing goods and maintaining inventory. By incorporating fixed manufacturing costs into the cost of manufacturing, absorption costing provides a more accurate perspective of the overall cost of producing an item. This method proves particularly useful in manufacturing as it enables companies to calculate the actual cost of fabricating a product, allowing for informed decisions regarding pricing and profitability. (Lakmal, 2014; Royen & Pratiwi, 2011; Wardhana & Armein, 2011) By considering all costs of production, absorption cost analysis empowers manufacturing companies to make wise choices and optimize their financial outcomes.

Table 2: Absorption Cost Analysis

Steps	Notes	Unit Cost, $
Define Unit		
Determine No. of Units		
Calculate The Direct Cost		
Material Cost:		
Other:		
Total Direct Cost:		
Calculate Indirect Cost		
Fasteners:		
Utilities:		
Other:		
Total Indirect Cost:		
Calculate Overhead Cost		
Overhead Cost:	$\frac{Total\ Indirect\ Cost}{Total\ Number\ of\ Units}$	
Total Overhead Cost:		
Calculate the Unit Cost		
Total Cost	**Direct Cost + Indirect Cost + Overhead Cost**	

3 RESULTS AND DISCUSSIONS

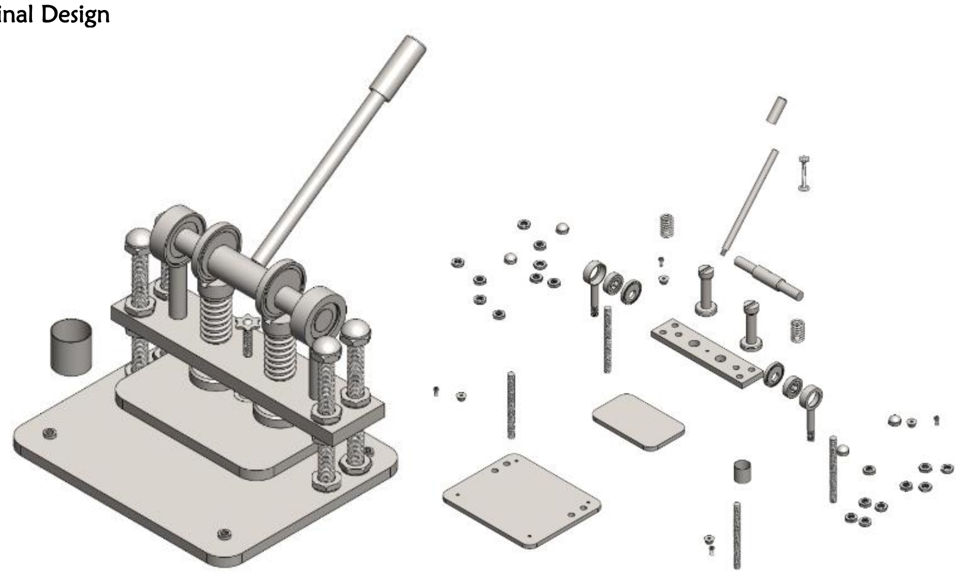
3.1 Design for Assembly Analysis using Manual Assembly

The method of DFA in manual assembly will utilize the handling and insertion table to determine the original part by part of Hand Press Machine. The classification system for manual handling was discussed using the Design for Manual Assembly Worksheet to obtain the design efficiency of the product.

3.1.1 List of Part for Hand Press Machine

The complete 3D model and the exploded view of the Hand Press Machine are modelled using SolidWorks software. The table after the drawing stated all the name and quantity of each part for the Hand Press Machine.

3.1.1.1 Original Design



(a) (b)

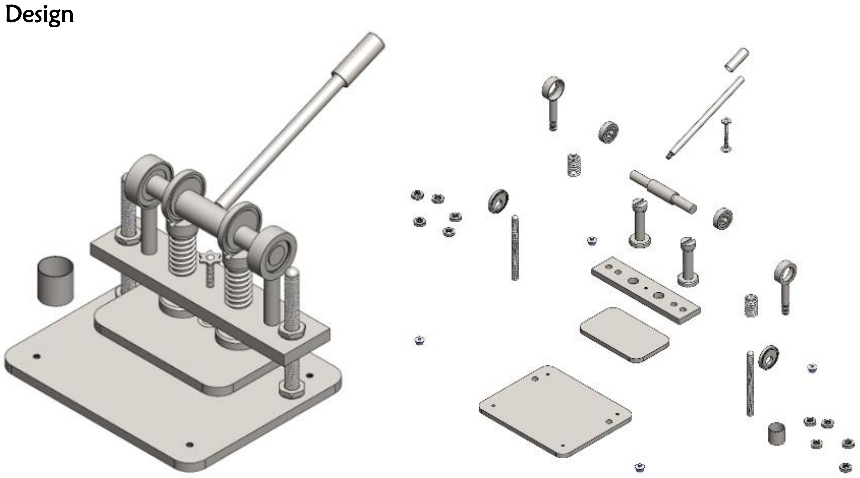
Figure 4: (a) Original Design of Hand Press Machine (b) Exploded View of Original Design

The Table 3 stated all the name and quantity of each part for the Hand Press Machine. There are 18 different components with a total of 52 parts that are required to complete this 3D model.

Table 3: List of Part for Original Design Hand Press Machine

No	Part Name	Quantity
1	380mm x 315mm Base Plate	1
2	Bearing Holder	2
3	Bearing	2
4	Guiding Shaft	2
5	Eccentric Circle	2
6	100mm Fixing Screw	1
7	330mm x 20mm diameter Handle	1
8	Handle Grip	1
9	260mm Main Shaft	1
10	Spring	2
11	M20 x 2.5 Nut	18
12	260mm x 160mm Press Plate	1
13	M10 Socket Cap Head Screw	4
14	Rubber Feet	4
15	M20 x 2.5 Screw Cap	4
16	380mm x 90mm Support Plate	1
17	230mm M20 x 2.5 Supporting Shaft	4
18	Die Cutting Tool	1
	Total number of parts	**52**

3.1.1.2 Improved Design



(a) (b)

Figure 5: (a) Improved Design of Hand Press Machine (b) Exploded View of Improved Design

The Table 4 stated all the name and quantity of each part for the Improved Hand Press Machine. There are 16 different components with a total of 34 parts that are required to complete this 3D model.

Table 4: List of Part for Improved Design Hand Press Machine

No	Part Name	Quantity
1	Base Plate Improved	1
2	Rubber Feet Improved	4
3	Supporting Shaft Improved	2
4	Support Plate Improved	1
5	Bearing Holder	2
6	Bearing	2
7	Guiding Shaft	2
8	Eccentric Circle	2
9	100mm Fixing Screw	1
10	330mm x 20mm diameter Handle	1
11	Handle Grip	1
12	260mm Main Shaft	1
13	Spring	2
14	M20 x 2.5 Nut	10
15	260mm x 160mm Press Plate	1
16	Die Cutting Tool	1
	Total number of parts	**34**

3.2 DFA Worksheet

3.2.1 Original Design of Hand Press Machine

Table 5 presents the results of the DFA worksheet analysis performed on the original design of hand press machine. The analysis aimed to determine the total theoretical minimum number of parts, total manual assembly time, and design efficiency.

Table 5: DFA Worksheet for Original Design

	C1	C2	C3	C4	C5	C6	C7	C8	C9
Name of part	Part ID	No of operations carried out consecutively	Manual handling code	Manual handling time per part	manual insertion code	Manual insertion time per part	Operation time C2(C4+C6)	Total angle of symmetry (α+β), deg (°)	Estimation for theoretical minimum parts
380mm x 315mm Base Plate	1	1	9 5	4	0 0	1.5	5.5	360+360 =720	1
Bearing Holder	2	2	1 0	1.5	3 8	6	15	360+0 =360	2
Bearing	3	2	0 1	1.43	0 0	1.5	5.86	180+0 =180	2
Guiding Shaft	4	2	1 0	1.5	9 4	7	17	360+0 =360	2
Eccentric Circle	5	2	0 1	1.43	0 0	1.5	5.86	180+0 =180	2
100mm Fixing Screw	6	1	1 0	1.5	4 8	8.5	10	360+0 =360	1
330mm x 20mm diameter Handle	7	1	1 0	1.5	3 8	6	7.5	360+0 =360	1
Handle Grip	8	1	1 0	1.5	3 0	2	3.5	360+0 =360	1
260mm Main Shaft	9	1	0 0	1.13	0 0	1.5	2.63	180+0 =180	1
Spring	10	2	0 1	1.43	0 0	1.5	5.86	180+0 =180	2
M20 x 2.5 Nut	11	18	0 0	1.13	3 8	6	128.34	180+0 =180	0
260mm x 160mm Press Plate	12	1	9 1	3	3 2	4	7	180+180 =360	1
M10 Socket Cap Head Screw	13	4	1 0	1.5	3 8	6	30	360+0 =360	0
Rubber Feet	14	4	0 0	1.13	0 0	1.5	10.52	180+0 =180	4
M20 x 2.5 Screw Cap	15	4	1 1	1.5	3 8	6	30	360+0 =360	0
380mm x 90mm Support Plate	16	1	9 0	2	0 0	1.5	3.5	180+180 =360	1
230mm M20 x 2.5 Supporting Shaft	17	4	0 0	1.13	0 0	1.5	10.52	180+0 =180	4
Die Cutting Tool	18	1	0 0	1.13	0 0	1.5	2.63	180+0 =180	1
Design Efficiency $=\frac{3NM}{TM}=\frac{3(26)}{301.22}=0.2589=25.89\%$							TM =301.22		NM =26

According to the data presented in Table 5, it can be observed that the assembly operational time for the original design of hand press machine is 301.22 seconds. Additionally, the analysis reveals that the total theoretical minimum number of parts for the original hand press machine is 26. Furthermore, the design efficiency of the original design is calculated to be 25.89%.

3.2.2 Improved Design of Hand Press Machine

Table 6 presents the results of the DFA worksheet analysis performed on the improved design of hand press machine. The analysis aimed to determine the total theoretical minimum number of parts, total manual assembly time, and design efficiency.

Table 6: DFA Worksheet for Improved Design

	C1	C2	C3	C4	C5	C6	C7	C8	C9
Name of part	Part ID	No of operations carried out consecutively	Manual handling code	Manual handling time per part	manual insertion code	Manual insertion time per part	Operation time C2(C4+C6)	Total angle of symmetry (α+β), deg (°)	Estimation for theoretical minimum parts
Improved Base Plate	1	1	9 5	4	0 0	1.5	5.5	360+360 =720	1
Bearing Holder	2	2	1 0	1.5	3 8	6	15	360+0 =360	2
Bearing	3	2	0 1	1.43	0 0	1.5	5.86	180+0 =180	2
Guiding Shaft	4	2	1 0	1.5	9 4	7	17	360+0 =360	2
Eccentric Circle	5	2	0 1	1.43	0 0	1.5	5.86	180+0 =180	2
100mm Fixing Screw	6	1	1 0	1.5	4 8	8.5	10	360+0 =360	1
330mm x 20mm diameter Handle	7	1	1 0	1.5	3 8	6	7.5	360+0 =360	1
Handle Grip	8	1	1 0	1.5	3 0	2	3.5	360+0 =360	1
260mm Main Shaft	9	1	0 0	1.13	0 0	1.5	2.63	180+0 =180	1
Spring	10	2	0 1	1.43	0 0	1.5	5.86	180+0 =180	2
M20 x 2.5 Nut	11	10	0 0	1.13	3 8	6	71.3	180+0 =180	0
260mm x 160mm Press Plate	12	1	9 1	3	3 2	4	7	180+180 =360	1
Die Cutting Tool	13	1	0 0	1.13	0 0	1.5	2.63	180+0 =180	1
Improved Rubber Feet	14	4	0 0	1.13	3 8	6	28.52	180+0 =180	4
Improved Supporting Shaft	15	2	0 0	1.13	0 0	1.5	5.26	180+0 =180	2
Improved Support Plate	16	1	9 0	2	0 0	1.5	3.5	180+180 =360	1
Design Efficiency= $\frac{3NM}{TM} = \frac{3(24)}{196.02}$ = 0.3656 =36.56%							TM =196.92		NM =24

According to the data presented in Table 6, it can be observed that the assembly operational time for the improved design of hand press machine is 196.92 seconds. Additionally, the analysis reveals that the total theoretical minimum number of parts for the improved hand press machine is 24. Furthermore, the design efficiency of the improved design is calculated to be 36.56%.

3.3 Design for Manufacture (DFM) Analysis

3.3.1 DFM Analysis on Original Design

The overall DFM concurrent costing for manufacturing the 12 out of 18 parts derived from the original design is obtained from the SolidWorks Costing software, as illustrated in the table below.

Table 7: Total of DFM Concurrent Costing for Original Design

No	Part Name	Process	Quantity	Price Per Part	Total Cost
1	380mm x 315mm Base Plate	CNC Machining (Milling, Drilling)	1	56.22	56.22
2	Bearing Holder	Casting	2	13.62	27.24
3	Guiding Shaft	Casting	2	14.17	28.34
4	Eccentric Circle	CNC Machining (Milling, Drilling)	2	10.95	21.90
5	100mm Fixing Screw	CNC Machining (Milling, Threading)	1	2.95	2.95
6	330mm x 20mm diameter Handle	Lathe Machining, CNC Machining (Threading)	1	13.86	13.86
7	Handle Grip	Lathe Machining, CNC Machining (Drilling)	1	5.05	5.05
8	260mm Main Shaft	Casting	1	14.56	14.56
9	260mm x 160mm Press Plate	CNC Machining (Milling)	1	18.22	18.22
10	380mm x 90mm Support Plate	CNC Machining (Drilling)	1	31.16	31.16
11	230mm M20 x 2.5 Supporting Shaft	CNC Machining (Threading)	4	5.08	20.33
12	Die Cutting Tool	Machining	1	12.21	12.21
	Total		**18**	**198.05**	**252.03**

Out of the initial 52 parts, only 18 parts were subjected to the DFM concurrent costing analysis. The remaining parts, which were not included in the analysis, were purchased from suppliers and are not part of the manufacturing process in terms of DFM. The price per part and total cost will be recorded in the next table. The total manufacturing cost for this original design of hand press machine is the sum of both costs. Total manufacturing cost of Original Design: =$252.03+$108.86 = $360.90

Table 8: Purchased Price of Remaining Parts for Original Design

No	Part Name	Quantity	Price Per Part	Total Cost
1	M20 x 2.5 Nut	18	0.82	14.72
2	M10 Socket Cap Head Screw	4	0.34	1.34
3	Rubber Feet	4	0.35	1.38
4	M20 x 2.5 Screw Cap	4	1.01	4.03
5	Spring	2	1.04	2.07
6	Bearing	2	42.66	85.32
	Total	**34**	**46.20**	**108.86**

3.3.2 DFM Analysis on Improved Design

The overall DFM concurrent costing for manufacturing the 12 out of 16 parts derived from the original design is obtained from the SolidWorks Costing software, as illustrated in the table below.

Table 9: Total of DFM Concurrent Costing for Improved Design

No	Part Name	Process	Quantity	Price Per Part	Total Cost
1	Improved Base Plate	CNC Machining (Milling, Drilling)	1	56.43	56.43
2	Bearing Holder	Casting	2	13.62	27.24
3	Guiding Shaft	Casting	2	14.17	28.34
4	Eccentric Circle	CNC Machining (Milling, Drilling)	2	10.95	21.90
5	100mm Fixing Screw	CNC Machining (Milling, Threading)	1	2.95	2.95
6	330mm x 20mm diameter Handle	Lathe Machining, CNC Machining (Threading)	1	13.86	13.86
7	Handle Grip	Lathe Machining, CNC Machining (Drilling)	1	5.05	5.05
8	260mm Main Shaft	Casting	1	14.56	14.56

9	260mm x 160mm Press Plate	CNC Machining (Milling)	1	18.22	18.22
10	Improved Support Plate	CNC Machining (Milling, Drilling)	1	28.73	28.73
11	Improved Supporting Shaft	CNC Machining (Threading)	2	5.13	10.26
12	Die Cutting Tool	Machining	1	12.21	12.21
	Total		**16**	**195.88**	**239.74**

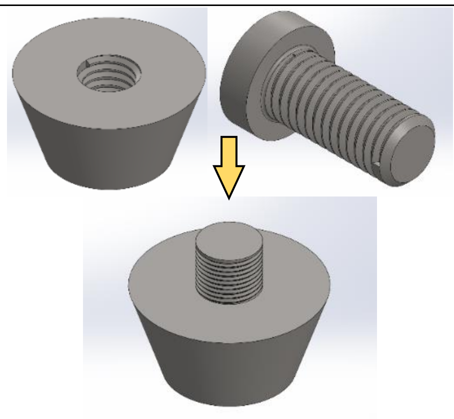
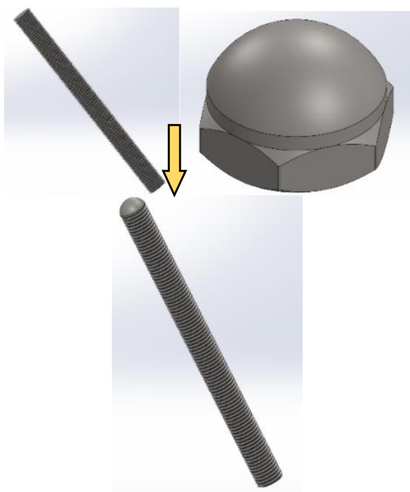
Out of the initial 34 parts, only 16 parts were subjected to the DFM concurrent costing analysis. The remaining parts, which were not included in the analysis, were purchased from suppliers and are not part of the manufacturing process in terms of DFM. The price per part and total cost will be recorded in the table below. The total manufacturing cost for this Improved Design of Hand Press Machine is the sum of both costs. Total manufacturing cost of Improved Design:
=$239.74+$98.91 =$338.65

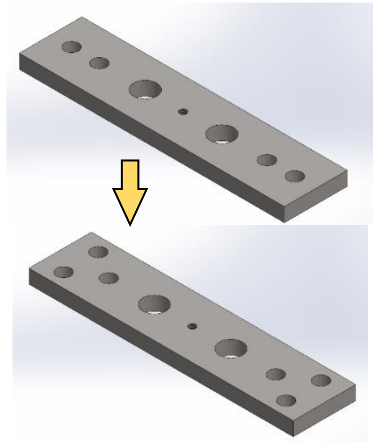
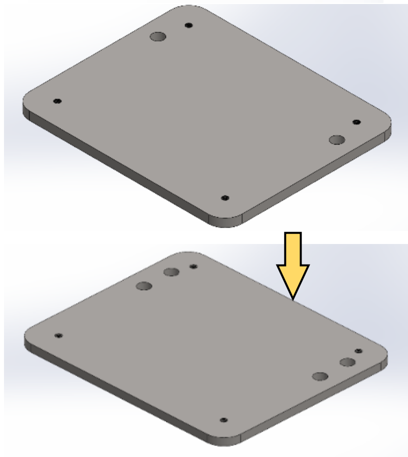
Table 10: Purchased Price of Remaining Parts for Improved Design

No	Part Name	Quantity	Price Per Part	Total Cost
1	M20 x 2.5 Nut	10	0.82	8.18
2	Improved Rubber Feet	4	0.83	3.34
3	Spring	2	1.04	2.07
4	Bearing	2	42.66	85.32
	Total	**16**	**45.35**	**98.91**

3.4 Design Improvement of Hand Press Machine

Table 11: Design Improvement for Hand Press Machine

No	Modification	Figure
1	Combine M10 Socket Cap Head Screw and Rubber Feet to become the Improved Rubber Feet. The improvement made will reduce number of parts and add the function of adjusting the flatness of base plate by altering the Improved Rubber Feet. Through this improvement, the M10 Socket Cap Head Screw is no longer needed. The old Rubber feet is replaced with the Improved design Rubber Feet. Total all 4 of M10 Socket Cap Head Screw will be reduced to none.	
2	Combine M20 x 2.5 Screw Cap and 230mm M20 x 2.5 Supporting Shaft to form the Improved Supporting Shaft. This improvement will avoid the fastening of the screw cap during the assembly. This improvement is made by rounding one end of the Supporting Shaft. The Screw Cap is no longer needed. This improvement reduces the quantity of Screw Cap from 4 to 0. This will also avoid wasting the time to assembly the part by fastening.	

3	Reduce the number of Supporting Shafts from 4 to 2. The holes drilled for Supporting Shafts on the Support Plate is also reduced from 4 to 2. This step of improvements eliminated 2 of the supporting shafts. The hole designated for the Supporting Shaft is reduced to 1 at each end. The number of shafts required is only 2 rather than 4 in the original design. The nut needed to fix the position of whole machine will be reduced by 8 nuts. The assembly time will be reduced vastly due to the large number of parts reduced.	
4	The number of holes drilled in the Base Plate is also reduced to match the drilled hole in the Support Plate. The improvement made is shown during the drilling process of the base to match the reducing of shafts above. The holes will reduce to 2.	

3.5 Absorption Cost Analysis

The Absorption cost, also referred to as the "Cost plus approach" is applied to both the Original Design Hand Press Machine and the Improved Design Hand Press Machine. The total absorption cost of the product is determined by combining the direct cost, indirect cost, and overhead cost.

3.5.1 Original Design of Hand Press Machine

Table 12 below presents the absorption costing analysis for the original design of the Hand Press Machine. The costs are calculated by determining the direct cost, indirect cost, and overhead cost associated with the Original Design product.

Table 12: Total Absorption Costing for Original Design

Steps	Notes			Unit Cost (USD)
Define Unit	Original Hand Press Machine			-
Determine No. of Units	18			-
Calculate Direct Cost	-			-
Material Cost:	1.	380mm x 315mm Base Plate	1 Piece	56.22
	2.	Bearing Holder	2 Pieces	27.24
	3.	Bearing	2 Pieces	85.32
	4.	Guiding Shaft	2 Pieces	28.34
	5.	Eccentric Circle	2 Pieces	21.90
	6.	100mm Fixing Screw	1 Piece	2.95
	7.	330mm x 20mm diameter Handle	1 Piece	13.86
	8.	Handle Grip	1 Piece	5.05
	9.	260mm Main Shaft	1 Piece	14.56
	10.	Spring	2 Pieces	2.07
	11.	260mm x 160mm Press Plate	1 Piece	1.45
	12.	380mm x 90mm Support Plate	1 Piece	31.16

	13.	230mm M20 x 2.5 Supporting Shaft	4 Pieces	20.33
	14.	Die Cutting Tool	1 Piece	12.21
	15.	Rubber Feet	4 Pieces	1.38
Other:		-		-
Total Direct Cost:		**-**		**340.82**
Calculate Indirect Cost		-		-
	1.	M20 x 2.5 Nut	18 Pieces	14.72
Fasteners:	2.	M10 Socket Cap Head Screw	4 Pieces	1.34
	3.	M20 x 2.5 Screw Cap	4 Pieces	4.03
Utilities:		-		-
Other:		-		-
Total Indirect Cost:		**-**		**20.08**
Calculate Overhead Cost		-		-
Overhead Cost:		$\frac{\textbf{Total Indirect Cost}}{\textbf{Total Number of Units}}$		-
Total Overhead Cost:		$\frac{\mathbf{20.08}}{\mathbf{18}}$		**1.12**
Calculate Unit Cost		-		-
Total Cost		**340.82+20.08+1.12**		**362.01**

3.5.2 Improved Design of Hand Press Machine

The table 13 below presents the absorption costing analysis for the improved design of the Hand Press Machine. The costs are calculated by determining the direct cost, indirect cost, and overhead cost associated with the Original Design product.

Table 13: Total absorption Costing for Improved Design

Steps	Notes			Unit Cost (USD)
Define Unit	Improved Hand Press Machine			-
Determine No. of Units		16		-
Calculate Direct Cost		-		-
	1.	Improved Base Plate	1 Piece	56.43
	2.	Bearing Holder	2 Pieces	27.24
	3.	Bearing	2 Pieces	85.32
	4.	Guiding Shaft	2 Pieces	28.34
	5.	Eccentric Circle	2 Pieces	21.90
	6.	100mm Fixing Screw	1 Piece	2.95
	7.	330mm x 20mm diameter Handle	1 Piece	13.86
Material Cost:	8.	Handle Grip	1 Piece	5.05
	9.	260mm Main Shaft	1 Piece	14.56
	10.	Spring	2 Pieces	2.07
	11.260mm x 160mm Press Plate		1 Piece	1.45
	12.	Improved Support Plate	1 Piece	28.73
	13.	Improved Supporting Shaft	2 Pieces	10.26
	14.	Die Cutting Tool	1 Piece	12.21
	15.	Improved Rubber Feet	4 Pieces	3.34
Other:		-		-
Total Direct Cost:		**-**		**330.48**
Calculate Indirect Cost		-		-
Fasteners:	1.	M20 x 2.5 Nut	10 Pieces	8.18
Utilities:		-		-

Other:	-	-
Total Indirect Cost:	**-**	**8.18**
Calculate Overhead Cost	-	-
Overhead Cost:	$\frac{\textbf{Total Indirect Cost}}{\textbf{Total Number of Units}}$	-
Total Overhead Cost:	$\frac{\mathbf{8.18}}{\mathbf{16}}$	**0.51**
Calculate Unit Cost	-	-
Total Cost	**330.48+8.18+0.51**	**339.16**

3.6 Comparison Between Original Design and Improved Design of Hand Press Machine

Table 14: Comparison Between Original Design and Improved Design

	Original Design	Improved Design
Total Manual Assembly Time, TM (s)	301.22	196.92
Theoretical number of parts, NM	26	24
Design Efficiency, DE (%)	25.89	36.56
Manufacturing Cost (USD)	252.03	239.74
Purchase Cost (USD)	108.86	98.91
Total Manufacturing Cost (USD)	360.90	338.65
Total Absorption Cost (USD)	362.01	339.16

Table above shows the comparison of total manual assembly time (TM), theoretical number of parts (NM), and design efficiency (DE) between the original design and improved design of Hand Press Machine. As shown in the table above, TM has reduced by 104.30s, from 301.22s to 196.92s after the improvement has been made. The theoretical number of parts (NM) was also reduced from 26 parts to 24 parts. However, on the other hand, the design efficiency (DE) has increased from 25.89% to 36.56%. The difference of 10.67% in DE has proved that the improvement made is effective. The table demonstrates that the manufacturing cost has decreased from $252.03 to $239.74 following the improvements. Similarly, the purchase cost has been reduced from $108.86 to $98.91. Consequently, there is a notable difference of $22.24 in the total manufacturing cost, which has decreased from $360.90 to $338.65, when comparing the original design to the improved design. Based on the information provided in table above, the total absorption cost of the Original Design Hand Press Machine is $362.01. On the other hand, the table reveals that the total absorption cost for the Improved Design Hand Press Machine is $339.16. Consequently, after the improvement, the total absorption cost of the Hand Press Machine has been reduced by $22.85.

4 CONCLUSIONS

The DFMA (Design for Manufacturing and Assembly) analysis and cost analysis were successfully conducted on a hand press machine design. The original design had 52 components, with 18 subjected to DFM (Design for Manufacturing) concurrent costing evaluation using SolidWorks Costing. The remaining 34 items were purchased from suppliers.

1. The redesigned hand press machine reduced the part count from 52 to 34. The manufacturing processes involved casting, lathe machining, and CNC machining for both the original and redesigned products.
2. The DFA (Design for Assembly) analysis showed that the total manual assembly time was reduced from 301.22 seconds in the original design to 196.92 seconds in the improved design, a decrease of 104.30 seconds. The theoretical number of parts also decreased by 2, from 26 to 24. This resulted in an increase in design efficiency from 25.89% to 36.56%.
3. The DFM analysis showed that the manufacturing cost of the original design was $252.03, while the improved design had a lower cost of $239.74, a savings of $12.29. The purchasing price also decreased by $9.91, leading to a total production cost reduction of $22.24.
4. The total absorption cost of the improved hand press machine was $339.16, compared to $362.01 for the original design, a cost advantage of $22.85 for the improved design.
5. It is strongly recommended to use the Boothroyd Dewhurst DFMA software for more accurate DFA and DFM analysis, as well as implementing a cost analysis software like aPriori to enhance the cost analysis.

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