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Design and Development of Pneumatic Coconut Cutter Using DFMA Approach

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Abstract

This research study examines a pneumatic coconut cutter machine that utilises Design for Manufacture and Assembly (DFMA) methodologies. DFMA, which encompasses Design for Manufacturing (DFM) and Design for Assembly (DFA), is employed to reengineer a preexisting product with the objective of minimising expenses, time, and components. The objective of the study is to improve the efficiency of design and the accuracy of cost estimation for a pneumatic coconut cutting machine, in order to make it more effective. The present product is remodelled and a new design, called pneumatic coconut cutter v2, is proposed using SolidWorks 2022 software. The DFA manual handling worksheet is utilised to compute the duration of manual assembly, demonstrating an enhancement in design efficiency from 24.5% to 34.7%. The cost assessment shows that the pneumatic coconut cutter v2 is cheaper, with a price of RM366.88, compared to the original design, which costs RM528.22. The study confirms the efficacy of DFMA in attaining enhanced product results, providing prospective advantages to the machine manufacturing industry by developing a cost-efficient pneumatic coconut cutter without sacrificing functionality.

1 Introduction

Design for Manufacturing and Assembly (DFMA) is an engineering methodology that emphasizes the ease of manufacturing components and simplified assembly during the initial design phases of a product's lifecycle. Originating in the early 1970s, Dr. Geoffrey Boothroyd and Dr. Peter Dewhurst developed the DFMA concept, and it is trademarked by their company, Boothroyd Dewhurst, Inc [3][9]. DFMA has been widely used by companies like Ford and Chrysler in designing military products.[1][5][8]. The methodology has traditionally found applications in industries like automotive and consumer goods, where large quantities of high-quality products are produced.

Reducing material waste, increasing process dependability, and optimizing the number of manufacturing stages are the three main goals of DFMA. To maximize the benefits of DFMA, it is typically used post-design and before to manufacture.[2][4][8].

In this case study, pneumatic coconut cutter is chosen to be studied and implementing DFMA rules. Pneumatic coconut cutting is an upgrade tool for cutting the coconut into half. Traditionally humans use sharp edges to open ad coconut such as axe, stone, traditional coconut opener or by using external forces. This method is slow and may injured the operators as the tools is manually operated while adding pneumatic system, energy consumed to open a coconut is reduced as the opening tools use semi-automatic operation.

1.1 Design for Assembly

Design for Assembly (DFA) is a methodology centered on creating products with easy assembly in mind. The primary goal is to minimize the number of assembly operations and reduce the overall cost of product assembly [1][10]. DFA involves a thorough analysis of both the cost and duration of the assembly process. The key objective is to simplify the assembly process, and a DFA assessment provides insights into how a product can be efficiently assembled in the shortest possible time. Additionally, DFA ensures that the product can be physically assembled with ease.

The Design for Assembly (DFA) method involved the following steps:

i. Determining the product's specifications, purpose, and standard-parts list.
ii. Determine your actual part count.
iii. Analyse potential for quality (error proofing).
iv. Evaluate chances for handling (grip & orientation).
v. Identify and recognise insertion chances.
vi. Investigate for methods to scale back additional operations.
vii. Data analysis for new designs.

1.1.1 DFA Guideline

Reducing the assembly cost is DFA's main goal. The following are some guidelines that must be adhered to apply the DFA technique:[5]

i. Cutting down on the number of parts: This can be achieved by designing the product with the fewest possible parts or by creating a component that can utilize several parts.
ii. Reduced the number of fasteners and their parts.
minimizing the amount of material used in the product or creating a component that can combine different parts to reduce the number of parts needed.
iii. Minimum design parts
The portion that is reduced will result in a lower cost. This is crucial since multiple parts can be joined to function as a single unit.

1.2 Design for Manufacturing

Design for Manufacture (DFM) is a methodology that strives to simplify the manufacturing of a product's components by making them as straightforward as possible. This involves selecting cost-effective materials and production methods to minimize manufacturing complexity.[10][2]. DFM focuses on streamlining the fabrication process for components, aiming to reduce both cost and complexity in manufacturing. Strategies may include minimizing machines to facilitate faster production and lower overall expenses. The ultimate goal of DFM is to optimize the manufacturing process for efficiency and cost-effectiveness.

2 Methodology

The chosen DFMA methodology for analyzing the selected product is the manual Design for Assembly (DFA) analysis method, specifically following the approach developed by Boothroyd and Dewhurst. This decision is based on the unavailability of DFMA software. Figure 1 illustrates the process of manual DFA analysis, highlighting the steps involved in this method.

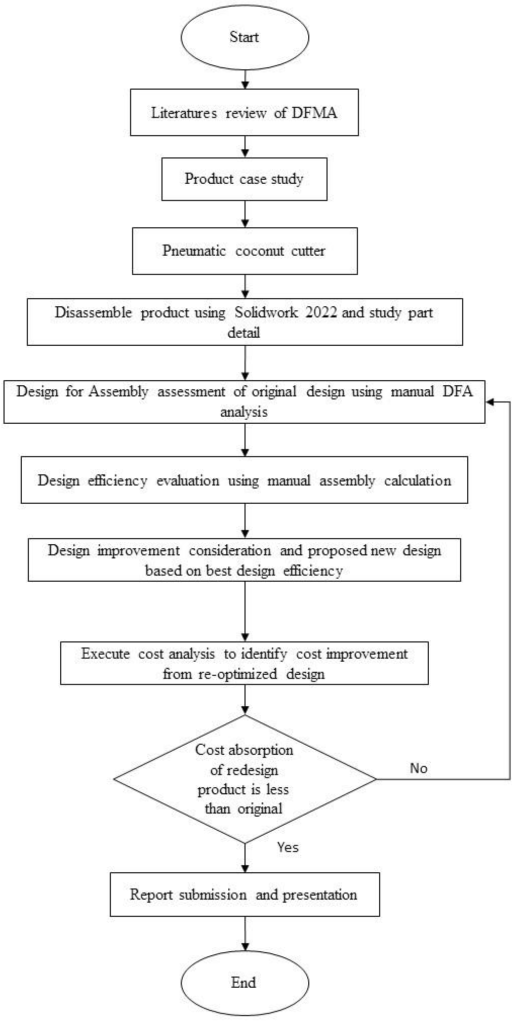


Fig. 1 *Study process methodology*

2.1 Method

The manual DFA analysis typically has been conducted in five stages of: [6]

i. Product dissembles and parts classification.

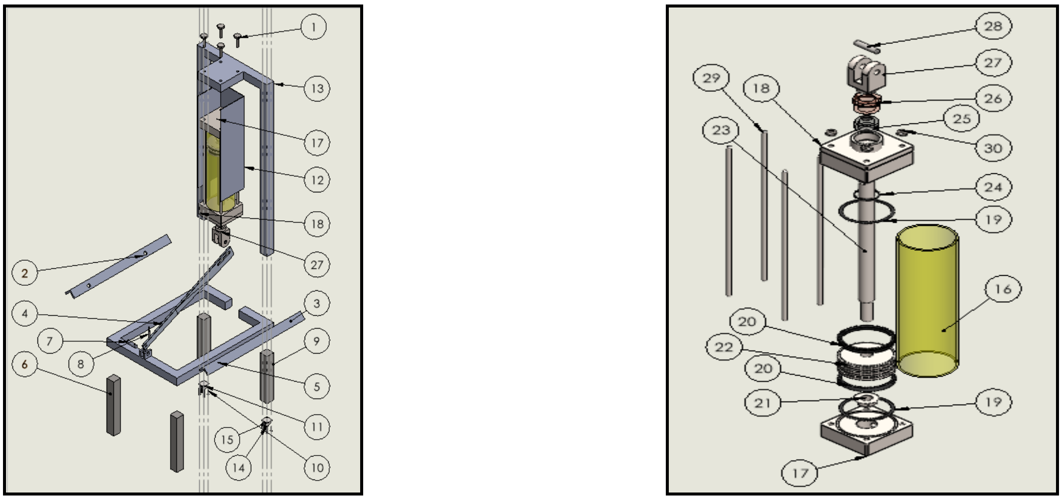
ii. Assembly process evaluation (Boothroyd Dewhurst Method)

iii. Description and modification of proposed parts

iv. Revaluation of modified parts (Boothroyd Dewhurst Method)

v. Comparison between original and modified parts

2.2 Product dissembles and part classification



(a) (b)

Fig. 2 *Exploded view of (a) pneumatic coconut cutter, (b) pneumatic system*

Table 1 shows thelist of materials foe pneumatic coconut cutter parts`.

Table 1 *List of part material*

No.	Name of part	Quantity of part	Material
1	M8x1.0mm hexagon bolt	4	Steel
2	Coconut holder left	1	Aluminum alloy
3	Coconut holder right	1	Aluminum alloy
4	Blade	1	Plain carbon steel
5	Cutting base	1	Aluminum alloy
6	Leg	2	Aluminum alloy
7	Blade pin	1	Plain carbon steel
8	Quick release pin	1	Steel
9	Leg with wheel	2	Aluminum alloy
10	Wheel bolt M6x1.0mm hexagon bolt	8	Plain carbon steel
11	Wheelbase	2	Plain carbon steel
12	Pneumatic cover	1	Aluminum alloy
13	Pneumatic holder	1	Aluminum alloy
14	Wheel pin	2	Steel
15	Wheel roller	2	Polyurethane
16	Pneumatic cylinder	1	Polyester resin
17	Pneumatic base	1	Aluminum alloy
18	Pneumatic top	1	Aluminum alloy
19	Pneumatic O-ring	2	rubber
20	Pneumatic piston O-ring	2	rubber

Table 2 *Continue*

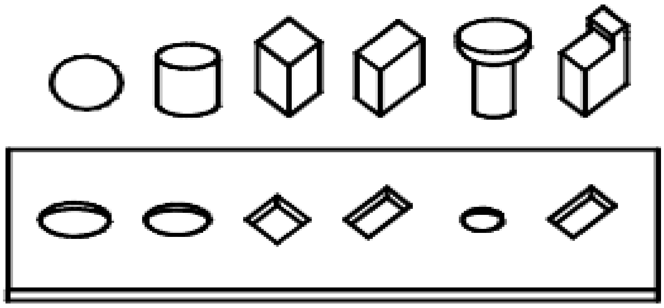
21	Pneumatic piston lock nut	1	Steel
22	Pneumatic piston	1	Plain carbon steel
23	Pneumatic push rod	1	Plain carbon steel
24	Pneumatic top O-ring	1	Rubber
25	Pneumatic rod O-ring	1	Rubber
26	Pneumatic rod securing nut	1	Steel
27	Pneumatic hinge	1	Plain carbon steel
28	Pneumatic hinge lock	1	Plain carbon steel
29	Pneumatic stud	4	Steel
30	Pneumatic stud nut	4	Steel

2.3 Assembly process evaluation (Boothroyd Dewhurst Method)

All the parts involved are evaluated using manual handling and insertion worksheet as show in Table 2 below.

Table 3 *Manual Handling and Insertion 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)	Operation cost 0.4(C7)	Estimation for theoretical minimum parts
$DE = \frac{3NM}{TM}$							TM		NM



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

Fig. 3 *Variation of insertion*

MANUAL HANDLING—ESTIMATED TIMES (seconds)

Key: ONE HAND

		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
parts can be grasped and manipulated by one hand without the aid of grasping tools: (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 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
parts can be grasped and manipulated by one hand but only with the use of grasping tools: 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°, 0 ≤ 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 required for LARGE SIZE

		parts can be handled by one person without mechanical assistance									parts need special tools for grasping and 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 required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

Fig. 4 *Manual handling worksheet*

MANUAL INSERTION—ESTIMATED TIMES (seconds)

Key: PART ADDED but NOT SECURED

		after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or 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
addition of any part (1) where neither the part itself nor any other part is finally secured immediately: 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

PART SECURED IMMEDIATELY

		no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
				plastic bending or torsion			rivetting or similar operation				
					not easy to align or position during assembly			not easy to align or position during assembly			
		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)	no resistance to insertion	resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	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
addition of any part (1) where the part itself and/or other parts are being finally secured immediately: 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

SEPARATE OPERATION

		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				metallurgical processes					
							additional material required				
		bending or similar processes	rivetting or similar processes	screw tightening (6) or other processes	snap fit, snap clip, press fit, etc.	no additional material required (e.g. resistance, friction welding, etc.)	soldering processes	weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	manipulation of parts or sub-assembly (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 *Manual insertion worksheet*

3 Result and Discussion

The goal of analysis is to put an improvement into practice by producing a higher-quality product with fewer parts than the original design. The DFA Manual calculation procedure that was carried out will be used to complete those analyses.

3.1 Dfa manual analysis of pneumatic coconut cutter

The manual DFA analysis approach was used when evaluating the pneumatic coconut cutter design. The product design will be assessed, changed, and then reassessed. Lastly, a comparison of the original and modified designs' design efficiency will be made. The results of the Boothroyd Dewhurst DFA analysis are displayed in Table 3.

The selected product, the pneumatic coconut cutter, will undergo evaluation using the Boothroyd Dewhurst Design for Assembly (DFA) manual analysis. The DFA manual evaluation worksheet will be employed to determine the design efficiency of the original design. The evaluatin result is shown in Table 3. As the design efficiency is 24.5%.

Table 4 *Manual DFA analysis of pneumatic coconut cutter*

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)	Operation cost 0.4(C7)	Estimation for theoretical minimum parts
M8x1.0 mm hexagon bolt	1	4	11	1.8	49	10.5	49.2	19.68	4
Coconut holder left	2	1	10	1.5	96	12	13.5	5.4	0
Coconut holder right	3	1	10	1.5	96	12	13.5	5.4	0
Blade	4	1	15	2.25	92	5	7.25	2.9	1
Cutting base	5	1	90	2	96	12	14	5.6	1
Leg	6	2	00	1.13	96	12	26.62	10.648	4

Table 5 *Continue*

Blade pin	7	1	10	1.5	92	5	6.5	2.6	0
Quick release pin	8	1	11	1.8	30	2	3.8	1.52	0
Leg with wheel	9	2	10	1.5	96	12	27	10.8	0
Wheel bolt M6x1.0mm hexagon bolt	10	8	11	1.8	49	10.5	98.4	39.36	0
Wheelbase	11	2	00	1.13	00	1.5	5.26	2.104	0
Pneumatic cover	12	1	21	2.1	96	12	14.1	5.64	0
Pneumatic holder	13	1	91	3	92	5	8	3.2	1
Wheel pin	14	2	10	1.5	30	2	7	2.8	0
Wheel roller	15	1	00	1.13	00	1.5	2.63	1.052	0
Pneumatic cylinder	16	1	00	1.13	00	1.5	2.63	1.052	1
Pneumatic base	17	1	00	1.13	00	1.5	2.63	1.052	1
Pneumatic top	18	1	00	1.13	00	1.5	2.63	1.052	1
Pneumatic O-ring	19	2	03	1.69	00	1.5	6.38	2.552	2
Pneumatic piston O-ring	20	2	03	1.69	01	2.5	8.38	3.352	2
Pneumatic piston lock nut	21	1	10	1.5	30	2	3.5	1.4	1
Pneumatic piston	22	1	10	1.5	00	1.5	3	1.2	1
Pneumatic push rod	23	1	00	1.13	00	1.5	2.63	1.052	1
Pneumatic top O-ring	24	1	23	2.36	00	1.5	3.86	1.544	1
Pneumatic rod O-ring	25	1	00	1.13	00	1.5	1.63	0.652	1

Table 6 *Continue*

Pneumatic rod securing nut	26	1	10	1.5	38	6	7.5	3	1
Pneumatic hinge	27	1	10	1.5	3	6	7.5	3	1
Pneumatic hinge lock	28	1	20	1.8	38	6	7.8	3.12	1
Pneumatic stud	29	4	10	1.5	38	6	30	12	4
Pneumatic stud nut	30	4	10	1.5	38	6	30	12	4
							TM = 416.83	CM = 166.132	NM = 34

3.2 Proposed modification

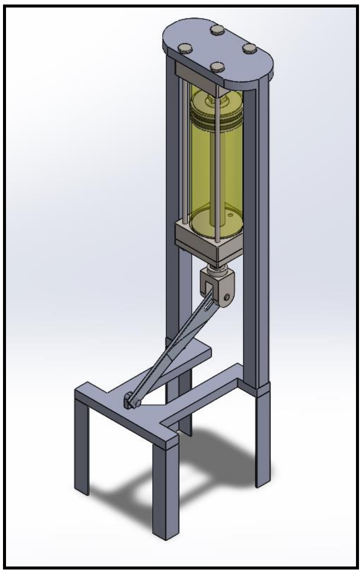


Fig. 6 *Pneumatic coconut cutter v2*

Table 4 show the list of material for pneumatic coconut cutter v2 parts

Table 7 *List of material of pneumatic coconut cutter v2 parts*

No.	Name of part	Quantity of part	Material
1	Leg v2	4	Aluminum alloy
2	Base v2	1	Aluminum alloy
3	Pneumatic holder v2	1	Aluminum alloy
4	Pneumatic cylinder	1	Polyester resin
5	Pneumatic base	1	Aluminum alloy
6	Pneumatic top	1	Aluminum alloy
7	Pneumatic O-ring	2	rubber
8	Pneumatic piston O-ring	2	rubber
9	Pneumatic piston lock nut	1	Steel
10	Pneumatic piston	1	Plain carbon steel
11	Pneumatic push rod	1	Plain carbon steel

12	Pneumatic top O-ring	1	Rubber
13	Pneumatic rod O-ring	1	Rubber
14	Pneumatic rod securing nut	1	Plain carbon steel
15	Pneumatic hinge	1	Plain carbon steel
16	Pneumatic hinge lock	1	Plain carbon steel
17	Pneumatic stud	4	Steel
18	Pneumatic stud nut	4	Steel
19	Blade v2	1	Plain carbon steel
20	M8x1.0mm hexagon bolt	4	Steel

3.2.1 DFA evaluation of pneumatic coconut cutter v2

Table 8 *Manual DFA analysis of Pneumatic coconut cutter v2*

0	C1	C2	C3	C4	C5	C6	C7	C8	C9
Name of part	Part ID	No of operations were carried out consecutively	Manual handling code	Manual handling time per part	Manual insertion code	Manual insertion time per part	Operation time C2(C4+C6)	Operation cost 0.4(C7)	Estimation for theoretical minimum parts
Leg v2	1	4	30	1.95	96	12	55.8	22.32	4
Base v2	2	1	30	1.95	96	12	13.95	5.58	1
Pneumatic holder v2	3	1	20	1.8	96	12	13.8	5.52	1
Pneumatic cylinder	4	1	00	1.13	00	1.5	2.63	1.052	1
Pneumatic base	5	1	00	1.13	00	1.5	2.63	1.052	1
Pneumatic top	6	1	00	1.13	00	1.5	2.63	1.052	1
Pneumatic O-ring	7	2	03	1.69	00	1.5	6.38	2.552	2
Pneumatic piston O-ring	8	2	03	1.69	01	2.5	8.38	3.352	2
Pneumatic piston lock nut	9	1	10	1.5	30	2	3.5	1.4	1

Table 5 *Continue*

Pneumatic piston	10	1	10	1.5	00	1.5	3	1.2	1
Pneumatic push rod	11	1	00	1.13	00	1.5	2.63	1.052	1
Pneumatic top O-ring	12	1	23	2.36	00	1.5	3.86	1.544	1
Pneumatic rod o–ring	13	1	00	1.13	00	1.5	1.63	0.652	1
Pneumatic rod securing nut	14	1	10	1.5	38	6	7.5	3	1
Pneumatic hinge	15	1	10	1.5	3	6	7.5	3	1
Pneumatic hinge lock	16	1	20	1.8	38	6	7.8	3.12	1
Pneumatic stud	17	4	10	1.5	38	6	30	12	4
Pneumatic stud nut	18	4	10	1.5	38	6	30	12	0
Blade v2	19	1	15	2.25	92	5	7.25	2.9	1
M8x1.0mm hexagon bolt	20	4	11	1.8	38	6	31.2	12.48	2
							TM = 242.07	CM = 97.828	NM = 28

3.2.2 Comparison DFA analysis

After calculation, data for total manual assembly time, total number of theoretical parts, and design efficiency of both design is recorded in table 6.

Table 9 *Comparison between pneumatic coconut cutter and pneumatic coconut cutter v2*

	Pneumatic coconut cutter	Pneumatic coconut cutter v2
Total manual assembly time, TM (sec)	332.18	246.05
Total number of theoretical parts, NM	33	33
Design efficiency (%)	29.8	40.23

3.3 DFM pneumatic coconut cutter using SolidWorks 2022

Table 10 *DFM costing for pneumatic coconut cutter*

Part number	Part name	Quantity	Price/piece, RM	Total cost, RM
1	Coconut holder left	1	7.79	7.79
2	Coconut holder right	1	7.79	7.79
3	Blade	1	27.48	27.48

4	Cutting base	1	33.73	33.73
5	Leg	2	23.85	47.70
6	Blade pin	1	6.15	6.15
7	Leg with wheel	2	24.00	48.00
8	Wheelbase	2	7.87	15.74
9	Pneumatic cover	1	8.50	8.50
10	Pneumatic holder	1	47.29	47.29
11	Wheel pin	2	2.62	5.28
12	Pneumatic cylinder	1	9.69	9.69
13	Pneumatic base	1	53.39	53.39
14	Pneumatic top	1	143.76	143.76
15	Pneumatic piston	1	39.28	39.28
16	Pneumatic hinge	1	26.69	26.69
Total		20	469.88	528.22

3.4 DFM pneumatic coconut cutter v2 using SolidWorks 2022

Table 11 *DFM costing for pneumatic coconut cutter v2*

No.	Name of part	Quantity	Price part / piece, RM	Total cost, RM
1	Leg v2	4	5.12	20.48
2	Base v2	1	14.84	14.84
3	Pneumatic holder v2	1	39.64	39.64
4	Pneumatic cylinder	1	9.69	9.69
5	Pneumatic base	1	53.39	53.39
6	Pneumatic top	1	143.76	143.76
7	Pneumatic piston	1	39.28	39.28
8	Pneumatic hinge	1	26.69	26.69
9	Blade v2	1	19.21	19.21
	Total	11	351.62	366.88

4 Conclusion

The study applied the Boothroyd Dewhurst method through manual calculation to assess the original design of a pneumatic coconut cutter, yielding a design efficiency of 29.8%. Design for Manufacturing and Design for Assembly were then utilized to analyze the improved model, Pneumatic Coconut Cutter v2, resulting in a reduced part count from 53 to 33. The material selection included aluminum alloy and plain carbon steel, with casting and machining processes employed. The redesigned model achieved a lower production cost of RM359.06 per 1000 units compared to the original's RM528.22. Notably, Pneumatic Coconut Cutter v2 exhibited a 10.3% higher design efficiency (40.23%) than the original design (29.8%), emphasizing the importance of careful DFMA analysis.

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