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Design of Ergonomic Adjustable Welding Work Facilities Using the DFMA Method

Ahmad Noveldi S.A.R[1], Faisal Ashari[2], Rio Chandra Pratama[3]

Universitas Bojonegoro[1,2,3]

Correspondence Email: ahmad.noveldi@gmail.com[1]

Abstract

In this modern and sophisticated era, the manufacturing industry is developing both service industries and those that produce products with a variety of shapes and models to attract customers. For example, adjustable welding tables, motorbikes, cars, and others. Companies compete with each other in terms of price, product excellence, product innovation, and product convenience in order to find the right consumer market. DFMA (Design for Manufacturing and Assembly) is a method of making products that aims to facilitate the manufacturing and assembly process where existing designs can be simplified and adapted to the capabilities of the manufacturing facility by considering technical aspects. The scope of design and ergonomics activities includes problems related to human needs, including interior design, furniture design, environmental equipment design, transportation equipment design, textile design, graphic design, etc. (Setiawan, M. S. 2022). At this stage, data collection is carried out, and the author needs to design an adjustable welding table. However, first recompose the table components and determine which are assembly parts and subassembly parts. Then identify each component. Product size and components, labor time, manufacturing data, and others to support research. 1. Analysis of Design Needs 2. Preliminary Design Sketching 3. Design Evaluation 4. Final Design Refinement 4. Final Design Refinement 4. Final Design Refinement 4. Final Design Refinement 4. Final Design Refinement 4. Final Design Refinement. 1) In the previous product development, design 3 was completed with a design that is certainly more ergonomic than design 1, because design 3 has been adjusted to body size using ergonomic standards. 2) Based on the results of the development of this adjustable welding table product, option 3 is the one with the lowest cost because it has a smaller number of components and total assembly steps compared to options 1 and 2. The cost of option 1 is around Rp. 1,780,000; option 2 is around Rp. 1,515,000; and option 3 is around Rp. 870,000. The total assembly steps for option 1 are 40; option 2 is 34; and option 3 is 25. The number of components in options 1 and 2 is 10, while option 3 is only 9.

Keywords: DFMA, ergonomics, anthropometry.

INTRODUCTION

In this modern and sophisticated era, the manufacturing industry is developing both service industries and those that produce products with a variety of shapes and models to attract customers. For example, adjustable welding tables, motorbikes, cars, and others. Companies compete with each other in terms of price, product excellence, product innovation, and product convenience in order to find the right consumer market.

Due to competition in the development of these products, research was carried out on the design of adjustable welding table products, where there were several additional components and modifications to make it easier to use the adjustable welding table.

Welding is an important process in the manufacturing industry, especially for joining workpieces made of metal or similar materials. A welding process that is not carried out

properly can pose a risk of accidents and injuries to workers. In addition, welding work facilities that are not ergonomic can cause physical stress and fatigue in workers, which can affect their productivity and well-being. Therefore, ergonomic redesign of welding work facilities is very important to improve occupational health and safety as well as productivity.

By designing this product, consumers do not need to add components to make the job easier, which usually involves many other tools such as electrodes and messy welding machines, which can be more neatly organized with just one tool that has multiple functions. For security, it is very safe and comfortable when used with the safety specifications of its external components. And the production process uses the design for manufacture and assembly (DFMA) method.

By using the DFMA method, there will be several changes in terms of design, additional components, and comfort. The function of DFMA itself is to determine a product design that can truly remove and add components in order to perfect the tool and develop the product.

METHOD

There are many methods and tools that help make the product design and development process easier for us. It is not uncommon for several methods to be combined to get the best results. Some of these methods include the following.

1. DFM (Design for manufacture)

DFM is the process of designing components by considering the processes that will be used to make the components to ensure that manufacturing costs are reduced. One example of the application of DFM can be seen in Figure 1. In the figure, there is a design of two parts assembled into one, which is then replaced with a single stamping design (Nugroho 2008).

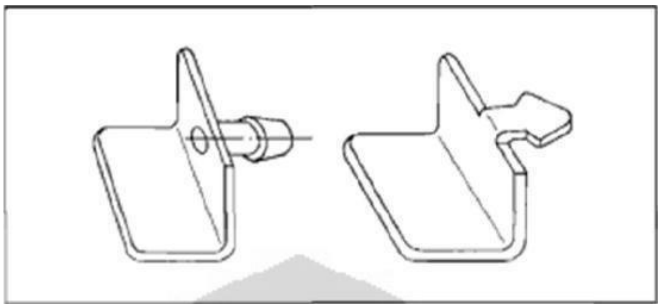


Figure 1. DFM Application

2. DFA (design for assembly)

DFA is a design process to improve product design so that assembly costs are lower and it is easier to assemble, focusing on function and the ability to be assembled simultaneously. DFA aims to simplify products so that assembly costs can be reduced (Nugroho, 2008).

3. Design For Manufacturing and Assembly (DFMA)

DFMA (Design for Manufacturing and Assembly) is a product manufacturing method that aims to facilitate the manufacturing and assembly process where existing designs can be simplified and adapted to the capabilities of manufacturing facilities by considering technical aspects (Boothoryd, 1994). The stages of applying the DFMA method are shown in Figure 2.

Figure 2. Application of the DFMA Method

The Design for Manufacturing and Assembly concept consists of two concepts, namely the DFM and DFA concepts. The DFMA concept is applied in the initial design stage. The principle of this concept is that early-stage product design and DFMA analysis are carried out simultaneously. One of the advantages of applying the DFMA concept to product design is that it shortens design time. This can be seen in Figure 2. which shows a comparison of a product design with and without the application of the DFMA concept (Yoewono, 2014).

4. Application of the DFMA Method

   1. According to Virganda, M. F. A. (2016), the application of the DFMA method begins with several stages, namely:

   2. In the design concept stage, which produces a design concept for tools, one way is to use brainstorming.

   3. The design stage for assembly produces an assembly design between components and auxiliary tool assemblies for the lathe machine.

   4. The next stage is the selection of materials and the design process, which results in the type of material selected as raw material for tools and the selection of existing design alternatives.

From these stages, the best design concept is produced, followed by the design stage for manufacturing by producing working drawings that are ready to be made into finished products (Yuniarso, 2014).

5. Design and Ergonomics

Design can be interpreted as one of the broad activities of design and technological innovation that is initiated, created, exchanged (through buying and selling transactions), and functional (Susanto, A. 2019). Design is the result of human creativity (man-made objects) that is realized to meet human needs, which requires planning, designing, and developing designs, starting from the stage of exploring ideas or notions, followed by the development stages, design concepts, systems, and details, making prototypes and production processes, evaluation, and ending with the distribution stage. So it can be concluded that design is always related to the development of ideas, technical development, production processes, and market improvement (Rizali, A. E. N. 2020).

RESULT AND DISCUSSION

A desk that meets ergonomic standards is usually designed to support worker comfort and efficiency during long hours of work. Here are some characteristics of an ideal desk that meets ergonomic standards:

Table 1. Description of Research Data

Calculation	TBD	TSD	PSJ	JTA	JTD
Amount	148	134	102	394	132
Average	74	67	51	197	66
BKA	95	90	52	219	85
BKB	63	57	34	178	52
Max	83	76	54	212	78
Min	65	58	48	182	54
N limit type	Variety	Variety	Variety	Variety	Variety
	12	18	3	10	7
Note: Number of Samples	Enough	Enough	Enough	Enough	Enough
Small Percentile	62	49	48	187	59

Table 2. Determination of Design Sizes According to Anthropometric Calculations

No	Measured Components	Body Dimensions	Small Percentile (cm)	Design (cm)
	The highest limit of the uppermost size of the adjustable welding table	Height when sitting (TBD)	62	60
	Adjustable welding table length	Elbow height when sitting (TSD)	49	47
	The width limit on the welding table is adjustable	Perpendicular elbow position (PSJ)	48	50
	Adjustable welding table width limit	Top hand reach (JTA)	187	76

	Adjustable welding table width	Hand reach forward (JTD)	59	46

1) Appropriate Table Height: The ideal ergonomic table height generally ranges from 70 to 76 cm from the floor. This allows users to sit in a comfortable position with their arms at a 90-degree angle while typing.
2) Spacious Table Surface: The table must have a surface large enough to accommodate work equipment. Sufficient space allows users to work without having to squeeze into work space and minimizes the risk of excessive clutter.
3) Optimal Table Depth: The ideal table depth ranges from 60 to 80 cm. This distance allows the user to reach the equipment comfortably without having to reach too far or bend excessively.
4) The bottom of the table is free from obstacles: Make sure the bottom of the table is high enough and free from obstacles such as brackets or drawers that interfere with leg space. This allows the user to have enough legroom.
5) Appropriate Table Surface Material: Choose a table surface material that suits your work activities. Material that is easy to clean and resistant to scratches or stains can increase the long-term durability of the table.
6) Desk Height Adjustment: Ideally, an ergonomic desk can be adjusted in height to suit the user's body height. Some desks are equipped with a height adjustment system, allowing users to adjust the height of the desk according to their preference and comfort.
7) Cable Management: A good ergonomic desk also has a good cable management system to avoid messy cables and reduce the risk of tripping over cables.

1. Data Collection

Data collection for this research was carried out using existing secondary data sources as well as primary data obtained directly from the product manufacturing process.

2. Initial Design Product Image

Below is a picture of the semi-automatic adjustable welding table product design with dimensions of 70 cm x 60 cm x 100 cm. This semi-automatic welding table uses four table legs and is equipped with four locks on each table leg. Using this feature certainly requires many components, which are set for this welding table at IDR 1,780,000.

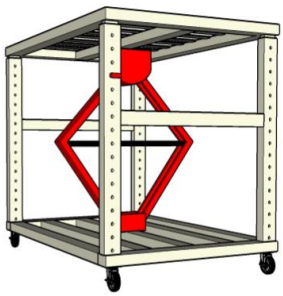


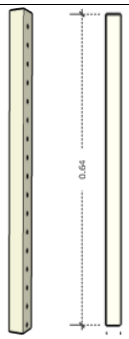
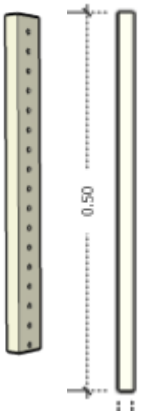
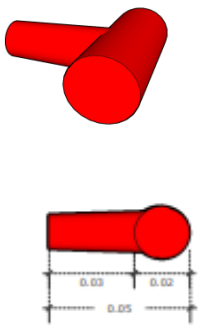
Figure 3. Design option 1
Source: Personal Documents

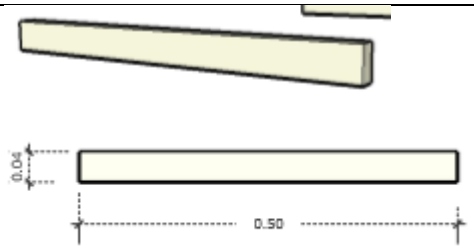
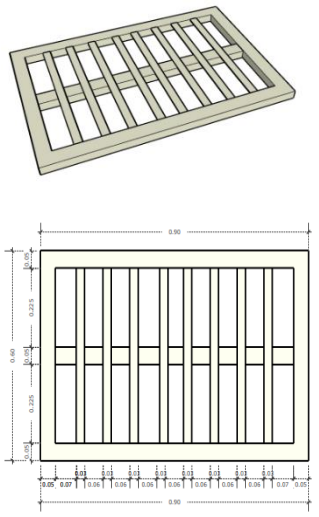
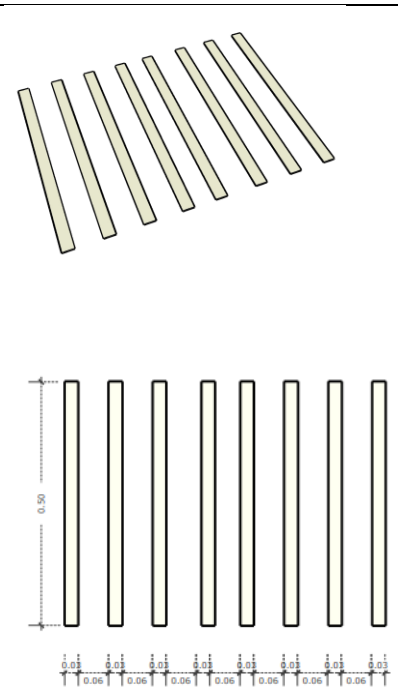
3. Number of Initial Product Components

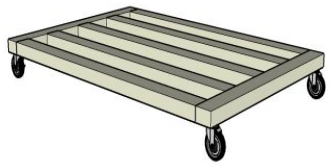
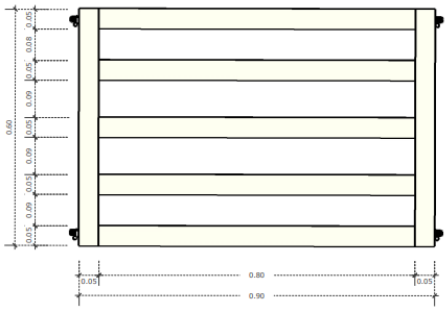
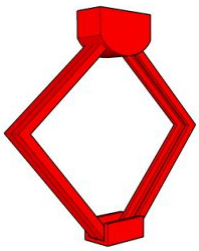
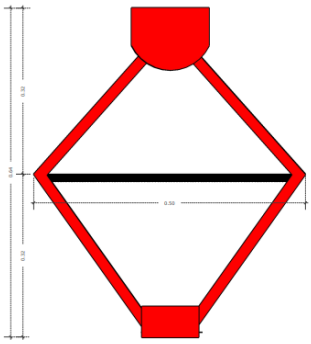
The number of components of an initial product is a product that has an initial design, which is translated by researchers into a meaningful form to transform the initial product into a more advanced development product.

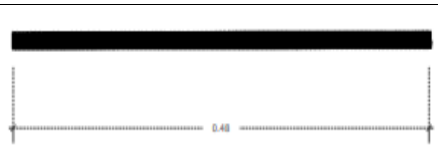
The following is an initial description of the design of the tool that will be analyzed by researchers.

Table 3. Design Component Table 1

No	Component Name	Component Image	Caption
1.	Table leg		There are 4 table legs
2.	Adjustable Support Pole		There are 4 adjustable support poles
3.	Locking bolt		Iron material for locking table legs, 4 pieces

4.	Place the welding head clamp		There are 2 iron materials for the welding head
5.	Welding Table Board		This welding table board has 5 components
6.	Table Base Plate		Table base plates with a total of 14 pieces

7.	Under Table Coaster	 	The Under Table Coaster Has 7 Components
8.	Jack	 	1 Jack
9.	Table Wheel		There are 4 table wheels
10.	Iron screw		The number of threaded iron is 1

Source: Personal Documents

The table above contains details about the assembly of each component, with a total of 47 pieces.

Innovation Product Images

In this product innovation process, researchers have two design options for developing previously existing adjustable welding tables. The aim of this development was to make design changes without sacrificing functionality or affecting the performance of the table.

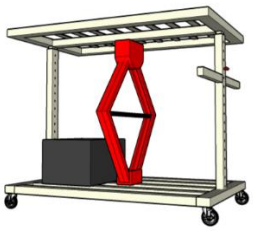


Figure 4. Design Option 2

In the design section of option 2, there are significant design changes. The number of legs on the table has been reduced from 4 to only 2 table legs, and the number of table locks has also been reduced from 4 to 2. In addition, this option 2 design also adds a tool box at the bottom of the table, which functions as a storage space for items.

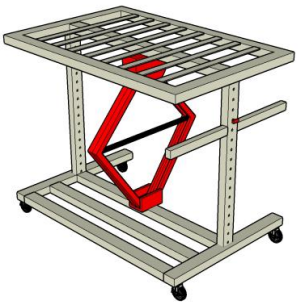


Figure 5. Design Option 3

Then in design 3, it is almost similar to design 2. There is a reduction in components, namely the bottom coaster, which was previously numbered 5. Now there are only 3. Design 3 also does not involve a tool box. This component reduction is carried out to reduce production costs and facilitate the assembly process without sacrificing the function and efficiency of the product.

Innovation Product Data

Assembly time for designs 2 and 3

To assemble a product, it is necessary to fill in a table similar to the one below, which lists the assembly process along with the estimated time required for each assembly stage.

Table 4. Option 2 Design Assembly Time

No	Assembly of Each Component	Time (Minute)	Time (Seconds)
1.	Assembly of welding table boards to become a frame	480	28.800
2.	Installation of table legs on the bottom frame	240	14.400
3.	Installation of adjustable support poles on the table board frame	240	14.400
4.	Installation of the frame table base plate	480	28.800
5.	Installation of jacks on the frame	60	3.600
6.	Installation of table underlays	350	21.000
7.	Installation of the welding head clamp	20	120
8.	Table wheels	60	7.200
9.	Jack	30	1.800
10.	Locking bolt	10	600
11.	Welding Machine Box	60	3.600
Total		2.030	124.320

Source: Personal Documents

Table 5. Option 3 Design Assembly Time

No	Assembly of Each Component	Time (Minute)	Time (Seconds)
1.	Assembly of welding table boards to become a frame	480	28.800
2.	Installing table legs on the bottom frame	240	14.400
3.	Installation of adjustable support poles on the table board frame	240	14.400

4.	Installation of the frame table base plate	480	28.800
5.	Installation of jacks on the frame	60	3.600
6.	Installation of table underlays	300	18.000
7.	Installation of the welding head clamp	20	120
8	Table wheels	60	7.200
9	Jack	30	1.800
10	Locking bolt	10	600
Total		1.920	117.720

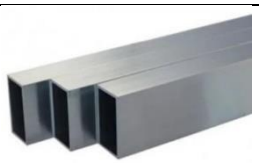
Source: Personal Documents

The table above is an assembly table for each component and has time units in minutes and seconds.

Number of Innovation Product Components

Number of Product Components Innovation is the manipulation of data into a meaningful form to process initial products and development products.

Table 6. Number of Design Components

NO	Name of Material and Tool Components	Picture	Number (units)	Information
1.	Iron Holo Cube		1	Size 5x5 Length 6 Meters
2.	Stainless Steel		1	Size 4x4 Length 1.5 Meters
3.	Iron Holo Beam		2	Size 2x4 12 meters long

4.	Jack		1	Minimum Height, 88mm ; Maximum Height, 383mm
5.	Iron Nut		2	20mm in diameter
6.	Holo Iron		2	Size 12mm Length 2 meters
7.	Table Wheel		4	Size 2 inches
8	Iron screw		1	500 Grams Light Blue Color

Source: Personal Documents

The table above is a table of components and the number of supporting components needed to assemble the design product. There are 8 components, namely cube holo iron material, which has 1 unit with a description of the size 5x5 6 meters long, stainless steel, which has 1 unit with a description of the size 4x4 1.5 meters long, block holo iron, which has 1 unit with a description of the size 2x4 meters long, 1 unit of jack, 2 units of iron nuts with dimensions of 20 mm, threaded iron with a length of 50 cm and a diameter of 12 mm, holo iron material, which has 1 unit with dimensions of 12 mm, 2 meters long, and 4 table wheel materials.

DFA Method

The DFA method is a product development strategy that has been designed with the aim of obtaining information about the results obtained during the process of filling in research data.

DFA Table Filling and Analysis

Based on the assembly time data for each part (Table 4.2) and the number of raw material components (Table 4.3), the DFA table can be filled in as follows:

Table 7. DFA Design Innovation Component Installation Section 2

No	Assembly of Each Component	Time (Minutes)	Time (Seconds)
1.	Assembly of welding table boards to become a frame	5	28.800
2.	Installing table legs on the bottom frame	2	14.400
3.	Installation of adjustable support poles on the table board frame	2	14.400
4.	Installation of the frame table base plate	14	28.800
5.	Installation of jacks on the frame	1	3.600
6.	Installation of table underlays	5	21.000
7.	Installation of the welding head clamp	2	120
8	Table wheels	4	7.200
9	Iron screw	1	1.800
10	Locking bolt	2	600
11.	Welding Machine Box	5	3.600
Total		43	124.320

Source: Personal Documents

Table 8. DFA Component Installation Section Design Innovation 3

No	Assembly of Each Component	Time (Minutes)	Time (Seconds)
1.	Assembly of welding table boards to become a frame	5	28.800
2.	Installing table legs on the bottom frame	2	14.400
3.	Installation of adjustable support poles on the table board frame	2	14.400

4.	Installation of the frame table base plate	14	28.800
5.	Installation of jacks on the frame	1	3.600
6.	Installation of table underlays	5	18.000
47.	Installation of the welding head clamp	2	120
8	Table wheels	4	7.200
9	Iron screw	1	1.800
10	Locking bolt	2	600
Total		38	117.720

Source: Personal Documents

In the DFA table for innovation design 2 and innovation design 3, it can be seen that the number of parts in the installation process for all components of innovation 2 is 11 parts with a total of 43 processes, while innovation 3 has 10 parts and a total of 38 processes. It can be seen from this table that the total amount of assembly time in making design 2 requires 124,320 seconds, or 2,030 minutes, and design 3 requires 117,720 seconds, or around 1,920 minutes.

Innovation Product Assembly Efficiency

To determine the level of product assembly efficiency, the following formula can be used:

Design 2.

$$E = \frac{3\,x\,NM}{TM}$$

$$E = \frac{3\,X\,43}{2.030}$$

$$E = 0{,}064$$

Design 3

$$E = \frac{3\,x\,NM}{TM}$$

$$E = \frac{3\,X\,38}{1.960}$$

$$E = 0{,}058$$

E = assembly efficiency

NM = theoretical minimum number of components

TM = actual time required to assemble

From the assembly efficiency calculation, product design 2 has an assembly efficiency of 0.064 with a total assembly time of 124,320, or 2,030 seconds, and design 3 has an assembly efficiency of 0.058 with a total assembly time of 117,720 seconds, or around 1,920 seconds.

It can be concluded that the efficiency of design 3 of this innovative product is more effective than design 2 because assembly time is shorter.

Overhead Costs and Labor Costs

Table 9. Types of Costs

No	Fee Type	Amount
1.	Overhead : -Electricity -Electrode -Welding	Rp.230.000,00
2.	Wages	Rp.200.000,00
Total		Rp.430.000,00

Source: Personal Documents

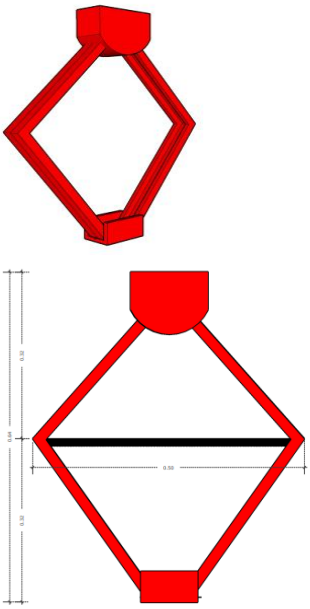
Based on the results of the table above, there are two types of costs, namely overhead and work wages, which total Rp. 430,000.00.

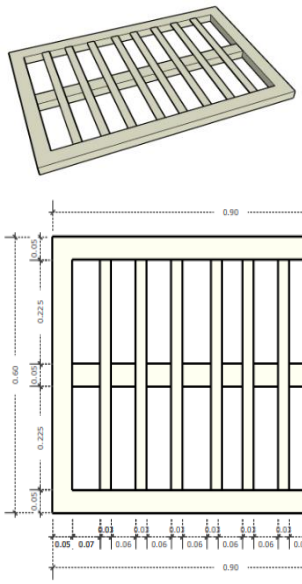
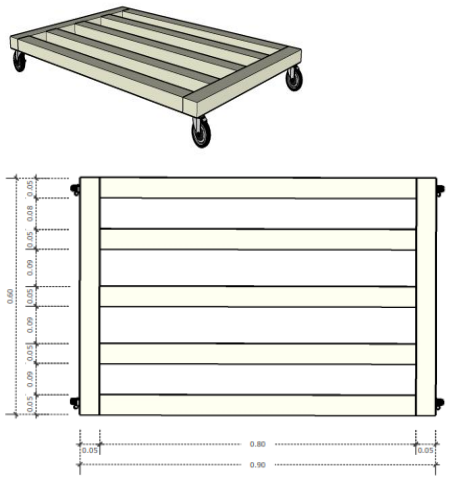
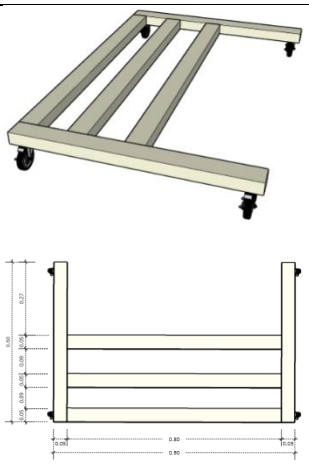
Results of Needs Analysis

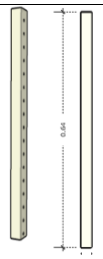
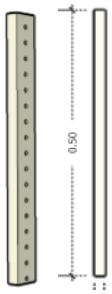
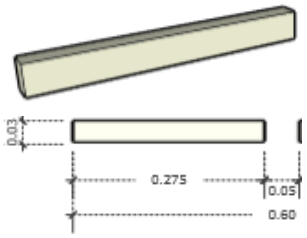
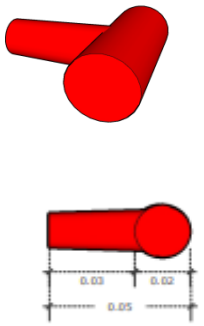
In the process of making an adjustable welding table, it consists of several components and materials, as below are the components and tools needed to make an adjustable welding table.

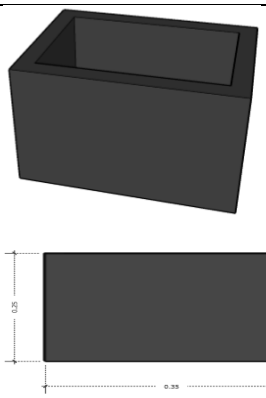
In this section, the researcher explains the component requirements for each design option, as shown in the table below.

Table 10. Comparison of Designs 2 and 3

No	Component Name	Component Image	Number of components	Option 2	Option 3
1.	Jack		1	✓	✓

2.	Welding Table Board		14	✓	✓
3.	Type 2 bottom coaster		5	✓	
4.	Type 3 bottom coaster		3	✓	

5.	Table leg		2	✓	✓
6.	Adjustable Support Pole		2	✓	✓
7.	Welding Head Clamp Holder		2	✓	✓
8.	Locking Bolt		2	✓	✓
9.	Jack Thread		1	✓	✓

10.	Table Wheel		4	✓	✓
11.	Toolbox		1	✓	

Source: Personal Documents

From the component requirements analysis carried out, it turns out that option 3 requires a smaller number of components than the other options. More precisely, option 3 requires nine components in the manufacturing process.

Test result

This section will display the results of the analysis from two aspects, namely the total assembly cost for each design option and the total assembly steps for each design option.

Total Assembly Cost

Manufacturing cost analysis focuses on how many components are used in the manufacturing process. Of the three design options that have been created, the following is a breakdown of the manufacturing costs for each option.

Table 11. Total Assembly Costs

No	Tool	Component	Price	Cost
1	Option 1	1) Legs	Rp 400.000	Rp 1.780.000
		2) Adjustable Support Pole	Rp 300.000	
		3) Locking bolt	Rp 30.000	
		4) Place the welding head clamp	Rp 55.000	
		5) Welding Table Board	Rp 300.000	
		6) Table Base Plate	Rp 120.000	
		7) Under the table coaster	Rp 300.000	
		8) Jack	Rp 150.000	
		9) Table wheels	Rp 75.000	
		10) Threaded iron	Rp 50.000	
2	Option 2	1) Table Legs	Rp 100.000	Rp 1.515.000
		2) Adjustable Support Pole	Rp 100.000	
		3) Locking bolt	Rp 30.000	
		4) Place the welding head clamp	Rp 30.000	
		5) Welding Table Board	Rp 130.000	
		6) Table Base Plate	Rp 100.000	
		7) Under the table coaster	Rp 300.000	

		8) Jack 9) Table wheels 10) Toolbox	Rp 150.000 Rp 75.000 Rp 500.000	
3	Option 3	1) Table Legs 2) Adjustable Support Pole 3) Locking bolt 4) Place the welding head clamp 5) Welding Table Board 6) Table Base Plate 7) Under the table coaster 8) Jack 9) Table Wheel	Rp 100.000 Rp 100.000 Rp 30.000 Rp 40.000 Rp 130.000 Rp 100.000 Rp 175.000 Rp 120.000 Rp 75.000	Rp 870.000

Source: Personal Documents

From the results of the cost analysis above, it was found that design option 3 has cheaper manufacturing costs than the other two design options, namely Rp. 870,000.

Total Assembly Steps

In this section, the researcher will reveal the results of the analysis regarding the total assembly steps.

Table 12. Total Assembly Steps

No	Tool	Total Assembly Steps
1	Option 1	47 Steps
2	Option 2	34 Steps
3	Option 3	25 Steps

Source: Personal Documents

Based on the results of the cost analysis above, it can be concluded that design option 3 is one of the options that has the fewest total number of assembly steps, namely 25 assembly steps.

Discussion of Product Development Results

Based on the three aspects of the assessment that have been analyzed, the results obtained will be the basis for researchers in determining the selected design.

1. Has The Least Number Of Components

Of the three existing options, option 3 has the fewest number of components compared to the other options. Option 1 has a total of 46 components, Option 2 has a total of 34 components, and Option 3 only has a total of 32 components.

2. Has Few Total Assembly Steps

Of the three options available, option 3 is one of the options that has the smallest total number of assembly steps. The comparison of total assembly steps is as follows: option 1 has a total of 40 assembly steps, option 2 has a total of 34 assembly steps, and option 3 has a total of 25 assembly steps.

3. Low Cost

Of all the available options, option 3 has the lowest cost. This is due to the smaller number of components compared to options 1 and 2. The cost comparison for each option is as follows: option 1 has the highest cost in the range of Rp. 1,780,000, option 2 has costs in the

range of Rp. 1,515,000, and option 3 has a cost in the range of Rp. 870,000.

After reviewing the three available options, the researchers concluded that option 3 was the most efficient tool design, as it excelled in almost every aspect of the analysis. This option has the fewest number of components, the cheapest manufacturing costs, and the lowest total number of assembly steps. In this study, researchers also found that variations in design had a significant influence on the DFMA analysis process.

Application of Research Results

The results of applying this design can be applied to:

1) It is hoped that the results of this adjustable welding table design, after being reviewed and analyzed from the perspective of ease in the manufacturing and assembly processes, can meet consumer needs. This adjustable welding table is designed to be used in various daily activities according to user needs.
2) Furthermore, the results of the adjustable welding table design using the DFMA method can be applied to product design courses. In this course, students will be asked to design a product with the help of software. Apart from that, students will also be asked to analyze the advantages and disadvantages of the products they have designed, as well as describe how the tools they have designed work.

CONCLUSION

Based on the research results, the following conclusions can be drawn: In previous product development, design 3 has been completed with a design that is certainly more ergonomic than design 1, because design 3 has been adjusted to body size by using ergonomic standards. Based on the results of this adjustable welding table product development, option 3 is the one with the lowest cost because it has a smaller number of components and total assembly steps compared to options 1 and 2. The cost of option 1 is around Rp. 1,780,000; option 2 is around Rp. 1,515,000; and option 3 is around Rp. 870,000. The total assembly steps for option 1 are 40; option 2 is 34; and option 3 is 25. The number of components in options 1 and 2 is 10, while option 3 is only 9.

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