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Design Efficiency and Early Cost Estimation of Dual-Function Waste Chopper Machine through DFMA Approach

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ABSTRAK

Design for Manufacture and Assembly (DFMA) adalah metodologi yang diakui secara luas yang mengoptimalkan desain produk untuk mempercepat proses manufaktur dan perakitan. DFMA dapat menghasilkan penghematan biaya yang signifikan, peningkatan kualitas, dan mempersingkat waktu ke pasar dengan mempertimbangkan kemampuan manufaktur dan persyaratan perakitan sejak awal pengembangan produk. Dalam tinjauan mini ini, kita akan membahas prinsip dan manfaat utama DFMA dan penerapannya pada praktik manufaktur modern. Artikel ini juga menunjukkan penerapan metode DFMA pada Mesin Penghancur Limbah Fungsi Ganda untuk menganalisis kemampuan perakitan dan kemampuan manufakturnya. Dengan menerapkan metode DFMA, insinyur dan desainer dapat mengoptimalkan kemampuan manufaktur dan perakitan produk yang didesain ulang, menghasilkan peningkatan efisiensi, kualitas, dan kepuasan pelanggan. Ulasan ringkas ini berfungsi sebagai referensi untuk memahami konsep utama dan manfaat penggunaan metode DFMA dalam mendesain ulang produk. Dengan mengadopsi prinsip-prinsip DFMA, produsen dapat secara signifikan meningkatkan kemampuan manufaktur dan efisiensi perakitan produk, meningkatkan daya saing pasar.

Kata Kunci: *Design for Manufacture and Assembly (DFMA),* Mesin Penghancur Limbah Fungsi Ganda, Desain Ulang Produk, Efisiensi Desain

ABSTRACT

Design for Manufacture and Assembly (DFMA) is a widely recognized methodology that optimizes product design to expedite manufacturing and assembly processes. DFMA can result in significant cost savings, enhanced quality, and a shortened time-to-market by contemplating manufacturability and assembly requirements from the outset of product development. In this mini-review, we will discuss the DFMA's main principles and benefits and its applicability to modern manufacturing practices. This article also demonstrates the implementation of DFMA methods on a Dual-Function Waste Crushing Machine to analyze its assembly ability and manufacturability. By applying the DFMA method, engineers and designers can optimize the manufacturing capabilities and assembly of the redesigned products, resulting in improved efficiency, quality, and customer satisfaction. This concise review serves as a reference to understand the main concepts and benefits of using the DFMA method in redesigning products. By adopting DFMA principles, manufacturers can significantly improve manufacturing capabilities and product assembly efficiency, increasing market competitiveness.

Keywords*: Design for Manufacture and Assembly (DFMA), Dual-Function Waste Crushing Machine, Product Redesign, Design Efficiency.*

INTRODUCTION

In today's dynamic and competitive industrial landscape, effective product design and development has a central role in determining the success of an organization. One approach that has gained increasing attention over the years is the Design for Manufacture and Assembly (DFMA) methodology. DFMA is a systematic approach that aims to optimize product design to make it easy to manufacture, assemble, and cost-efficient overall. By considering manufacturing and assembly factors from the beginning of the design process, organizations can simplify the production process, reduce costs, and improve product quality. (Boothroyd, 1994).

This article critically reviews the Design for Manufacture and Assembly methodology and explores its application in the context of waste shredder design improvements. The waste management industry faces increasingly complex challenges due to increased waste production and environmental concerns. (R. Aj. Nuriyati Arini Dewi, 2021). Efficient waste shredding is important to reduce waste volume, improve recycling processes, and minimize environmental impact. Implementing DFMA principles in the design of waste shredding machines provides opportunities to optimize manufacturing and assembly processes, resulting in better performance, lower production costs, and higher sustainability.

A review of the DFMA methodology will include its core principles, benefits, and examples of success in several studies. It involves analysing existing designs, identifying potential areas for improvement, and incorporating DFMA concepts to create an optimized design considering manufacturability, assembly efficiency, and overall lifecycle costs. This case study will highlight how integrating DFMA principles can lead to a more efficient and effective design process, resulting in a waste shredder that not only meets performance requirements but also excels in terms of production and assembly feasibility.

In conclusion, this paper aims to provide a comprehensive understanding of the Design for Manufacture and Assembly methodology, its significance, and its application in the design improvement of waste shredding machines. By combining innovative design approaches with sustainability goals, organizations can create products that are not only functional and have high performance, but are also in line with the principles of resource optimization and environmental responsibility. Through examining the application of the DFMA methodology in the design of waste shredders, this paper contributes to the broader discourse on engineering practices that balance efficiency, cost-effectiveness, and ecological considerations.

RESEARCH METHODS

DFMA Method Overview

The literature review involved collecting, analysing, and integrating literature relevant to the application of the DFMA method. The literature review serves as a basis for understanding current knowledge developments and shapes the direction of new research.

Application of DFMA to Waste Shredding Machine

The application of DFMA to the waste chopping machine is used as an approach for reference in designing a more efficient waste chopping machine in terms of production and assembly. The DFMA analysis process will be assisted by relevant DFMA analysis software, namely DFM Concurrent costing software and Design for Assembly software. The explanation in this analysis will cover the concrete steps taken in the DFM and DFA analysis, including the use of DFM Concurrent costing software and Design for Assembly software. The output of this analysis process is the value of the DFA index, total cost per product, and total assembly labour time.

RESULT AND DISCUSSION

Design for X (DFX)

The term "Design for X" (DFX) was coined by Parsaei (1993) here X represents other upstream and downstream capabilities and functions. Some DFX techniques are based on conventional techniques that interact with economic aspects of sustainability. For example, the DFMA technique was developed to cover the manufacturing step by combining Design for Assembly (DFA) and Design for Manufacture (DFM) (Juniani et al., 2022). Benabdellah et al. (2019) categorized DFX techniques based on size, scope, abbreviations, and sustainable design considerations. This analysis provides a systematic review by investigating and discussing past and present analyses of each DFX technique. A conceptual and methodological framework for improving DFX communication and collaboration is concluded as a future research direction. It also proposes integrating DFX engineering to redesign some mechanical products considering assembly, safety, service, supply chain, quality, and reliability' advantages.

Therefore, there are several perspectives to study the integration of methods in DFX, especially in terms of manufacturing cost reduction, supply chain, and environmental consequences.

Design for Manufacture and Assembly (DFMA) Boothroyd and Dewhurst conceptualized Design for Assembly (DFA) as a method to account for assembly methods, time, and cost during the product design process. DFM evolved from DFA to incorporate materials and manufacturing processes into product design. Later, DFMA was created to integrate DFA and DFM, promoting the simplification of component and product design to reduce the number of components, lower manufacturing costs, improve reliability and quality, and expand production capacity (Kuo dkk. 2001). FMA offers a simpler design framework without compromising customer requirements or product quality. The Westinghouse method is the most common DFA approach, while other DFA approaches include the Boothroyd-Dewhurst (B&D), Lucas method, and Hitachi-AEM method. The four indicators used in B&D practice are assembly time, cost, minimum number of components, and design effectiveness (Borchani dkk., 2019). The DFA approach with the B&D method has critical assumptions that must be considered in its application (Dochibhatla dkk, 2019):

a. components are added one by one during assembly;
b. product components are large and random; and
c. each component has complete information on dimensions and specifications.

The Lucas method includes scale points to assess the difficulty in implementing the assembly process. This technique provides design efficiency, feeding index, and installation index. Dochibhatla et al. (2019) simultaneously conquered the implementation of Lucas and B&D methodologies. It is emphasized to use the Lucas method at an early stage because this method does not require part dimension data to achieve design efficiency. Meanwhile, the B&D method (Boothroyd, 1994) refines the design by using precise design parameter data. The application of this method causes the designer's processing time to increase. Only the Lucas method can be applied when product data is less specific. The Lucas method is considered during the conceptual design phase. The B&D, Hitachi, or Westinghouse methods, on the other hand, can be considered during the detailed engineering design phase. Borchani et al.(2019) found that DFMA tools can save time when evaluating designs and should be implemented early in the design selection process. The product is evaluated while the initial design is examined, changed, and redesigned in preparation for product evaluation. Bin Ahmad et al. (2018) adopted a DFMA approach to reduce the cost of a water nozzle. This strategy incorporates the techniques used in this study to assess the DFMA requirement steps associated with industrial machinery. Harlaka dkk. (2016) established a case study of the DFMA methodology in the white goods industry (refrigerators, toasters, food processors, etc.). They presented a case study of a redesigned consumer product with decreased cost and increased reliability. The home appliance industry focuses on low cost, high manufacturability, and lasting dependability. Therefore, the DFMA approach can really benefit this industry. DFMA aims to simplify the product structure to facilitate assembly and upgrade components to facilitate production. In addition, this approach allows designers to reduce the number of components used, simplify and restructure manufacturing procedures, use standard parts and materials across product lines, and eliminate or reduce the amount of customization required (Harlaka dkk., 2016).

Application of DFMA to Waste Chopping Machine

There are several steps in the DFMA analysis process on the waste chopping machine, including the following:

a. Machine data collection

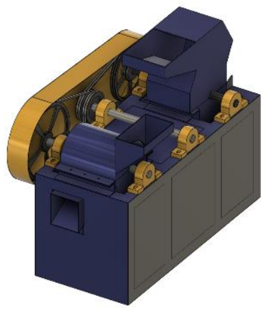
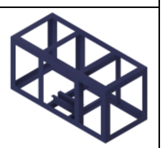
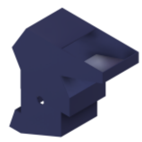
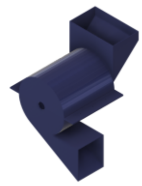
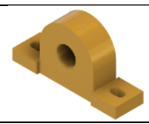
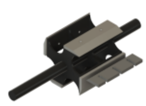
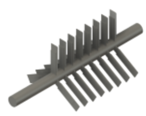
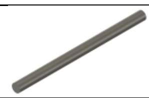


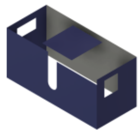
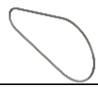
Figure 1 Existing Design of dual-function Waste Shredding Machine

Figure 1 is the initial design of the waste shredding machine that will be improved. The machine has dimensions of 1560 mm x 860 mm x 1280 mm. Some components of the waste shredder have the potential to be eliminated in order to reduce the manufacturing and assembly process. Data on the components that make up the dual-function waste shredder are presented in Table 1 as follows.

Table 1 Component list of waste shredder

Sequence	Part Name	Repetition	Shape Dimension (mm)	*Process*	*Securing Method*	*Handling Difficulties*	*3D Model*
1	Machine frame: a. Vertical Iron b. long iron c. Wide Iron d. Motor Mount	 8 4 8 2	 725 x 75 x 75 t=5 1522 x 75 x 75 t=5 670 x 75 x 75 t =5 380 x 75 x75 t=5	*Cut from* *stock* *Cut from* *stock*	*Electric* *Electric* *Electric* *Electric*	*Two hands* *Two persons* *Two hands* *Two hands*	

Sequence	Part Name	Repetition	Shape Dimension (mm)	*Process*	*Securing Method*	*Handling Difficulties*	*3D Model*
				Cut from stock *Cut from stock*			
2	Organic and Plastic Cover Stand	4	400 x 60 x60 t=6	*Cut from stock*	*Electric*	*Two hands*	
3	Plastic Shredder Cover: a. bottom plate 1 b. bottom plate 2 c. bottom plate 3 d. bottom plate 4 e. Top Plate1 f. Top Plate2 g. Top Plate3 h. Top Plate4 i. Top Plate5 j. Top Plate6 k. Top Plate7 l. Stopper	 2 1 1 1 2 2 2 1 1 1 1 1	 P=447 L=330 t=5 P=312 L=180 t=5 P=312 L=185 t=5 P=312 L=50 t=5 P=782 L=570 t=5 P=312 L=140 t=5 P=312 L=150 t=5 P=312 L=234 t=5 P=312 L=300 t=5 P=312 L=380 t=5 P=312 L=80 t=5 P=100 L=75 t=5	 *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser*	 *Securing later* *Securing later* *Electric* *Electric* *Stake* *Electric* *Electric* *Electric* *Electric* *Electric* *Electric* *Electric*	 *Two hands* *Two hands* *Two hands* *Two hands* *Two hands* *Two hands* *Two hands* *Two hands* *Two hands* *Two hands* *Two hands* -	
4	Organic Shredder Cover: a. Bottom Plate1 b. Bottom Plate2 c. Bottom Plate3 d. Bottom Plate4 e. Support Plate f. Top Plate1 g. Top Plate2 h. Top Plate3 i. Top Plate4 j. Top Plate5 k. Top Plate6 l. Top Plate7	 2 1 1 1 3 1 1 1 1 1 1 2	 P=470 L=357 t=5 P=204 L=439 t=5 P=204 L=200 t=5 P=557 L=400 t=5 P=400 L=71 t=5 P=360 L=155 t=5 P=557 L=400 t=5 P=360 L=50 t=5 P=346 L=276 t=5 P=346 L=60 t=5 P=346 L=248 t=5 P=200 L=248 t=5	 *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser*	 *Electric* *Electric* *Electric* *Electric* *Securing later* *Stake* *Electric* *Electric* *Electric* *Electric* *Electric* *Electric*	 *Two hands* *Two hands* - *Two hands* *Two hands* *Two hands* *Two hands* *Two hands* *Two hands* *Two hands* *Two hands* -	
5	Bearing UCP 310	6	275 x 75 x 143	*Mix*	*Securing later*	*Two hands*	
6	Plastic Knife Set: a. Plastic Shaft b. Knife Stand 1 c. Knife Stand 2 d. Knife Stand 3 e. Plastic Knife	 1 3 4 1 5	 P=796 Ø50 P=212 L=212 t=8 P=268 L=98 t=8 360 x 75 x75 t=6 280 x 100 x 15	 *Cut from stock* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cut from stock*	 *Push/ press* *Electric* *Electric* *Electric* *Securing later*	 *Two hands* - - - *Two hands*	
7	Organic Knife Set: a. Organic Shaft b. Org Knife Stand c. Organic Knife	 1 24 24	 P=756 Ø50 P=117 L=30 t=3 P=130 L=40 t=2	 *Push/ Press* *Electric* *Electric*	 *Two hands* - -	 *Push/ Press* *Electric* *Electric*	
8	Reducer Shaft	1	P=771 Ø50	*Push / Press*	*Two hands*	*Push / Press*	
9	Electric Motor 7.5Kw	1	501 x 205 x 315	*Securing later*	*Mobile Crane*	*Securing later*	

Sequence	**Part Name**	**Repetition**	**Shape Dimension (mm)**	***Process***	***Securing Method***	***Handling Difficulties***	***3D Model***
10	Frame Cover: a. Frame Plate 1 b. Frame Plate 2 c. Frame Plate 3 d. Frame Plate 4	 1 1 1 1	 P=1524 L=725 t=5 P=1524 L=725 t=5 P=670 L=725 t=5 P=670 L=725 t=5	 *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser*	 *Securing later* *Securing later* *Securing later* *Securing later*	 *Two persons* *Two persons* *Two hands* *Two hands*	
11	Tension	1		*Mix*	*Tread*	-	
12	Pulley PD100	1	Ø100	*Casting*	*Push / Press*	-	
13	Pulley PD200	1	Ø200	*Casting*	*Push / Press*	*Two hands*	
14	Pulley PD400	1	Ø400	*Casting*	*Push / Press*	*Two hands*	
15	Pulley PD500	1	Ø500	*Casting*	*Push / Press*	*Two hands*	
16	V-Belt B58	2	1473 x 16.5 x 11	*Molding*	*Securing later*	*Two hands*	
17	V-Belt B77	2	1956 x 16.5 x 11	*Molding*	*Securing later*	*Two hands*	
18	V-Belt B85	1	2159 x 16.5 x 11	*Molding*	*Securing later*	*Two hands*	
19	Cover Pulley: a. Pulley Plate1 b. Pulley Plate2 c. Pulley Plate3 d. Pulley Plate4 e. Pulley Plate5 f. Pulley Plate6 g. Pulley Plate7	 1 1 1 1 1 1 1	 P=1480 L=811 t= 2 P=998,7 L=150 t= 2 P=730,2 L=150 t= 2 P=558,8 L=150 t= 2 P=691,7 L=150 t= 2 P=703,2 L=150 t= 2 P=103 L=150 t= 2	 *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser* *Cutting Laser*	 *Securing later* *Electric* *Electric* *Electric* *Electric* *Electric* *Electric*	 *Two persons* *Two hands* *Two hands* *Two hands* *Two hands* *Two hands* -	

b. Creation of part library in DFM Concurrent costing software

The part library is data on the components that make up the machine, including the shape, dimensions, and treatment process of the material. The data is entered into the DFM Concurrent Costing software. Each component is stored in one DFM file. So that the number of DFM files is the same as the number of components that make up the machine.

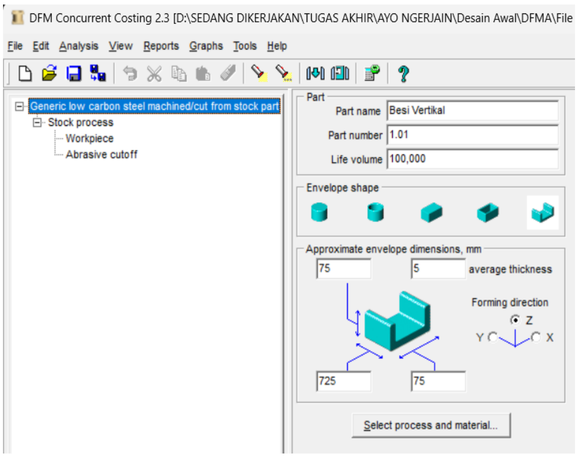


Figure 2 DFM Concurrent costing software display

Figure 2 is a view of the DFM Concurrent costing software. "Part name" is the name of the component. "Envelope shape" is the basic shape of the material before machining. The dimensions used are the dimensions that have been recorded in Table 1. If the shape of the component is not like the basic shape of the material, it is necessary to make additional input through the "Geometry Calculator" menu on the "View" menu as shown in Figure 3 as follows:

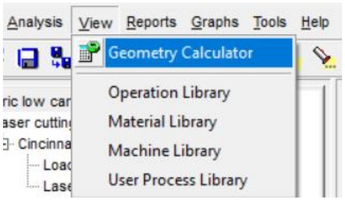


Figure 3 Geometry Calculator Menu

The Geometry Calculator display will be shown as in Figure 4 as follows:

On the left bar there are several shapes. The left shape icon is the geometry that is part of the component shape. While the right one is the hole geometry that occurs in the base material. Once all dimensions have been entered, the DFM file can be saved. Each component is created with one DFM file.

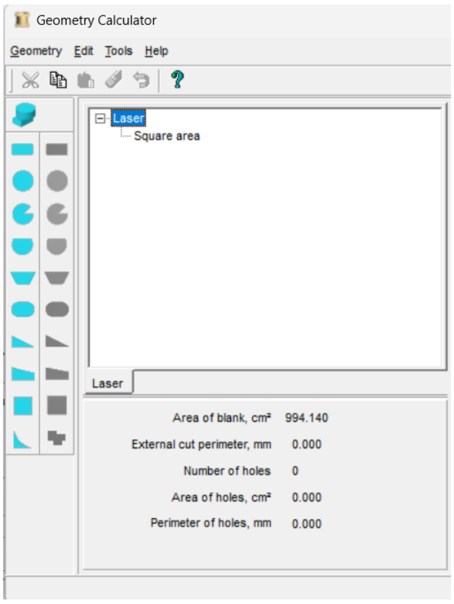


Figure 4 Geometry Calculator view

c. DFA Analysis on Design for Assembly Software

The DFM files of each component are entered into the Dedign for Assembly software according to the assembly sequence. The Design for Assembly software display can be seen in Figure 5 as follows:

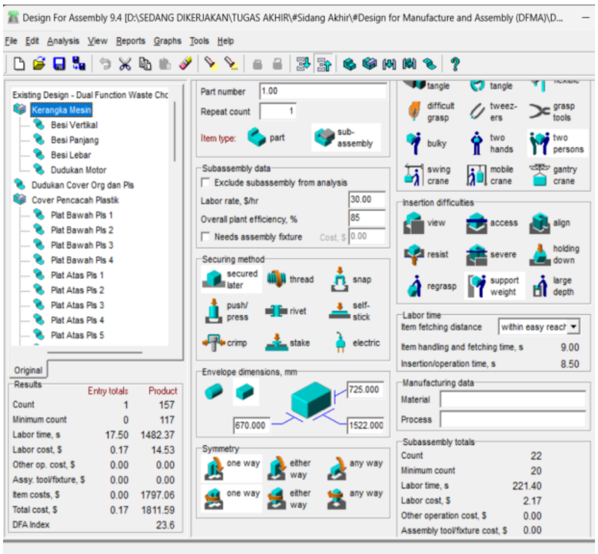


Figure 5 Design for Assembly software view

Data on the number of repetitions, securing methods, and handling difficulties for each component are obtained from the data in Table 1. After all the data has been entered, the next step is to get the DFMA executive summary results by selecting the DFMA executive summary menu in the "Reports" bar. The DFMA summary results of the waste shredder can be seen in Table 2 as follows:

Table 2. Executive Summary DFMA of waste shredding machine

Category	Result
Product life volume	10.000
Number of entries (including repeats)	157
Number of different entries	64
Theoretical minimum number of items	117
DFA Index	**23,6**
Total weight (kg)	509,33
Total assembly labour time (s)	**1482,37**
Total cost for manufactured items (including tooling) ($)	1797,06
Total assembly labour cost ($)	14,53
Other operation cost per product ($)	0,00
Total manufacturing piece part cost ($)	1797,06
Total cost per product without tooling ($)	1811,59
Assembly tool or fixture cost per product ($)	0,00
Manufacturing tooling cost per product ($)	0,00
Total cost per product ($)	**1811,59**

The value of the DFMA results of the waste chopping machine can be increased by making a redesign. In the Design for Assembly software there are results in the form of suggestions for improvement in redesign. How to issue the results of suggestions for redesign is by selecting the suggestions for redesign menu on the "reports" bar. Suggestion for redesign on waste chopping machines can be seen in Table 3 as follows:

Table 3 Suggestion for Redesign Results Table

Component Name	Suggestion	Quantity
Reducer	Combine	1
Pulley PD200	Attempt to rearrange	1
V-Belt B58	Attempt to rearrange	1
V-Belt B77	Attempt to rearrange	1
V-Belt B85	Attempt to rearrange	1
Support Plate	Combine	3
Tension	Attempt to rearrange	1
Frame Cover	Remove	4
Pulley Cover	Attempt to rearrange	7
Frame Iron	Attempt to rearrange	4

CONCLUSION

Based on the literature review regarding the "Design for Manufacture and Assembly" (DFMA) method, it can be concluded that DFMA is a significant approach in product engineering that aims to optimize production and assembly processes. Research that has been conducted in various industries shows that the application of DFMA can yield substantial benefits, including reduced production costs, improved product quality, and reduced production time. DFMA provides concrete guidance to product designers in avoiding design errors that can affect production costs and time. Specialized software or analysis tools that support the application of DFMA also provide support in material selection, alternative design testing, and assembly process simulation.

The results of the DFMA analysis on the dual function waste chopper machine found that the DFA index of the manufacturing process was 23.6. The weight of the waste chopping machine is 509.33 kg. And the number of entries from its components is 157 items. These conditions make it possible to redesign the design of the waste chopping machine. The redesign process can apply the points contained in the suggestion for redesign results from the DFMA analysis results.

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