



# Design Optimization Analysis of Grass Chopper Machine Through the Application of Design for Manufacture and Assembly (DFMA) Approach

M. Fauzan<sup>1</sup>, Tamara Kartika<sup>1</sup>, Khakam Ma'ruf<sup>1\*</sup>

<sup>1</sup> Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta, 55281, Indonesia

Correspondence: [hakammaruf70@gmail.com](mailto:hakammaruf70@gmail.com)

## Article Info

### Article history:

Received September 30<sup>th</sup>, 2025

Revised October 16<sup>th</sup>, 2025

Accepted October 26<sup>th</sup>, 2025

### Keyword:

Design, DFMA, Grass Chopper Machine.

## ABSTRACT

The livestock sector in Indonesia necessitates efficient grass chopper technology to enhance animal feed productivity. However, conventional grass choppers continue to exhibit design complexity, elevated production costs, and assembly inefficiencies that impede technology adoption at the farm level. This study aims to analyze and redesign the grass chopper by applying the Design for Manufacture and Assembly (DFMA) approach to optimize operational efficiency and reduce manufacturing expenses. The research method employs a Design-Based Research (DBR) framework encompassing problem identification, documentation of the existing design via the Bill of Materials (BOM) and Operational Process Chart (OPC), design evaluation using DFMA principles, redesign implementation, and financial feasibility analysis. DFMA implementation is executed through three strategies: reducing component count in the chute output and cover assemblies, optimizing material thickness from 3 mm to 2.5 mm based on CAE simulation results, and incorporating a hopper feature for automatic feeding. The study results indicate a marginal increase in production time of 3.29% (from 730 to 754 minutes), which is considered negligible relative to the added value. From a financial perspective, the Cost of Goods Sold (HPP) decreased substantially from Rp. 171,202,626.53 to Rp. 3,277,373.33 per unit; the profit margin increased from 10.56% to 27.17%; the Net Present Value (NPV) rose from Rp. 55,845,740.49 to Rp. 365,135,757.34; and the Internal Rate of Return (IRR) improved from 26.22% to 81.30%. With a unit selling price of Rp. 4,500,000, the redesigned product remains competitive in the market, offering a payback period of two years, thus presenting a financially viable solution for developers and enhancing the likelihood of adoption by local farmers



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## 1. INTRODUCTION

The livestock sector in Indonesia plays a strategic role in supporting national food security and the rural economy (Nugroho et al., 2022). Within livestock operations, provision of high-quality feed is a critical determinant of ruminant productivity (Puspitasari & Baru, 2025). Grass, as the primary feed for ruminant livestock, necessitates a shredding process to enhance palatability and consumption efficiency. The manual shredding method employed by farmers is time- and energy-intensive, thereby reducing operational efficiency (Worldailmi et al., 2025). Mechanical grass shredding machines represent a pivotal technology for optimizing feed preparation, conserving labor and time, and improving feed quality delivered to livestock (Anugrah et al., 2024; Mashudi et al., 2022).

Conventional grass chopping machines currently available on the market continue to exhibit various technical deficiencies that impede technology adoption at the livestock farmer level (Margono et al., 2021). The primary issues include suboptimal operational mechanisms in the chopping output, resulting in non-uniform particle sizes that adversely affect feed quality. Moreover, the multiplicity and heterogeneity of parts and components complicate repair and maintenance when the machine is damaged or experiences wear (Fadlullah et al., 2024). High design complexity further contributes to elevated production and maintenance costs, rendering these machines less affordable for smallholder farmers. Additionally, limited efforts in redesign and development have constrained innovation and optimization of grass chopping technology, causing local products to lag behind more expensive

imported alternatives. The availability of an efficient shredding machine could have a significant impact on enhancing livestock productivity (Imaduddin et al., 2024; Maru et al., 2024), specifically for small and medium scale farmers who face constraints in labor and time for feed management.

The Design for Manufacturing and Assembly (DFMA) approach provides a systematic framework for addressing prevailing grass chopper design deficiencies. DFMA constitutes a design methodology that integrates manufacturability and assemblability considerations from the initial phases of product development (Azalia & Mendrofa, 2023). Key elements include design simplification, component count reduction (Chenio et al., 2025), part standardization (Carolla, 2019), and optimization of assembly processes, all aimed at minimizing production costs and enhancing product quality (Hartadi et al., 2025). Implementing DFMA in the grass chopper redesign is anticipated to yield a configuration that is more efficient, cost-effective, and conducive to streamlined manufacturing. Moreover, this approach incorporates maintainability and serviceability considerations, thereby facilitating ease of repair and upkeep by farmers. Consequently, DFMA represents an appropriate framework for the development of grass chopper machines tailored to the requirements and capacities of local farming communities.

This study aims to conduct an analysis and subsequent redesign of a grass chopper machine through the application of the Design for Manufacture and Assembly (DFMA) approach, with the objectives of enhancing operational efficiency and reducing production costs. By conducting an in-depth evaluation of the existing design and systematically identifying areas for improvement, the study is anticipated to yield a chopper machine design characterized by increased efficiency, reduced production costs, simplified assembly and maintenance, and enhanced reliability. The study is also expected to stimulate the growth of the domestic agricultural machinery manufacturing sector and diminish reliance on imported technologies. The scope of the study encompasses performance analysis of the existing chopper machine, identification of critical design parameters, development of alternative designs via the DFMA approach, simulation and validation of the redesigned machine, and evaluation of the economic feasibility of the proposed design to ensure its implementability at the industrial level and its accessibility for adoption by farmers.

## 2. LITERATURE REVIEW

The development of grass chopping machine technology for animal feed has emerged as a focal area of research aimed at enhancing the efficiency of the livestock sector. Numerous studies have investigated the design and technological evolution of chopping machines, encompassing configurations from reel-type blade systems to slicing mechanisms tailored for diverse feed materials. The following literature review examines prior research pertinent to grass chopping machine development, with particular emphasis on elucidating existing design shortcomings and identifying opportunities for improvement through the Design for Manufacture and Assembly (DFMA) approach.

The first study conducted by Satriyo et al. (2023) developed a grass chopper machine for animal feed with a reel-type knife and a 7 HP engine power that was successfully developed effectively. This machine is capable of chopping elephant grass at high speed, producing uniform cuts of around 250 mm for leaves and 65 mm for stems, with a capacity of 1 kg per minute. Functional and feasibility tests by lecturers showed very good values, 92.5% and 90% respectively. A user satisfaction survey from farmers with 50 goats also produced a score of 90%, proving that this tool is feasible and efficient to use. Although this study shows success in terms of functionality, it has not explored design optimization from the perspective of ease of manufacture and assembly which is the main focus of the DFMA approach.

The second study conducted by Sugandi et al. (2016) successfully developed a elephant grass shredder machine with a reel-type blade for animal feed. The machine measuring 800×750×1042 mm was able to shred elephant grass with a capacity of 1988 kg/hour using 1.6 kW of power. The shredded results reached a length of 1-3 cm, according to the standard for animal feed silage (1-5 cm). The machine produced a noise level of 78.91 dB and a vibration of 18.23 mm/s. The characteristics of the elephant grass used had an average length of 99.4 cm with a water content of 81.1%, providing a mechanization solution for animal feed needs in the Lembang area. This study showed the achievement of high production capacity, but the relatively large dimensions of the machine indicated design complexity that could potentially increase production costs and complicate the assembly process.

The third study conducted by Marsono & Septian (2018) showed that the prototype of the ATC (Alkali Treated Cottonii) seaweed shredding machine was successfully developed with a slicing mechanism using a pair of moving and stationary knives. This machine is capable of shredding dry ATC with a variation in the length of the shredded results of 1–3 cm and a minimum production capacity of 180 kg/hour. Although not all the shredded results have reached the ideal length of 14 mm uniformly, this prototype has proven to be able to cut dry ATC well and is a more effective alternative than conventional shredding machines which are less efficient for dry ATC. This study identified the problem of non-uniformity of shredded results which is in line with the problems identified in the introduction regarding the machine's less than optimal working system in the shredding output section.

Based on the literature review above, several research gaps have been identified that can be filled through the DFMA approach in redesigning grass chopper machines. First, previous studies have focused more on the functionality and performance aspects of the machine without considering design optimization from the perspective of ease of manufacture and assembly. Second, the problem of design complexity that causes high production costs and maintenance difficulties, as identified in the introduction, has not received adequate attention in previous studies. Third, component standardization and design simplification, which are the main principles of DFMA, have not been implemented systematically.

This study fills the gap by implementing the DFMA approach to overcome the design problems of existing grass chopper machines. Focusing on reducing the number of components, standardizing parts, and optimizing the assembly process is expected to produce a design that is more efficient, economical, and easy to produce compared to designs that have been developed in previous studies. Thus, this study contributes to developing grass chopper machine technology that is not only superior in terms of performance, but also optimal from the perspective of manufacturability and maintainability.

### **3. RESEARCH METHODS**

#### **A. Research Approach**

This study employed a Design-Based Research (DBR) approach that focused on the development and improvement of grass chopper machine designs by applying Design for Manufacture and Assembly (DFMA) principles. The DBR approach was chosen because it allowed the development of design solutions iteratively through design testing in real contexts, as well as evaluation of enhanced functionality (Judijanto et al., 2024). This approach also enabled the researchers to identify existing problems, test design solutions, and validate the outcomes of improvements in the assembly and operational processes of the machine (Setiawan et al., 2024).

#### **B. Location and Object of Research**

This research was conducted at the Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada. The object of the research analyzed was a grass chopper machine used in the livestock sector, especially for processing grass as animal feed. The main focus of this research was to analyze the design of existing grass choppers, as well as to redesign certain components to increase production efficiency and reduce operational costs using the DFMA principle.

#### **C. Research Stages**

This research was conducted through seven systematic stages, beginning with the identification of problems in the existing grass chopper design to uncover deficiencies such as assembly complexity, high costs, and insufficient operational efficiency. Then, comprehensive documentation of the existing design was undertaken via the preparation of a Bill of Materials (BOM) and an Operational Process Chart (OPC) to record all components, assembly processes, and associated time requirements. In the third stage, the existing design was evaluated using the Design for Manufacture and Assembly (DFMA) principle, which included component functionality analysis, part standardization, and assembly process analysis to identify potential improvements. DFMA implementation was then executed by simplifying the design through part reduction, reducing material thickness from 3 mm to 2.5 mm based on CAE simulation, and incorporating a hopper feature for automatic feeding.

Based on the DFMA implementation, a new design was developed that simplified complex components, such as the chassis and body by reducing sub-components and replacing welding operations with bending to expedite assembly. In the sixth stage, a financial feasibility analysis of the

new design was performed by calculating HPP, NPV, IRR, and payback period to assess the impact of DFMA implementation on profitability. The study concluded with a comparative analysis between the existing and redesigned machines based on BOM, OPC, assembly time, production cost, and profitability metrics to determine the success of DFMA implementation in enhancing efficiency without compromising machine functionality.

#### **D. Research Instruments**

The research instruments included CAD/CAE software SolidWorks for design planning and analysis, a Bill of Materials (BOM) and an Operational Process Chart (OPC) for component documentation and assembly process mapping, a stopwatch for actual time measurement, and CAE simulation for design strength testing. A software engineering approach was employed for design optimization by leveraging SolidWorks 3D modeling and structural analysis capabilities, systematic documentation via the BOM, workflow mapping via the OPC, and empirical validation through manual time measurements to ensure the efficiency of the optimized assembly process.

#### **E. Data Collection Technique**

Data collection in this study was conducted through several complementary methods. First, direct observation of the grass chopper assembly process was undertaken to gain a deeper understanding of the assembly stages, the constraints encountered, and the time required. In addition, to evaluate the strength and durability of the new design, simulations were performed using Computer-Aided Engineering (CAE), which enabled analysis of structural integrity and identification of potential operational issues. Time measurements were also recorded to determine the duration of each assembly stage, thereby providing relevant data on process efficiency. Finally, cost data were gathered by surveying market prices for various machine components and estimating production expenses, which were subsequently used to calculate the cost of goods sold and assess the financial feasibility of the new design.

#### **F. Data Analysis Techniques**

Data collected from various methods were analyzed using qualitative and quantitative approaches. Qualitatively, the machine design was evaluated according to Design for Manufacture and Assembly (DFMA) principles to determine whether the design had simplified the assembly process and reduced costs. Component functionality evaluations were also performed to ensure that each component had operated optimally without redundancy. Besides that, quantitative analyses were conducted to assess financial aspects, including calculations of Net Present Value (NPV), Internal Rate of Return (IRR), and payback period. This analysis aimed to evaluate the economic feasibility of the redesigned machine. As a complementary measure, benchmarking was performed against similar market offerings to compare the redesigned machine with competitors' products and verify its competitiveness. Consequently, the data analysis provided a comprehensive assessment of the advantages and limitations of the redesigned machine from technical and financial perspectives.

#### **G. Standards and Assumptions**

This study adopted several basic assumptions, including the use of standard materials for angle iron, iron plates, and bearings in accordance with prevailing industry specifications; component prices reflecting contemporary market values; and operational costs derived from factory and supplier estimates. These assumptions were established to ensure analytical consistency by employing validated industry specifications that assured quality and market price data that yielded realistic cost estimates.

### **4. RESULTS AND DISCUSSION**

#### **A. Existing Product Description**

The initial design of the grass chopper machine in Figure 1 consists of 105 components assembled during the assembly process from a total of 17 parts on the machine. At this stage, an analysis has also been conducted using the Bill of Materials (BOM) for the initial design of the chopper machine, arranged in a tiered structure that details the decomposition of the product from the final assembly down to individual components. The BOM for this machine consists of 5 levels, starting from level 0 (finished product) and breaking down to level 4. Level 1 includes the Motor, Chassis, Body, and Cutting System,

which are further broken down into deeper levels, with each sub-assembly decomposed into its constituent components at levels 2 and 3 to provide a clear view of the relationships between components. The analysis related to the BOM also reflects the mixed manufacturing strategy (make/buy) being implemented. Standard components purchased from external suppliers (buy) include motors, pulleys and V-belts, UCP 205 bearings, and wheels. Meanwhile, components that require specific fabrication, such as chassis and body structures, are classified as components made in-house (make), indicating the presence of internal manufacturing capabilities in metalworking.

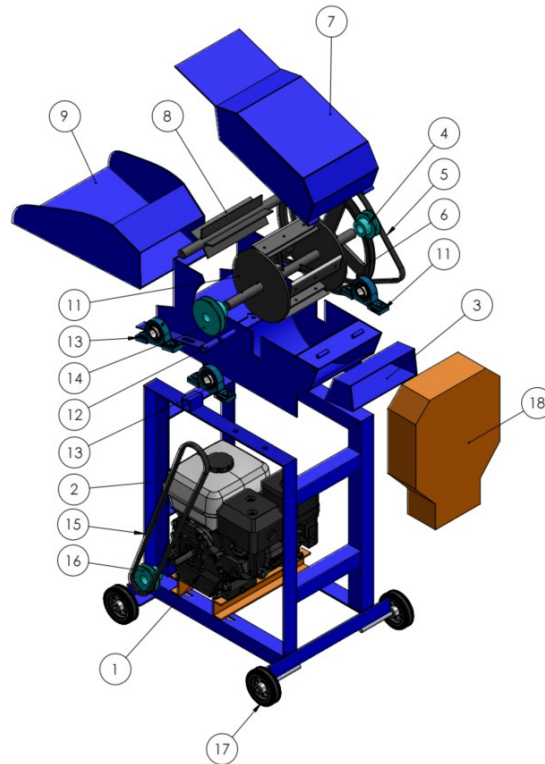


Figure 1. Existing Chopper Machine Design

In terms of technical specifications, the working drawing serves as the main reference. The chassis structure primarily uses 45x45x4 mm angle iron (Siku material), while the cover components, such as the body and cover, are made from 3 mm plate. Standard functional components, including UCP bearings, wheels, V-belts, and pulleys, follow specifications available on the market. Then, in overall, the initial design BOM illustrates a product with a modular architecture and high internal assembly complexity, indicating strong potential as a target for design optimization. More detailed technical specifications are listed in the part list in Table 1. After the part list analysis, an Operational Process Chart (OPC) was prepared to show the assembly process and time. The assembly time is shown as a total of 730 minutes (12 hours and 10 minutes).

Table 1. Part List of Existing Chopper Machine

| No | Level | Part No. | Part Name       | Qty/Unit | Make/Buy |
|----|-------|----------|-----------------|----------|----------|
| 1  | 0     | 1000     | Chopper Machine | 1        | Make     |
| 2  | 1     | 1100     | Motor           | 1        | Buy      |
| 3  | 1     | 1200     | Chassis         | 1        | Make     |
| 4  | 1     | 1300     | Body            | 1        | Make     |
| 5  | 1     | 1400     | Cutting System  | 1        | Make     |
| 6  | 2     | 1210     | Upper Chassis   | 1        | Make     |
| 7  | 2     | 1220     | Under Chassis   | 1        | Make     |

| No | Level | Part No. | Part Name            | Qty/Unit | Make/Buy |
|----|-------|----------|----------------------|----------|----------|
| 8  | 2     | 1310     | Bracket Chute Output | 1        | Make     |
| 9  | 2     | 1320     | Chute Output         | 1        | Make     |
| 10 | 2     | 1330     | Chute Input          | 1        | Make     |
| 11 | 2     | 1340     | Main Body            | 1        | Make     |
| 12 | 2     | 1350     | Cover                | 1        | Make     |
| 13 | 2     | 1410     | Pully 1              | 1        | Buy      |
| 14 | 2     | 1420     | Pully 2              | 1        | Buy      |
| 15 | 2     | 1430     | Pully 3              | 1        | Buy      |
| 16 | 2     | 1440     | Pully 4              | 1        | Buy      |
| 17 | 2     | 1450     | Vanbelt 1            | 1        | Buy      |
| 18 | 2     | 1460     | Vanbelt 2            | 1        | Buy      |
| 19 | 2     | 1470     | Roll                 | 1        | Buy      |
| 20 | 2     | 1480     | Saw                  | 1        | Buy      |
| 21 | 2     | 1490     | Engsel UCP           | 2        | Make     |
| 22 | 2     | 150(0)   | UCP 205              | 4        | Buy      |
| 23 | 3     | 1211     | CH 1                 | 1        | Make     |
| 24 | 3     | 1212     | CH 2                 | 1        | Make     |
| 25 | 3     | 1213     | CH 3                 | 1        | Make     |
| 26 | 3     | 1214     | CH 4                 | 1        | Make     |
| 27 | 3     | 1215     | CH 5                 | 1        | Make     |
| 28 | 3     | 1216     | CH 6                 | 1        | Make     |
| 29 | 3     | 1217     | CH 7                 | 2        | Make     |
| 30 | 3     | 1218     | CH 8                 | 4        | Make     |
| 31 | 3     | 1221     | CH 9                 | 1        | Make     |
| 32 | 3     | 1222     | CH 10                | 1        | Make     |
| 33 | 3     | 1223     | CH 11                | 2        | Make     |
| 34 | 3     | 1224     | Silinder Wheel       | 4        | Make     |
| 35 | 3     | 1225     | Wheel                | 4        | Buy      |
| 36 | 3     | 1311     | BCO 1                | 1        | Make     |
| 37 | 3     | 1312     | BCO 2                | 1        | Make     |
| 38 | 3     | 1313     | BCO 3                | 2        | Make     |
| 39 | 3     | 1321     | CO 1                 | 1        | Make     |
| 40 | 3     | 1322     | CO 2                 | 2        | Make     |
| 41 | 3     | 1323     | CO 3                 | 2        | Make     |

| No | Level | Part No. | Part Name | Qty/Unit | Make/Buy |
|----|-------|----------|-----------|----------|----------|
| 42 | 3     | 1324     | CO 4      | 2        | Make     |
| 43 | 3     | 1325     | CO 5      | 2        | Make     |
| 44 | 3     | 1326     | CO 6      | 1        | Make     |
| 45 | 3     | 1327     | CO 7      | 1        | Make     |
| 46 | 3     | 1331     | CI 1      | 1        | Make     |
| 47 | 3     | 1332     | CI 2      | 1        | Make     |
| 48 | 3     | 1333     | CI 3      | 2        | Make     |
| 49 | 3     | 1341     | MB 1      | 2        | Make     |
| 50 | 3     | 1342     | MB 2      | 1        | Make     |
| 51 | 3     | 1343     | MB 3      | 1        | Make     |
| 52 | 3     | 1344     | MB 4      | 1        | Make     |
| 53 | 3     | 1345     | MB 5      | 1        | Make     |
| 54 | 3     | 1346     | MB 6      | 1        | Make     |
| 55 | 3     | 1347     | MB 7      | 1        | Make     |
| 56 | 3     | 1348     | MB 8      | 2        | Make     |
| 57 | 3     | 1349     | MB 9      | 2        | Make     |
| 58 | 3     | 135(0)   | MB 10     | 2        | Make     |
| 59 | 3     | 1351     | C 1       | 1        | Make     |
| 60 | 3     | 1352     | C 2       | 1        | Make     |
| 61 | 3     | 1353     | C 3       | 1        | Make     |
| 62 | 3     | 1354     | C 4       | 1        | Make     |
| 63 | 3     | 1355     | C 5       | 1        | Make     |
| 64 | 3     | 1356     | C 6       | 1        | Make     |
| 65 | 3     | 1357     | C 7       | 2        | Make     |
| 66 | 3     | 1358     | C 8       | 2        | Make     |
| 67 | 3     | 1471     | Silinder  | 1        | Buy      |
| 68 | 3     | 1472     | Plate     | 5        | Buy      |
| 69 | 3     | 1481     | S 1       | 2        | Make     |
| 70 | 3     | 1482     | S 2       | 2        | Make     |
| 71 | 3     | 1483     | S 3       | 1        | Make     |
| 72 | 3     | 1484     | S 4       | 4        | Make     |
| 73 | 3     | 1485     | S 5       | 4        | Make     |
| 74 | 3     | 1486     | S 6       | 4        | Make     |
| 75 | 3     | 1491     | EU 1      | 2        | Make     |

| No | Level | Part No. | Part Name | Qty/Unit | Make/Buy |
|----|-------|----------|-----------|----------|----------|
| 76 | 3     | 1492     | EU 2      | 2        | Make     |

## B. DFMA Approach Analysis

There are three DFMA approaches used to redesign the shredder machine, including:

### 1) Part Reduction

Part reduction is conducted on several components of the grass chopper machine, such as by combining the chute output bracket and chute output components into a simplified output part. As a result, the chute component is reduced to only three parts as shown in Figure 2. In addition, the cover component is also simplified to just four parts as shown in Figure 3. This simplification involves the use of a bending process to replace welding on several parts, thereby accelerating the assembly process.

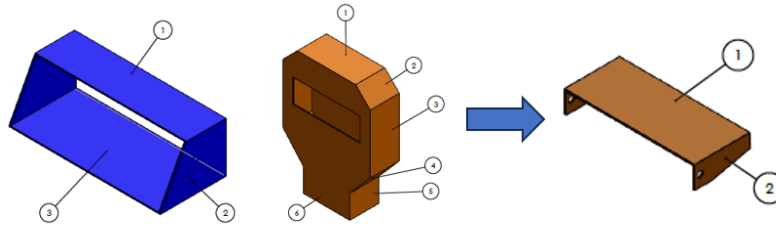


Figure 2. Part Reduction in Chute Output

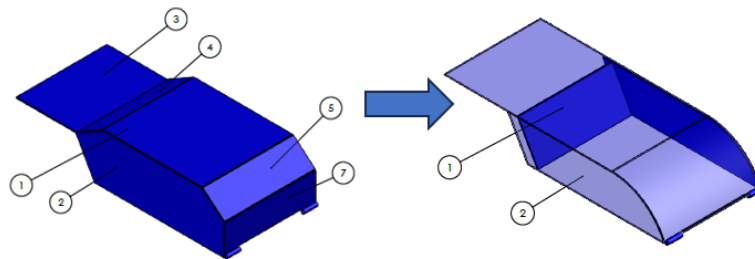


Figure 3. Part Reduction in Cover

### 2) Material Dimension Reduction

The selection of the thickness of the iron plate on the grass chopper machine was changed from 3 mm to 2.5 mm. This decision was based on the results of a Computer-Aided Engineering (CAE) analysis, which evaluated the forces acting on the chassis. In addition, changes were also made to the dimensions of the angle iron used in the chassis, from 3 mm x 3 mm to 2.5 mm x 2.5 mm. The analysis considered the forces generated by the body, saw, roll, UCP bearing, and other components acting on the surface of the chassis, with a total force of approximately 530 N, plus an additional grass load of up to 370 N during the chopping process. Based on the analysis, the total force exerted is estimated to be in the range of 900 N to 1000 N. The simulation results indicate that the chassis can still safely withstand the load and is ready for the machine operation process. The CAE analysis of the chassis is shown in Figure 4.

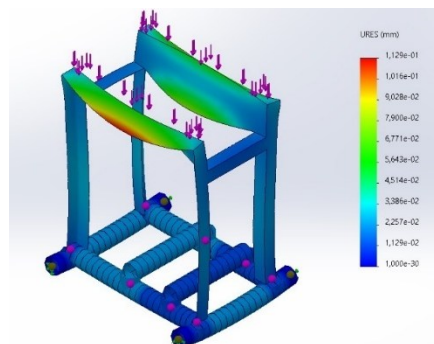


Figure 4. CAE Analysis on Chopper Machine Chassis

### 3) Feature Additions

Addition of a hopper feature for automatic feeding and improvement of shredder flow. The rear chute, which initially had a limited capacity for grass feeding, has been improved by adding a hopper that increases the machine's feeding capacity, enabling it to reach a processing capacity of up to 2 tons per hour. This improvement can be seen in Figure 5.

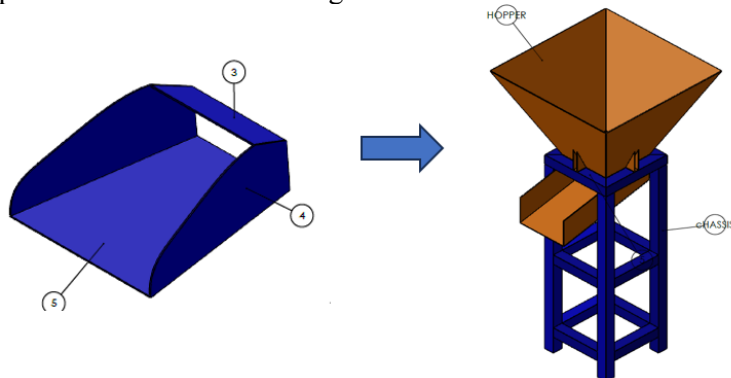


Figure 5. Replacing the Input Chute with a Hooper

The chassis of the hopper uses hollow iron with dimensions of 40 mm x 40 mm. The selection of this iron size is based on its ability to support loads from the hopper and grass, up to a maximum of 30 kg, resulting in a total force applied to the chassis of 480 N. With this design, the feeding process can be effectively supported from above the hopper, allowing the machine to automatically pull the grass. The CAE analysis of this hopper chassis can be seen in Figure 6.

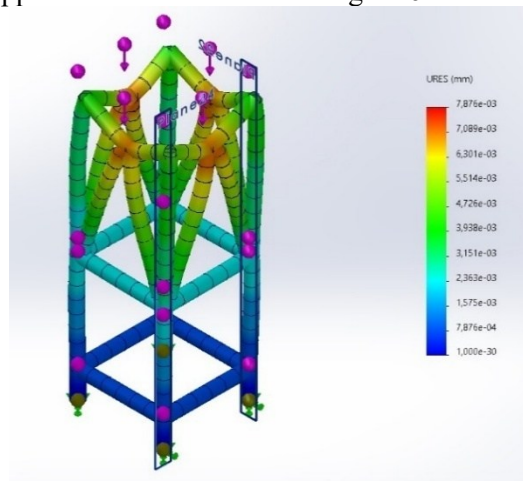


Figure 6. CAE Analysis of Chassis Hopper

### 4) KANO Diagram Analysis

The design changes made in DFMA refer to the Kano model introduced by Kano in 1984 (Mikulić and Prebežac, 2011). The Kano model as shown in Figure 7, is one of the commonly used methods to determine product development priorities based on the effect of attribute fulfillment levels on customer satisfaction (Mikulić and Prebežac, 2011). According to Kano (1984, in Violante and Vezzetti, 2017), quality attributes can be classified into five categories: Must-be attributes are basic elements that are very important and considered prerequisites by customers. Their presence does not significantly increase customer satisfaction, as customers see them as minimum standards that must be present in a product or service; however, if they are not fulfilled, customers will feel very dissatisfied. One-dimensional attributes have a linear and positive relationship with customer satisfaction, meaning that satisfaction increases in proportion to the level of fulfillment of these attributes. Attractive attributes are features not expected or explicitly requested by customers, but their presence can provide a disproportionately high level of satisfaction. Customers will be very pleased if these features are present but not disappointed if they are absent. Indifferent attributes are features whose presence or absence does not impact customer satisfaction or dissatisfaction. In other words, customers do not care or may not even be aware of the existence of these attributes in the product or service. Reverse attributes are

features whose presence can cause customer dissatisfaction, while their absence may lead to satisfaction.

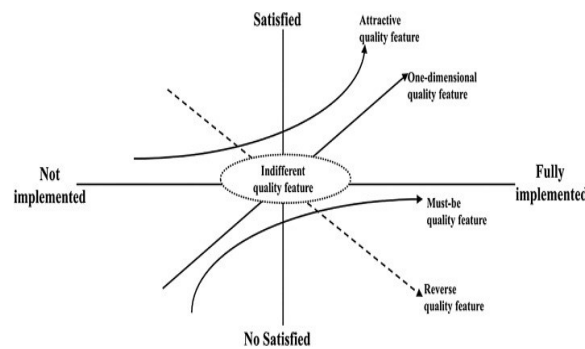


Figure 7. Kano Diagram (Kano, 1984 in Violante and Vezzetti, 2017)

The implementation of Design for Manufacturing and Assembly (DFMA) integrates Kano attributes to optimize the design of a feed shredder machine. This approach combines must-be aspects, which focus on production efficiency through part simplification and proper material selection, with attractive aspects that enhance product appeal by introducing automatic feeding features and more efficient chute output designs to achieve optimal customer satisfaction.

The principle of the must-be attribute is applied by simplifying the design through part reduction and material changes without affecting the machine's functionality. The reduced part is the cover, where smaller welded components are combined into a single part using a bending process. Material changes are made to all components originally using 3 mm plate iron, which are replaced with 2.5 mm plate iron to lower costs while still meeting technical requirements based on CAE analysis.

The principle of the attractive attribute is applied by improving the flow of material (grass) through the addition of a hopper and redesigning the output chute to enhance customer appeal. The hopper is added to support the automatic feeding feature, allowing large quantities of grass (animal feed) to be fed into the machine at once. Changes to the output chute design involve simplifying its structure and adjusting its slope to allow the processed feed to exit more smoothly.

### C. New Product Description

Changes in product architecture in Figure 8, as a result of the implementation of Design for Manufacture and Assembly (DFMA) principles. The hierarchical structure of the new design has been expanded to accommodate increased functionality. At Level 1, in addition to the core subassemblies such as Motor, Chassis, Body, and Cutting System, there are now two new major subassemblies: Body Hopper and Chassis Hopper. This addition directly reflects the enhancement of product features aimed at improving ease of use. The mixed manufacturing strategy (make/buy) is maintained, with standard components such as the Motor and UCP 205 Bearings purchased from suppliers, while major structural components such as the Chassis, Body, and now Hopper are manufactured in-house (Make). The most significant aspect of the new BOM is the simplification of the design and the reduction in assembly complexity. This is most evident in the Body subassembly (Part No. 1300). In the original design, the Body consisted of five sub-components at Level 2; in the new design, it has been drastically simplified to just three sub-components: Chute Output, Main Body, and Cover. The number of fabrication components at a deeper level (Level 3) has also been significantly reduced, indicating that the assembly process has become faster and easier. Similarly, the Chassis structure has been optimized, as reflected in the reduction of its cost.

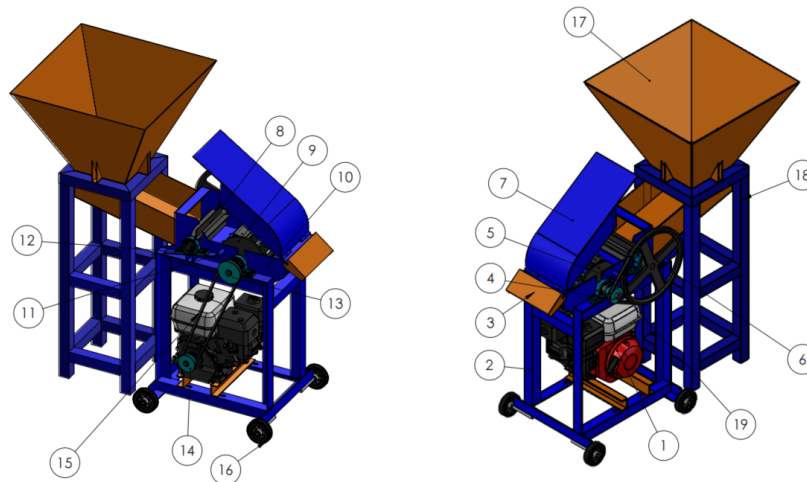


Figure 8. New Chopper Machine Design

In terms of technical specifications, the new Chassis structure still uses the elbow with dimension 45x45x4. Cover components such as the Body and Cover use 2.5 mm Plate. Standard functional components like UCP bearings, wheels, V-belts, and pulleys conform to market standards. More detailed technical specifications are listed in the part list in Table 2 below. Based on the part list, an OPC analysis was conducted, showing the assembly process and total time of 754 minutes (12 hours and 34 minutes).

Table 2. New Chopper Machine Part List

| Level | Part No. | Part Name       | Qty/Unit | Make/Buy |
|-------|----------|-----------------|----------|----------|
| 0     | 1000     | Chopper Machine | 1        | Make     |
| 1     | 1100     | Motor           | 1        | Buy      |
| 1     | 1200     | Chassis         | 1        | Make     |
| 1     | 1300     | Body            | 1        | Make     |
| 1     | 1400     | Cutting System  | 1        | Make     |
| 1     | 1500     | Body Hopper     | 1        | Make     |
| 1     | 1600     | Chassis Hopper  | 1        | Make     |
| 2     | 1210     | Upper Chassis   | 1        | Make     |
| 2     | 1220     | Under Chassis   | 1        | Make     |
| 2     | 1310     | Chute Output    | 1        | Make     |
| 2     | 1320     | Main Body       | 1        | Make     |
| 2     | 1330     | Cover           | 1        | Make     |
| 2     | 1410     | Pully 1         | 1        | Buy      |
| 2     | 1420     | Pully 2         | 1        | Buy      |
| 2     | 1430     | Pully 3         | 1        | Buy      |
| 2     | 1440     | Pully 4         | 1        | Buy      |
| 2     | 1450     | Vanbelt 1       | 1        | Buy      |
| 2     | 1460     | Vanbelt 2       | 1        | Buy      |
| 2     | 1470     | Roll            | 1        | Make     |
| 2     | 1480     | Saw             | 1        | Make     |
| 2     | 1490     | Engsel UCP      | 2        | Make     |

| Level | Part No. | Part Name      | Qty/Unit | Make/Buy |
|-------|----------|----------------|----------|----------|
| 2     | 150(0)   | UCP 205        | 4        | Buy      |
| 2     | 1510     | BH 1           | 4        | Make     |
| 2     | 1520     | BH 2           | 8        | Make     |
| 2     | 1530     | BH 3           | 4        | Make     |
| 2     | 1540     | BH 4           | 1        | Make     |
| 2     | 1550     | BH 5           | 1        | Make     |
| 2     | 1560     | BH 6           | 2        | Make     |
| 2     | 1570     | BH 7           | 1        | Make     |
| 2     | 1610     | CH 1           | 4        | Make     |
| 2     | 1620     | CH 2           | 4        | Make     |
| 2     | 1630     | CH 3           | 8        | Make     |
| 3     | 1211     | C1             | 1        | Make     |
| 3     | 1212     | C2             | 1        | Make     |
| 3     | 1213     | C3             | 1        | Make     |
| 3     | 1214     | C4             | 1        | Make     |
| 3     | 1215     | C5             | 1        | Make     |
| 3     | 1216     | C6             | 1        | Make     |
| 3     | 1217     | C7             | 2        | Make     |
| 3     | 1218     | C8             | 2        | Make     |
| 3     | 1221     | C9             | 1        | Make     |
| 3     | 1222     | C10            | 1        | Make     |
| 3     | 1223     | C11            | 2        | Make     |
| 3     | 1224     | Silinder Wheel | 4        | Buy      |
| 3     | 1225     | Wheel          | 4        | Buy      |
| 3     | 1311     | CO 1           | 1        | Make     |
| 3     | 1312     | CO 2           | 1        | Make     |
| 3     | 1313     | CO 3           | 2        | Make     |
| 3     | 1321     | MB1            | 2        | Make     |
| 3     | 1322     | MB2            | 1        | Make     |
| 3     | 1323     | MB3            | 1        | Make     |
| 3     | 1324     | MB4            | 1        | Make     |
| 3     | 1325     | MB5            | 1        | Make     |
| 3     | 1326     | MB6            | 1        | Make     |
| 3     | 1327     | MB7            | 1        | Make     |
| 3     | 1328     | MB8            | 2        | Make     |
| 3     | 1329     | MB9            | 2        | Make     |

| Level | Part No. | Part Name | Qty/Unit | Make/Buy |
|-------|----------|-----------|----------|----------|
| 3     | 133(0)   | MB10      | 2        | Make     |
| 3     | 1331     | CV1       | 1        | Make     |
| 3     | 1332     | CV2       | 1        | Make     |
| 3     | 1333     | CV3       | 2        | Make     |
| 3     | 1334     | CV4       | 2        | Make     |
| 3     | 1471     | Silinder  | 1        | Buy      |
| 3     | 1472     | Plate     | 5        | Buy      |
| 3     | 1481     | S1        | 2        | Make     |
| 3     | 1482     | S2        | 2        | Make     |
| 3     | 1483     | S3        | 1        | Make     |
| 3     | 1484     | S4        | 4        | Make     |
| 3     | 1485     | S5        | 4        | Make     |
| 3     | 1486     | S6        | 4        | Make     |
| 3     | 1491     | EU 1      | 2        | Make     |
| 3     | 1492     | EU 2      | 2        | Make     |

#### D. Chopper Machine Material Cost Analysis

##### 1) Existing Material Chopper Machine

The analysis of the existing chopper machine's material cost is the initial step in the economic evaluation of product development. Table 3 below presents a breakdown of all chopper machine components, covering ten main elements classified by the make or buy decision. Each component has been evaluated based on quantity per unit, procurement strategy (purchase or manufacture), and accurate cost estimates. This data serves as the basis for calculating the total investment required to produce one unit of the chopper machine in accordance with the specifications and quality defined in the technical design.

Table 3. Existing Chopper Machine Material Prices

| Part Name            | Qty/Unit | Make/Buy | Price (Rp) | Total Price(Rp)  |
|----------------------|----------|----------|------------|------------------|
| Motor                | 1        | Buy      | 850,000    | 850,000.00       |
| Chassis              | 1        | Make     | 214,750    | 214,750.00       |
| Body                 | 1        | Make     | 659,760    | 659,760.00       |
| Cutting System       | 1        | Make     | 749,500    | 749,500.00       |
| Upper Chassis        | 1        | Make     | 101,550    | 101,550.00       |
| Under Chassis        | 1        | Make     | 113,200    | 113,200.00       |
| Bracket Chute Output | 1        | Make     | 8,900      | 8,900.00         |
| Chute Output         | 1        | Make     | 126,000    | 126,000.00       |
| Chute Input          | 1        | Make     | 37,000     | 37,000.00        |
| Main Body            | 1        | Make     | 85,040     | 85,040.00        |
| <b>Total</b>         |          |          |            | <b>3,018,640</b> |

Based on the analysis in the table, the total material cost for one unit of the existing chopper machine reaches Rp. 3,018,640. This cost structure provides a realistic picture for production planning and competitive selling price determination.

##### 2) New Material Chopper Machine

The material cost analysis of the new chopper machine shows the total material required for the main components of the machine. The following table provides a detailed breakdown of the cost for each part based on the procurement strategy, whether through direct purchase (buy) or in-house

production (make). The main components include the motor as the drive, the chassis as the basic frame, the body as the protector, the cutting system as the main cutter, and the body hopper as the material container. This data serves as a reference for evaluating the efficiency of production costs.

Table 4. Price of New Chopper Machine Material

| Part Name      | Qty/Unit | Make/Buy | Price (Rp) | Total Price(Rp)  |
|----------------|----------|----------|------------|------------------|
| Motor          | 1        | Buy      | 850,000    | 850,000          |
| Chassis        | 1        | Make     | 141,050    | 141,050          |
| Body           | 1        | Make     | 74,240     | 74,240           |
| Cutting System | 1        | Make     | 749,500    | 749,500          |
| Body Hopper    | 1        | Make     | 304,100    | 304,100          |
| <b>Total</b>   |          |          |            | <b>2,335,290</b> |

Based on the table above, the total cost of the new chopper machine material reaches Rp. 2,335,290, the new machine components have decreased by Rp. 683,350 compared to the existing machine.

### 3) Factors Decreasing the Price of New Chopper Machine Materials

The reduction in material costs of Rp 683,350.00 for the new chopper machine is the result of design optimization based on Computer-Aided Engineering (CAE) analysis. The main changes involved reducing the thickness of the chassis iron plate from 3 mm to 2.5 mm and adjusting the dimensions of the angle iron from 3 mm x 3 mm to 2.5 mm x 2.5 mm. These modifications maintain the required structural strength while reducing material usage. Cost efficiency was also achieved through component simplification, reducing the number of elements from ten to five main components. Total material costs decreased from Rp. 3,018,640 to Rp. 2,335,290, resulting in savings of 22.6%. This strategy demonstrates that technical optimization can deliver significant economic benefits without compromising the performance of the chopper machine.

## E. Chopper Machine Production Cost Analysis

### 1) Assumptions Used

The first assumption is Tax, Based on Law Number 7 of 2021 concerning Harmonization of Tax Regulations, the PPh calculation mechanism with a normal scheme for Individual Taxpayers who run a business (MSMEs with turnover <Rp. 4.8 billion) with single status is regulated as follows:

- Non-Taxable Income (PTKP): The net income reduction for single Taxpayers is Rp. 54,000,000 per year.
- Progressive Rate: Tax rates are imposed progressively on Taxable Income (PKP), namely the difference between net income and PTKP, with the following provisions:
  - 5% for PKP layers up to IDR60,000,000.
  - 15% for PKP layers above IDR60,000,000 up to IDR250,000,000.
  - 25% for PKP layers above IDR250,000,000 up to IDR500,000,000.
  - 30% for PKP layers above IDR500,000,000 up to IDR5,000,000,000.
  - 35% for PKP layers above IDR5,000,000,000.

The second assumption is the interest rate uses Bank Indonesia's interest rate of 5.5% (Bank Indonesia, 2025). Then next is Depreciation, Depreciation is calculated using the straight-line method. The equation for calculating depreciation using the straight-line method is in equation (4.1) Asset Depreciation Method The calculation of asset depreciation uses the straight-line method, the formula of which is referred to in Equation (x). All assets are assumed to have a salvage value of zero (Rp0.00) because they cannot be resold at the end of their useful life.

$$\text{Depreciation} = \frac{\text{Asset Acquisition Cost} - \text{Residual Value}}{\text{Asset Useful Life}} \quad (4.1)$$

Investment assets are classified into two groups of useful lives as follows:

- Assets with a 10 Year Useful Life:
  - Plasma Cutting Machine
  - Plasma Cutting Compressor
  - Milling Machine
  - Welding Machine (MIG/TIG/Arc Welding)

- 5) Press Machine / Hydraulic Press
- 6) Hand Drill Machine
- b. Assets with a Useful Life of 5 Years:
  - 1) Lathe Machine
  - 2) Table Drilling Machine
  - 3) Hand Grinding Machine
  - 4) Manual Tools (Screwdriver, Wrench, Hammer, etc.)
  - 5) Grinding Machine End Mill Drill Bit

## 2) Cost Analysis of Existing Chopper Machine

Based on the evaluation, this project requires an initial investment cost of Rp174,950,000.00. In Table 5. The following are the initial investment costs in the 5 and 10 year periods.

Table 5. Initial Investment Costs in the 5 and 10 year Term of Existing Chopper Machine

| Investment                                                                 | No | Type of Fee                                     | Price                  |
|----------------------------------------------------------------------------|----|-------------------------------------------------|------------------------|
| Initial Investment Cost (10 years)                                         | 1  | Plasma Cutting Machine                          | Rp. 9,500,000          |
|                                                                            | 2  | Plasma Cutting Compressor                       | Rp. 2,500,000          |
|                                                                            | 3  | Milling Machine                                 | Rp. 55,000,000         |
|                                                                            | 4  | Welding Machine (MIG/TIG/Arc Welding)           | Rp. 3,500,000          |
|                                                                            | 5  | Press Machine / Hydraulic Press                 | Rp. 5,500,000          |
|                                                                            | 6  | Hand Drill Machine                              | Rp. 650,000            |
| <b>Total Initial Investment Cost (10 years)</b>                            |    |                                                 | <b>Rp. 76,650,000</b>  |
| Initial Investment Cost (5 years)                                          | 1  | Lathe Machine                                   | Rp. 80,000,000         |
|                                                                            | 2  | Table Drilling Machine                          | Rp. 2,200,000          |
|                                                                            | 3  | Hand Grinding Machine                           | Rp. 550,000            |
|                                                                            | 4  | Manual Tools (Screwdriver, Wrench, Hammer etc.) | Rp. 3,000,000          |
|                                                                            | 5  | Grinding Machine End Mill Drill Bit             | Rp. 8,250,000          |
| <b>Total Initial Investment Cost (5 years)</b>                             |    |                                                 | <b>Rp. 94,550,000</b>  |
| Initial Installation Costs (Electricity and Water)                         | 1  | Water Installation                              | Rp. 250,000            |
|                                                                            | 2  | Electrical Installation (3500 Watt)             | Rp. 3,500,000          |
| <b>Total Initial Investment Cost (5 years) + (10 years) + Installation</b> |    |                                                 | <b>Rp. 174,950,000</b> |

The profitability of this project is based on a healthy cost and revenue structure from the sale of 156 machines per year. With a total Cost of Goods Sold (COGS) of Rp171,202,626.53 and a product selling price of Rp4,500,000.00 per unit, this project is able to generate a profit level of 10.56%. This profit margin indicates that operational activities are able to provide positive returns and become the foundation for cash inflows that will cover the initial investment.

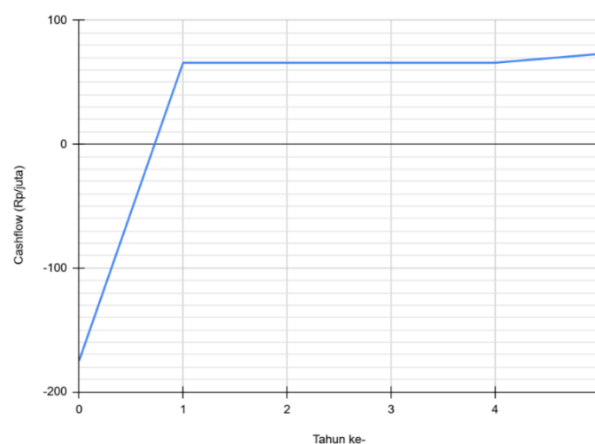


Figure 9. Potential Profitability of Existing Chopper Machine

The initial design demonstrates strong financial viability and promising profitability, as reflected in the projected cash flow presented in Figure 9. The investment feasibility is assessed through three key financial metrics. First, the project yields a positive Net Present Value (NPV) of Rp55,845,740.49, indicating that the present value of projected future cash flows exceeds the initial investment cost, thereby generating net economic value for the firm. Second, the Internal Rate of Return (IRR) is calculated at 26.22%, a highly competitive return that significantly surpasses the Bank Indonesia benchmark interest rate of 5.75%, signifying efficient capital utilization and a strong return potential. Third, the project has a Payback Period of only two years, illustrating its ability to recover the initial investment within a relatively short timeframe.

### 3) New Chopper Machine Cost Analysis

Based on the analysis that has been done, this project is generally very feasible to run. This project requires an initial investment of Rp186,950,000.00 which is projected to provide a very high rate of return. In Table 6. the following are the initial investment costs in the 5 and 10 year periods.

Table 6. Initial Investment Costs in 5 and 10 Years for New Chopper Machine

| Investment                                                                 | No | Type of Fee                                       | Price                  |
|----------------------------------------------------------------------------|----|---------------------------------------------------|------------------------|
| Initial Investment Cost (10 years)                                         | 1  | Plasma Cutting Machine                            | Rp. 9,500,000          |
|                                                                            | 2  | Plasma Cutting Compressor                         | Rp. 2,500,000          |
|                                                                            | 3  | Milling Machine                                   | Rp. 55,000,000         |
|                                                                            | 4  | Welding Machine (MIG/TIG/Arc Welding)             | Rp. 3,500,000          |
|                                                                            | 5  | Press Machine / Hydraulic Press                   | Rp. 5,500,000          |
|                                                                            | 6  | Hand Drill Machine                                | Rp. 650,000            |
|                                                                            | 7  | Roll Bending Machine (if there is a curved plate) | Rp. 12,000,000         |
| <b>Total Initial Investment Cost (10 years)</b>                            |    |                                                   | <b>Rp. 88,650,000</b>  |
| Initial Investment Cost (5 years)                                          | 1  | Lathe Machine                                     | Rp. 80,000,000         |
|                                                                            | 2  | Table Drilling Machine                            | Rp. 2,200,000          |
|                                                                            | 3  | Hand Grinding Machine                             | Rp. 550,000            |
|                                                                            | 4  | Manual Tools (Screwdriver, Wrench, Hammer etc.)   | Rp. 3,000,000          |
|                                                                            | 5  | Grinding Machine End Mill Drill Bit               | Rp. 8,250,000          |
| <b>Total Initial Investment Cost (5 years)</b>                             |    |                                                   | <b>Rp. 94,550,000</b>  |
| Initial Installation Costs (Electricity and Water)                         | 1  | Water Installation                                | Rp. 250,000            |
|                                                                            | 2  | Electrical Installation (3500 Watt)               | Rp. 3,500,000          |
| <b>Total Initial Investment Cost (5 years) + (10 years) + Installation</b> |    |                                                   | <b>Rp. 186,950,000</b> |

The profitability of the project stems from an efficient production cost structure. With a selling price per unit of Rp4,500,000.00 and a Cost of Goods Sold (COGS) per unit of Rp3,277,373.33, the project is able to achieve a healthy profit margin of 27.17% per unit. On the other hand, the investment feasibility of the project is quantitatively supported by several key financial indicators. The project generates a significantly positive Net Present Value (NPV) of Rp365,135,757.34. Furthermore, the project's Internal Rate of Return (IRR) reaches 81.30%, an exceptionally high rate of return that indicates strong efficiency in generating profit from invested capital. Cash flow projections show a consistent annual inflow of Rp157,507,022.00 (Figure 10), based on the cost structure and revenue from the sale of 156 units. The Payback Period is recorded at 2 years.

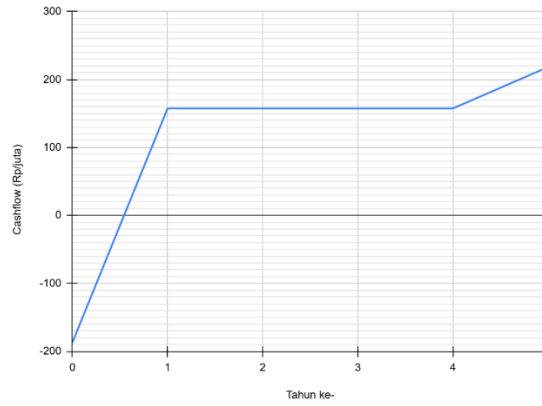


Figure 10. Potential Profitability of New Chopper Machine

## F. Comparative Analysis

### 1) Comparison of BOM and OPC of Existing and New Chopper Machine

Comparison between the BOM and OPC of the new design and the initial design quantitatively and qualitatively shows the success of the redesign process.

#### 1. Structural Integration and Complexity Reduction

The most fundamental change is the addition of functional features (Hopper) accompanied by a reduction in complexity. The new design intelligently simplifies existing components (especially Body and Chassis) to offset the addition of new components. The total number of individual fabricated components has been reduced, which directly simplifies the assembly workflow and reduces the potential for errors.

#### 2. Manufacturing Strategy and Fabrication Priorities

The core strategy has not changed, but the fabrication focus has shifted. In the original design, much of the fabrication effort was allocated to assembling a complex body from small pieces. In the new design, that effort is shifted to creating new value-added components (hoppers) and simplifying the assembly of existing components.

Table 7. Comparison of BOM and OPC of Existing and New Chopper Machine

| Aspect                | Initial Design (Old)                   | New Design (After DFMA)              | Change Analysis                                                                 |
|-----------------------|----------------------------------------|--------------------------------------|---------------------------------------------------------------------------------|
| Key Features          | Flat and small inlet funnel            | Added Large & Ergonomic Hopper       | Increased functionality and added value                                         |
| Body Complexity       | Very complex, 5 sub-components Level 2 | Simplified, 3 Level 2 sub-components | Decreased assembly time and difficulty                                          |
| Total Production Time | 730 minutes                            | 754 minutes                          | There was an increase in production time of 3.29% which is not very significant |

### 2) Comparison of Cost Analysis of Existing and New Chopper Machine

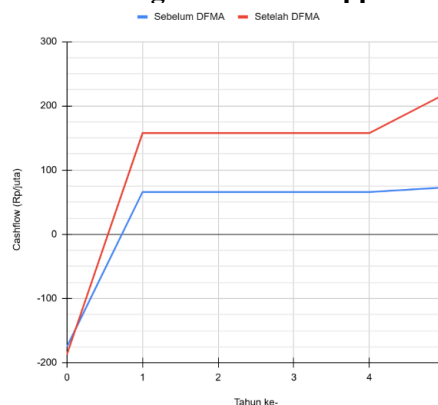


Figure 11. Comparison of Cost Analysis of Existing and New Chopper Machine

The implementation of the Design for Manufacture and Assembly (DFMA) methodology has demonstrably enhanced the feasibility and profitability of the project. The post DFMA financial analysis reveals substantial improvements across nearly all feasibility indicators, thereby affirming the effectiveness of the design optimizations implemented. A key outcome of the DFMA approach is the significant reduction in production costs, which has directly contributed to an increase in profit margins, overall project value, and improved cash flow, as illustrated in Figure 11. As presented in Table 8, the most notable transformation occurred within the cost structure, with the Cost of Goods Sold (COGS) per unit significantly reduced to Rp. 3,277,373.33. This sharp decline in production costs, while maintaining the selling price per unit at Rp. 4,500,000, resulted in a substantial increase in profit margin per unit, from 10.56% (before DFMA implementation) to 27.17%. This enhancement in profitability serves as the primary driver of the project's improved financial performance, despite a modest increase in the initial investment requirement to Rp. 186,950,000.

Table 8. Comparison of Cost Analysis Before and After DFMA is Implemented

| Financial Analysis | Before DFMA        | After DFMA         |
|--------------------|--------------------|--------------------|
| Investment Cost    | Rp. 174,950,000    | Rp. 186,950,000    |
| COGS               | Rp. 171,202,626.53 | Rp. 3,277,373.33   |
| Selling Price      | Rp. 4,500,000      | Rp. 4,500,000      |
| Profit per Unit    | 10.56%             | 27.17%             |
| NPV                | Rp. 55,845,740.49  | Rp. 365,135,757.34 |
| IRR                | 26.22%             | 81.30%             |
| Payback Period     | 2 years            | 2 years            |

The impact of improved cost efficiency is prominently reflected in the investment feasibility metrics presented in Table 8. The project's Net Present Value (NPV) increased dramatically from approximately Rp. 56 million to Rp. 365,135,757.34, representing a more than sixfold enhancement in absolute value creation for the firm. Correspondingly, the Internal Rate of Return (IRR) surged from 26.22% to 81.30%, indicating a substantial improvement in the project's capacity to generate returns on invested capital. This enhanced profitability is further corroborated by a significantly improved annual cash flow projection Rp. 157,507,022 for the first four years, increasing to Rp. 218,255,224.20 in the fifth year, which strengthens the project's financial resilience and accelerates capital recovery.

Although the Payback Period is recorded as two years in the investment summary table, a more precise calculation based on actual projected cash flows indicates a notably faster return on investment of approximately 1.2 years. This improvement in liquidity and reduction in financial risk are critical additional advantages resulting from the implementation of the DFMA methodology. Thus, the adoption of DFMA represents a strategically sound investment decision. The modest increase in initial capital outlay is more than offset by substantial reductions in production costs, leading to significantly enhanced project value (as measured by NPV) and return efficiency (as measured by IRR) relative to the original design.

### 3) Chopper Machine Price Comparison with Competitor Products

Based on a survey conducted on e-commerce sites, the price of chopper machines with similar specifications on the market through the Google Shopping feature (Figure 11), the price of a large capacity chopper machine complete with an engine has the lowest price of Rp. 3,050,000 and the highest price of Rp. 43,500,000. The Chopper Machine after DFMA is priced at Rp. 4,500,000 which is in accordance with the price on the market.

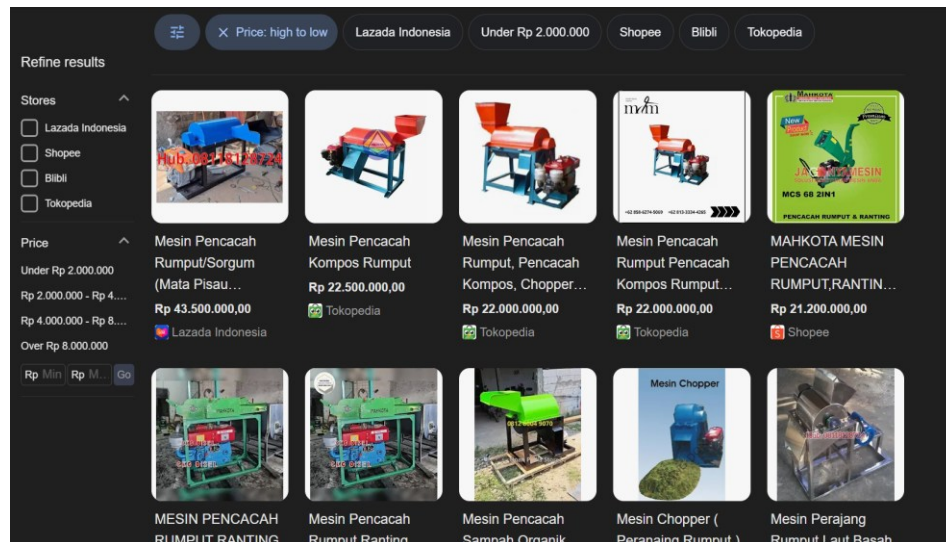


Figure 11. Price of Competitor's Chopper Machine Products

#### 4. CONCLUSION

Write down the findings or conclusions in a concise, concise, and clear manner. Conclusions are not recommended to be written into several parts or points.

The implementation of Design for Manufacturing and Assembly (DFMA) in the redesign of the grass chopper machine has been proven to have a significant positive impact on production efficiency and financial feasibility. Through three main approaches, part reduction, material dimension reduction, and the addition of hopper features. This study successfully simplified the design without compromising machine functionality. Part reduction in the chute output and cover components, changes in plate thickness from 3 mm to 2.5 mm based on CAE analysis, and the addition of a hopper for automatic feeding have resulted in a more efficient design. Although there was a slight increase in production time of 3.29% (from 730 minutes to 754 minutes), this increase was not significant compared to the added value gained.

From a financial perspective, the implementation of DFMA led to a substantial increase in project profitability. The Cost of Goods Sold (COGS) was significantly reduced from Rp. 171,202,626.53 to Rp. 3,277,373.33 per unit, causing the profit margin to rise from 10.56% to 27.17%. This resulted in an increase in Net Present Value (NPV) from Rp. 55,845,740.49 to Rp. 365,135,757.34 and the Internal Rate of Return (IRR) from 26.22% to 81.30%. With a selling price of Rp. 4,500,000.00, this product remains competitive in a market with a price range of Rp. 3,050,000.00 to Rp. 43,500,000.00. The 2-year Payback Period demonstrates a profitable investment for developers and supports increased technology adoption among local farmers.

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