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DESIGN FOR MANUFACTURING AND ASSEMBLY OF ECO-FRIENDLY MINI FOUR-WHEEL TOY USING PLA

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Abstrak

Dengan menggunakan pendekatan Design for Manufacturing and Assembly (DFMA), penelitian ini berkonsentrasi pada desain dan pembuatan produk yang ramah lingkungan yang menggunakan bahan Polylactic Acid (PLA) sebagai komponen kit mini 4WD. Tujuan utamanya adalah mengurangi limbah plastik dari mainan dengan menggunakan PLA, yang dapat terurai secara hayati, sebagai pengganti plastik konvensional. Untuk memenuhi persyaratan kecepatan, daya tahan, dan estetika pelanggan, penelitian ini melihat PLA dapat digunakan dalam produksi. Studi ini menunjukkan bahwa pengoptimalan DFMA mempercepat proses sambil mempertahankan bahan PLA yang ramah lingkungan. Dengan menggunakan teknik manufaktur aditif dengan printer 3D, bagian mini kit 4WD mengkonsumsi 11,81 meter dan 37,21 gram filamen PLA. Selain itu, proses produksi membutuhkan 8,89 jam dan biaya total IDR 159,302. Strategi branding yang menekankan fitur ramah lingkungan produk harus diterapkan untuk meningkatkan kesadaran pasar dan minat beli konsumen. Dengan mengganti bahan biodegradable seperti PLA dengan plastik konvensional dan menyederhanakan proses produksi dengan DFMA, bisnis dapat membuat produk ramah lingkungan yang memenuhi keinginan pelanggan sambil mengurangi dampak lingkungan mereka. Studi masa depan akan terus meningkatkan proses ini dan menyelidiki bahan-bahan baru yang lebih berkelanjutan.

Keywords**:** 3D Printing, DFMA, Polylactic Acid

Abstract

This research focuses on the design and production of eco-friendly products using Polylactic Acid (PLA) material for the mini 4WD kit components by utilizing the Design for Manufacturing and Assembly (DFMA) approach. The main objective is to reduce plastic waste in toys by replacing conventional plastic materials with biodegradable PLA. The research evaluates the potential of PLA in manufacturing, addressing consumer requirements for speed, durability, and aesthetics. The study highlights how DFMA optimization leads to efficient processes while maintaining the eco-friendly benefits of PLA material. By using additive manufacturing technique with a 3D Printer, the 4WD mini kit component consumed 11.81 meters and 37.21 grams of PLA filament. Moreover, time consumed for production process is 8.89 hours with total cost required in the amount of IDR 159,302. For the future market awarness and consumer purchase interest is to implement a branding strategy that highlights the product's environmentally friendly attributes. Businesses may create environmentally friendly products that satisfy customer wants while reducing their environmental effect by substituting biodegradable materials like PLA for conventional plastics and streamlining the production process with DFMA. Future studies will keep improving these procedures and investigating novel materials that have even more advantages for sustainability.

Keywords**:** 3D Printing, DFMA, Polylactic Acid

I. INTRODUCTION

The rapid advancement of manufacturing technologies in the era of Industry 4.0 has significantly transformed industrial practices. Companies are increasingly required to adapt and integrate modern technological systems into their business models to remain competitive [1]. One area experiencing considerable innovation is in material science, where the development of new input materials such as composites, advanced metals, and eco-friendly plastics has revolutionized fabrication and production processes. While these advancements offer efficiency and performance gains, they also present new challenges, particularly regarding their environmental impact[2].

Among the most pressing concerns is the growing volume of plastic waste generated by mass manufacturing. According to the Indonesian Ministry of Environment and Forestry, the country produces approximately 189,000 tons of waste per day, with a significant portion consisting of non-household plastic [3]. Toy products, particularly those made from conventional plastics, contribute notably to this problem. Mini 4WD model kits, a widely popular toy enjoyed by children and adults alike, are typically manufactured using petroleum-based plastic materials [4]. These products often become waste after their functional life ends, adding to the burden of long-degrading plastic pollution in the environment.

Replacing conventional petroleum-based polymers with biodegradable alternatives such as polylactic acid (PLA) offers a promising approach to reduce the environmental burden of plastic products.[5]. PLA is a biodegradable and bio-based polymer derived from renewable resources such as corn starch, sugarcane, and cassava. It offers promising environmental benefits by reducing dependency on fossil fuels and being capable of natural decomposition under certain conditions. However, PLA exhibits certain material weaknesses, particularly in terms of thermal resistance and mechanical durability. Product performance should be evaluated during the early design stages to ensure that the final product meets functional and safety requirements, especially in consumer products like toys [6].

To develop a functional and sustainable mini 4WD kit using PLA, this study adopts the Design for Manufacturing and Assembly (DFMA) methodology. DFMA provides a systematic approach to product design, focusing on minimizing production costs and complexity while maximizing manufacturability and performance [7]. DfMA is an integrated process to guide the design of module components and their connections, assembly sequence, and manufacturing in a controlled environment, optimizing time, reducing parts, and enhancing assembly efficiency. [8]. This method is especially valuable when working with alternative materials like PLA, as it allows designers to anticipate potential manufacturing issues and adapt the design accordingly.

This research aims to contribute to sustainable product development by designing an environmentally friendly version of a traditionally plastic-based toy. Several studies have adopted the biodegradable concept, such as the research conducted by Hanafi (2018), which developed food packaging based on polylactic acid (PLA) enriched with plant extracts like turmeric, mangosteen peel, and soursop leaves. The resulting film exhibited significant antioxidant activity and effectively slowed the spoilage of citrus fruits, making it a functional and environmentally friendly packaging alternative. However, this approach still primarily relies on agricultural-based raw materials. [9] By applying the DFMA approach in conjunction with the use of PLA material, the resulting product is expected to meet consumer requirements such as speed, durability, and aesthetic appeal while significantly reducing its ecological footprint. The findings from this study not only support the reduction of plastic waste in the toy industry but also demonstrate the feasibility of eco-design in non-essential consumer products through practical and innovative design methodologies.

II. LITERATURE REVIEW

A. Eco- Products

Green products are environmentally friendly products that cause minimal or no harm to the environment, reduce resource consumption, and aim for sustainability across their life cycle [10]. To minimize environmental impact, the ecological considerations of daily life must be factored into the development of green products. Growing concerns about global warming and environmental degradation have led consumers to increasingly prefer eco-friendly products that are safer for health and the planet [10]. Young consumers are emerging as key drivers of sustainability by adopting environmentally friendly behaviors and actively promoting green practices within their communities [11]. As consumers become more aware of the negative effects of unsustainable consumption, they alter their behavior and take pro-environmental actions. Environmental awareness drives young customers to act more responsibly, influencing their purchasing decisions. When consumers become aware of the negative effects of unsustainable consumption on the environment, they change their behavior and take pro-environmental actions. Environmental awareness encourages young customers to act more socially responsible toward the environment, which influences their purchasing decisions [12].

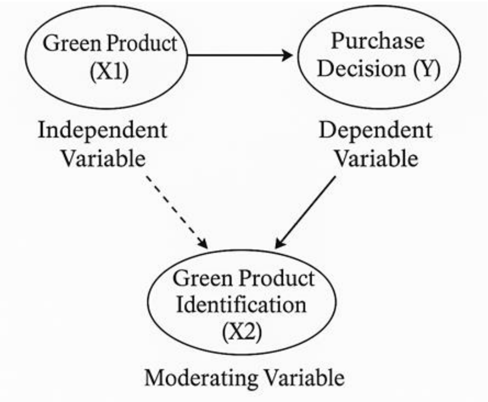

Figure 1. Environment awareness

B. Polylactic Acid (PLA)

Polylactic Acid (PLA) is a biodegradable thermoplastic made from renewable plant sources such as corn starch or sugarcane. PLA has several advantages over traditional plastics, including its biodegradability, lower carbon footprint during production, and the fact that it is derived from renewable resources [13]. However, PLA also has limitations such as its sensitivity to heat, lower mechanical properties compared to petroleum-based plastics, and vulnerability to moisture. The use of PLA in manufacturing, especially in products like toys, presents an opportunity to reduce environmental impact while meeting consumer demands for sustainable products [14].

C. Design for Manufacturing and Assembly

Design for Manufacturing and Assembly (DFMA) and design for deconstruction (DFD) principles are applied systematically to enhance efficiency, reduce waste, and improve construction product performance and assemblability. [15]. By focusing on ease of manufacturing and reducing production costs, DFMA helps companies produce high-quality products at lower costs while reducing environmental impacts. This approach is particularly useful in the context of eco-products, as it ensures that sustainability goals are met without compromising on product performance or cost efficiency. DFMA currently plays a significant role not only in conventional industries but has also expanded into project and construction industries [16], [17].

Compared to other approaches like DFM, DFA, or Concurrent Engineering, the Design for Manufacture and Assembly (DFMA) method was selected because it can combine manufacturing and assembly elements into a comprehensive approach, producing simpler, more effective, and more affordable product designs. DFMA promotes the use of standard and modular components that improve production and maintenance efficiency, makes it easier to identify unnecessary components, and permits quantitative cost analysis from the very beginning of the design process. Furthermore, by lowering waste and material consumption, DFMA has demonstrated its ability to support sustainability principles and expedite product launch times to market. DFMA is a better approach for thorough product design optimization because of these benefits. Huang, Zhang, and Jiang's (2012) study in the International Journal of Advanced Manufacturing Technology and Boothroyd, Dewhurst, and Knight's (2010) research in the book Product Design for Manufacture and Assembly both support this argument by demonstrating that the use of DFMA can greatly speed up the product development process and cut production costs by up to 50% [18], [19].

III. RESEARCH METHODS

The research applies the Design for Manufacturing and Assembly (DFMA) methodology to optimize the design and production of mini 4WD kit components made from PLA. DFMA is employed in the early stages of product design to reduce complexity and improve manufacturability by analyzing each component's design and evaluating its production feasibility.

A. Pre-Research and Literature Study Phase

This is the first stage of the research process, involving literature review, observation, and direct experimentation to plan the research.

B. Problem Identification Phase

After the pre-research, this phase involves identifying the research subject and object, followed by formulating the research problem.

C. *Data Collection Phase*

This includes primary data (e.g., measurements, material hardness tests, 3D printing, and product performance testing) and secondary data (e.g., material specifications).

D. *Data Processing Phase*

In this phase, 3D component designs are created using SolidWorks and processed with Creality Slicer. Data is processed through DFMA stages like Operation Process Chart (OPC), bill of materials, product efficiency, and test results.

E. *Analysis and Discussion Phase*

This phase involves analyzing and discussing the results obtained from data processing.

F. *Conclusion Phase*

The final phase, where conclusions and recommendations from the research are drawn.

The first step in integrating the DFMA framework with Sections C through E is to identify the elements and functions that will serve as the foundation for the Operation Process Chart (C). To streamline the work sequence and the use of PLA material, the assembly process is then examined using DFA principles. The integration is shown in Figure 2. The manufacturability of each component is then examined using a DFM analysis, which has a direct impact on Section D's material consumption. The quantity and kind of materials required are then recalculated using the results of the redesign, and Section E's production cost calculations are based on how well the enhanced process and materials work. To arrive at the most cost-effective and efficient final design choice, all results were examined and contrasted before and after the use of DFMA.

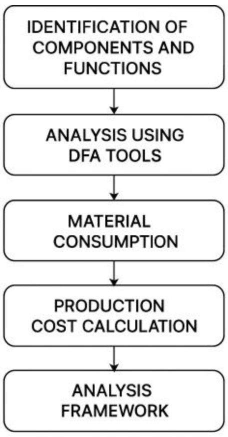

Figure 2. Integrated DFMA

IV. RESULT AND DISCUSSION

A. Product Design and Prototyping

The toy industry have continuously evolved over time and has never declined. Toy products are among the significant contributors to plastic waste, second only to food packaging. Another issue is that the packaging of toys themselves is made of plastic. This has led us to develop an environmentally friendly toy product, which is the mini 4WD model kit. The design of all components of the product is included in the attachment, with one of the designs being the body, as follows. Industry 4.0 is influencing the product design and development process, including the integration of smart technologies into product design [20].

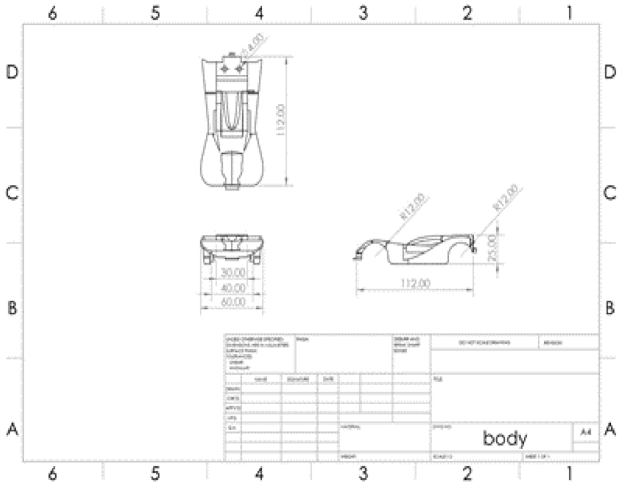

Figure 3. Mini 4WD Model Kit Body Technical Drawing

Figure 3 shows one of the 2D designs, including top, side, and front views. This design must be converted into a 3D format in an STL file so that it can be read by the Creality Slicer software and converted into G-Code. Before collecting data, we set up the 3D printer and tested it with the Tamiya 3D design for the body and chassis components. The results of this setup are shown in Figure 4 below:

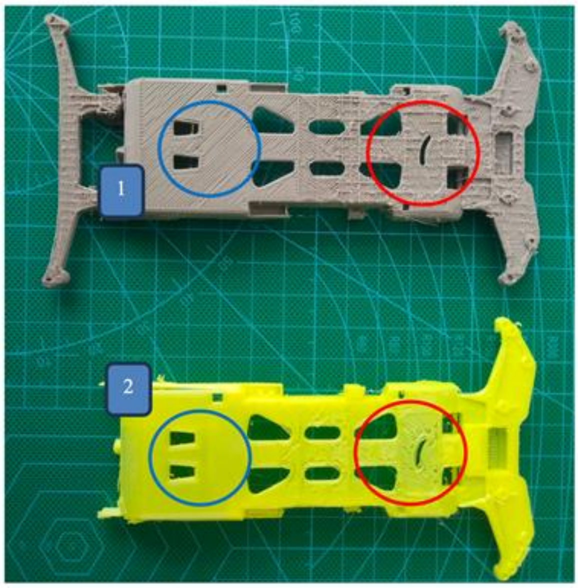

Figure 4. Setup Results with Chassis

The results from two different experiments are shown, with the red circle indicating dimensional differences and the blue circle indicating differences in the surface quality of the product. The product shown above uses the same filament material, CR-PLA, but with different setting variables. In setup 1, the variable setting did not use bottom thickness, resulting in a rough surface, while setup 2 used bottom thickness, producing a smoother surface. In terms of dimensional accuracy, setup 1 produced better results than setup 2.

Tabel 1. PLA physical properties

Physical Property	Unit	Value
Specific Gravity	-	1.27
Solid Density	g/cm³	1.2515
Boiling Point	°C	165
Tensile Strength	MPa	59
Elastic Modulus	MPa	3500
Young's Modulus	MPa	1280
Elongation Percentage	%	11.3

Source : kim poppy 2016

Based on table 1, PLA offers several advantages over other biopolymers. Its monomer is derived from biomass fermentation, specifically corn, which also contributes to significant CO2 fixation during production.[6] The manufacturing process is energy-efficient, and PLA can be recycled through hydrolysis or alcoholysis. Additionally, it is compostable, helping to reduce plastic waste in landfills. PLA's physical properties can also be adjusted through material modifications, offering greater flexibility in its applications.

B. Element Data

During the prototyping, we determined variables that affect the output of 3D printed products using an observation sheet. Below is one of the observation results during the printing process of the body and chassis lock using Sunlu PLA material. Three-dimensional (3D) data models can be used to create a wide variety of complex structures and geometries using additive manufacturing (AM) technology such as 3D printing [21]. Tabel 2 show input data for mini 4wd part by 3D Printer and table 3 show ouput data based on prototyping result.

Tabel 2. Input Data for Prototyping

No.	Component	Data 1	Data 2	Unit
1	Nozzle Temperature	200	215	°C
2	Hotbed Temperature	55	65	°C
3	Printing Speed	80	100	mm/s
4	Fill Density	80	100	%
5	Infill Pattern	Cubic	Triangle	Type

Tabel 3. Output Data by Prototyping (small part dimention)

No.	Component	Data 1	Data 2	Unit
1	Printing Setup Time	3.47 minutes	4.3 minutes	Minutes
2	Cycle Time	15.37	13.12	Minutes
3	Total Printing Time	15.37 minutes	13.12 minutes	Minutes
4	Standard Time	16.00	14.00	Minutes
5	Filament Length Used	0.69	0.69	Meters
6	Object Weight (by Creality Slicer)	2 g	2 g	Grams / Milligrams
7	Actual Object Weight (by Scales)	2.07 g	2.09 g	Grams / Milligrams

As a test sample to determine the most optimal component variables based on production time and dimensional accuracy, we used two designs: the lock and the body of a mini 4WD kit. The results in Table 3 show that the total printing time was faster in the second data column (Data 2), even though the infill used was higher, at 100%. The setup time was also longer due to the higher nozzle heating temperature, but the printing speed was faster. From the output results above, it can be concluded that the printing process for the chassis lock is more optimal using the variables in Experiment 2. One of the key findings was the importance of material selection and printing parameters in achieving the desired performance of PLA-based components. Factors such as layer height, infill density, and print speed were found to significantly impact the dimensional accuracy and surface finish of the components. The PLA material used in the research exhibited good biodegradability, but it was also sensitive to high temperatures and mechanical stress, which need to be addressed in future product iterations. Figure 5 is screen record from creality slicer application for input data setting before printing.

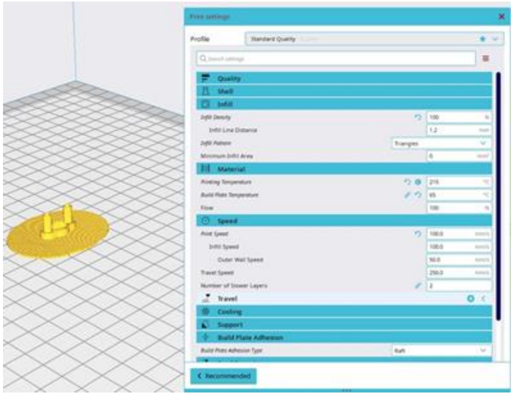

Figure 5. Creality Input Setting (Body key part)

The results of the study show that PLA can be effectively used to produce mini 4WD kit components with comparable functionality to traditional plastic materials. The DFMA approach significantly optimized the design and production process, resulting in a reduction in material waste and production time. The PLA components produced during the study demonstrated acceptable mechanical properties such as strength, durability, and flexibility, meeting the requirements for mini 4WD kits.

C. Operation Process Chart

The Operation Process Chart is one of the tools used to model a sequence of processes within an operation. In the manufacturing and production process of a mini 4WD toy using a 3D printer, a total of 32 operations, 2 inspections, and 1 assembly step were identified. The total processing time required was 31,967 seconds, equivalent to approximately 8.89 hours. In general, the processes involved can be performed in parallel, which allows for a reduction in total production time. For instance, utilizing more than one 3D printer simultaneously could reduce the overall time by up to 50%. Generally, the implementation of parallel operations can significantly reduce total production time. Studies have shown that assigning parts across multiple 3D printers in parallel setups can improve efficiency by reducing total processing time [22], [23]. For example, using more than one 3D printer may cut total production time by up to 50% [23]. in the context of producing a mini 4WD toy using 3D printing technology, the process comprises:

a. 32 operation steps, taking a total of 29,987 seconds
b. 2 inspection steps, requiring 180 seconds
c. 1 assembly process, taking 1,800 seconds.

This results in a total processing time of 31,967 seconds, equivalent to approximately 8.89 hours. Figure 6, show these activities are illustrated in a typical operation process chart using standard symbols: a circle for operations, a square for inspections, and an upside-down triangle for assembly steps.

D. Material Consumption

The material consumption in this process utilized 11.81 meters of filament, with a total weight of 37.21 grams. The weight of 37.21 grams for 11.81 meters of filament suggests the use of a common thermoplastic such as PLA or ABS, which typically has a density of around 1.24 g/cm³ for PLA. By applying optimized infill strategies such as 'lightning infill' and thermal control modifications in FFF printing, material consumption can be reduced by over 50%, enhancing resource efficiency during prototyping [21]. Moreover, understanding filament use aids in lifecycle analysis and environmental impact assessment of 3D printing projects. Table 4 shows for material consumption.

Tabel 4. Material consumption

No.	Part Name	Filament Length (m)	Filament Weight (g)
1	Large Axle	0.10	0
2	Double Gear Axle	0.05	0
3	Wheel Axle	0.10	0
4	Dynamo Axle	0.03	0
5	Copper Plate 1	-	-
6	Copper Plate 2	-	-
7	Copper Switch Plate	-	-
8	Tire Rubber	-	-
9	Double Gear	0.03	0.20
10	Dynamo Gear	0.04	0.20
11	Roller	0.05	0.23
12	Switch Button	0.05	0.23
13	Gear 3	0.09	0.27
14	Large Gear	0.15	0.78
15	Battery Lock	0.19	1.00
16	Body Lock	0.19	1.00
17	Front Cover	0.28	1.00
18	Body Wing	0.41	1.20
19	Upper Dynamo Case	0.34	1.00
20	Lower Dynamo Case	0.37	1.10
21	Rim	0.53	2.00
22	Tamiya Chassis	4.32	13.00
23	Tamiya Body	4.77	14.00
Total		**11.81 m**	**37.21 g**

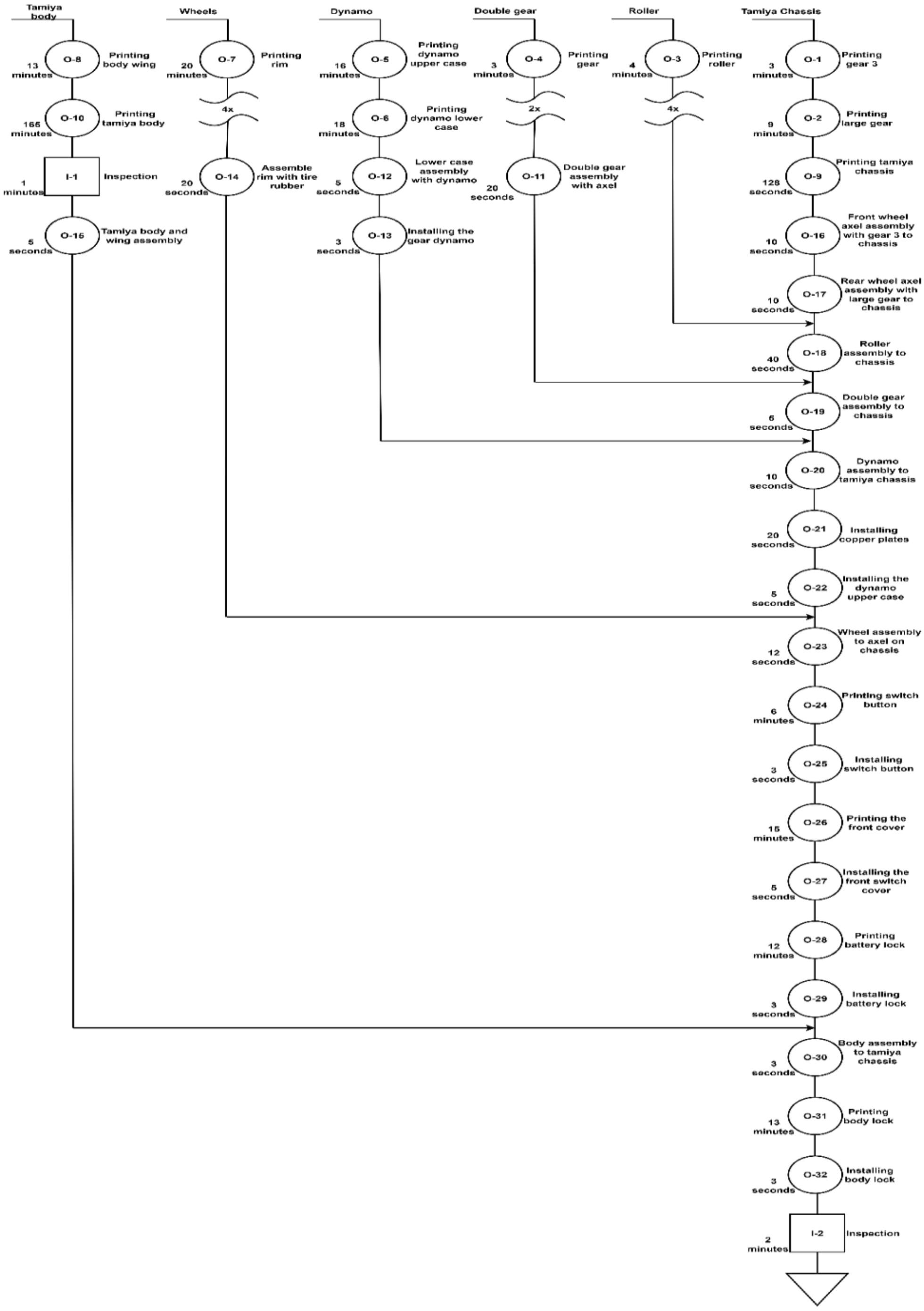

Figure 6. Operation Process Chart

Although polylactic acid (PLA) is a biodegradable bioplastic derived from renewable resources, it only breaks down efficiently in industrial composting settings with regulated humidity and temperature. PLA degrades very slowly or never at all in natural settings like soil or the ocean. Therefore, even though PLA is environmentally friendly, using it still requires taking into account a suitable waste management system[24], [25].

E. Production Cost Calculation

The calculation of production costs using the Design for Manufacturing and Assembly (DFMA) method serves as a supporting reference in decision-making related to the selected product design and manufacturing process. The main components of production costs typically include materials and labor. The cost elements considered in determining the cost of goods manufactured are shown in table 5. The average selling price of a mini 4WD product under the Tamiya brand is approximately IDR 150,000, depending on the model and series. If the product developed in this research is marketed under a specific brand that promotes eco-friendliness, it is expected to be well-received by consumers. In this study, DFM is implemented to guide the production design and cost calculation process. Its impact can be seen in the following aspects. Material selection prioritizes availability and manufacturability to minimize waste. Labor optimization is achieved through reduced assembly time and simplified parts. Energy consumption is minimized through efficient process planning. Component integration is enhanced by reducing unnecessary parts, aligning with modular design strategies. Applying DFM directly contributes to a more economical and sustainable production process, reinforcing the product's market competitiveness in both cost and environmental impact [26], [27].

Tabel 5. Production Cost

No.	Component	Unit	Qty.	Total Cost (IDR)
1	Filament Material	IDR 250 /gram	37.21 g	IDR 9,302.00
2	Labor	IDR 100,000 /8 hours	8.89 hours	IDR 110,000.00
3	Electricity	-	8.89 hours	IDR 10,000.00
4	Supporting Components	-	10 pcs	IDR 30,000.00
5	Infill Pattern	Cubic	Triangle	Type

Simulating the selling price for mass production is crucial because it helps companies make smart and well-informed decisions. First of all, it enables the assessment of profitability in several situations, including variations in production costs, shifts in production volume, and pressures from rival pricing. Second, by determining realistic profit margins, simulation helps to ensure that the final product's pricing stays profitable and competitive in the market. Finally, it facilitates the use of data to inform decisions, particularly when it comes to marketing strategies, manufacturing efficiency, and cost optimization. Businesses can proactively anticipate risks and opportunities by simulating various pricing systems, which improves both short-term profitability and long-term sustainability [28].

Example simulation :

a. Cost per unit (C) = IDR 159,302
b. Target profit margin (m) = 0.10 (10%)
c. Quantity (Q) = 1000 units

Then the selling price (P) is calculated using equation 1:

$$P = C \times (1 + m) \quad (1)$$

$$P = 159{,}302 \times (1 + 0.10)$$
$$= IDR\ 175{,}232.2$$

Profit per unit is calculated using equation 2:

$$Profit\ per\ unit = C \times m \quad (2)$$

$$Profit\ per\ unit = 159{,}302 \times 0.10$$
$$= IDR\ 15{,}930.2$$

Total profit for 1000 units is calculated using equation 3:

$$Total\ profit = Q \times profit\ per\ unit \quad (3)$$

$$Total\ profit = 1000 \times 15{,}930.2$$
$$= IDR\ 15{,}930{,}200$$

Selling price (P) and the production cost (C), then the profit margin (m) is calculated using equation 4:

$$m = \frac{(P - C)}{C} \quad (4)$$

Example Application:

$$if\ P = 159{,}302\ and\ C = 139{,}302$$

$$m = \frac{(159{,}302 - 139{,}302)}{139{,}302}$$

$$\approx IDR\ 15{,}930{,}200 \rightarrow 14.35\%$$

The price of a 4WD Tamiya car offered by competitors in the market is approximately IDR 150,000. If we set our selling price at IDR 159,302, it remains relatively competitive in numerical terms. The price difference of around 10% becomes a factor that consumers typically consider when comparing and deciding on a purchase. One approach to increase consumer purchase interest is to implement a branding strategy that highlights the product's environmentally friendly attributes. Table 6 presents the proposed branding scheme for this product. green advertising, eco-labelling, and eco-branding all have a positive and significant impact on consumers' intention to purchase environmentally friendly products [27].

Tabel 6. Product Branding Scheme

Aspect	Strength
Moral Value	Many customers are willing to pay more for environmentally responsible products.
Global Trend	Eco-friendly = premium = stronger branding and market differentiation.
Niche Communities	Sustainability. conscious hobbyists can become loyal brand advocates.
Sustainable Packaging	Compostable, recycled, or minimal packaging is a visible, tangible differentiator.

Through the application of DFMA, the research was able to identify key areas for improving the production process, such as reducing the number of assembly steps and simplifying component designs to minimize manufacturing complexity. By optimizing the design and production steps, the overall cost of production was reduced without compromising the quality or performance of the toy.

One of the key findings was the importance of material selection and printing parameters in achieving the desired performance of PLA-based components. Factors such as layer height, infill density, and print speed were found to significantly impact the dimensional accuracy and surface finish of the components. The PLA material used in the research exhibited good biodegradability, but it was also sensitive to high temperatures and mechanical stress, which need to be addressed in future product iterations.

This research applies the principles of Design for Manufacture and Assembly (DFMA) as an evaluation framework for the efficiency of product designs made using polylactic acid (PLA) material and processed with 3D printing technology (Fused Deposition Modeling – FDM). The evaluation is condu cted absolutely without comparison to the previous conventional process. Fokus utama adalah untuk menilai sejauh mana desain memenuhi kriteria DFMA, yaitu kesederhanaan proses manufaktur, substitusi material, dan efisiensi biaya serta waktu dalam produksi.

Three main parameters used in the evaluation are:

A. *Material Consumption*

As shown in Table 4, we obtain a material consumption of 37.21 g of filament, which can be interpreted as very minimal material used compared to similar products, which generally use around 7 g. The material used is also polylactic acid, which is claimed to be more easily degradable in nature (reference).

B. *Production process*

The working process cannot be directly compared to conventional production. If we look at references in the production of general products using molding, the printing process using a 3D printer is much simpler, where the hard components we use are only machines, humans, and materials. The process being carried out can be seen in Figure 6. This process can be highlighted because customization is highly possible with a 3D printer.

C. *Process Time*

In terms of production time, using a 3D printer is certainly much longer compared to conventional molding. The prototype printing process takes a long time, specifically 8.89 hours.

D. *Product Selling Price*

The estimated selling price is calculated based on filament costs, energy consumption, and production time. Because the 3D printing process allows for product creation in one step without additional assembly, labor and material costs can be reduced. A cost calculation simulation and potential product selling price have been conducted.

The product design is also optimized to integrate material changes as well as process changes. Ini menunjukkan penerapan prinsip Design for Assembly.Thus, although no explicit comparison was made with the initial design or other methods, the DFMA approach was used as a basis to assess the effectiveness and efficiency of the design in relation to PLA-based manufacturing and 3D printing processes.

V. CONCLUSION

This research has demonstrated that PLA is a viable alternative to conventional plastics in the production of mini 4WD kits, offering both environmental and economic benefits. The application of DFMA in the design and production process has shown improvements in efficiency as using 3D printer are flexible in production, competitive cost with same product is IDR 159,302, and material optimization using PLA as biodegradable material with 37.21 g consumtion. The results of the study support the adoption of PLA in the toy industry as part of a broader effort to reduce plastic waste and promote sustainable manufacturing practices.

By replacing traditional plastics with biodegradable materials like PLA and optimizing the manufacturing process through DFMA, companies can produce eco-friendly products that meet consumer demands while minimizing their environmental impact. Future research will continue to refine these processes and explore new materials that offer even greater sustainability benefits.

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