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Design and Finite Element Analysis of a Portable Bus Service Ramp to Reduce Dependence on Service Pits

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ABSTRACT

This study aims to: (1) design and analyze a portable ramp to improve bus repair efficiency at PT. United Tractors Semarang Branch, (2) with a focus on facilitating repairs and reducing dependence on service pits. (3) This portable ramp is expected to overcome access constraints to the underside of buses, speed up repair time, and improve work safety for mechanics. This study uses the DMADV (Define, Measure, Analyze, Design, Verify) method to develop portable ramps. These stages include problem discovery, technical data collection, analysis of materials, 3D model design using SolidWorks, and verification using Finite Element Analysis (FEA) to ensure structural strength and compliance with safety standards. This study successfully designed and analyzed a portable ramp for bus repairs, capable of withstanding an operational load of 88,750 Newtons with a safety factor≥ 3.0, a maximum deformation of ≤ 5 mm, and a safe von Mises stress distribution. The selection of ASTM A36 Carbon Steel resulted in optimal strength and weight, as well as cost efficiency. The ramp design also meets workshop operational needs and improves repair process efficiency. This research successfully designed an optimal portable ramp for the PT. United Tractors Semarang Branch Workshop, considering operational efficiency and safety, ASTM A36 Carbon Steel was selected as the best material based on strength, weight, and cost. It is recommended to implement this portable ramp, along with technician training, maintenance system development, and expansion to other branches, to improve bus repair efficiency.

1. Introduction

In the ever-growing transportation industry, buses remain an important mode of transportation, especially in developing countries, where they play a vital role in connecting cities and provinces [1]. The efficiency and reliability of bus fleet operations are crucial to meeting the community's mobility needs, supporting economic activity, and reducing traffic congestion. A fast, accurate, and efficient repair process will minimize downtime, ensure fleet availability, and improve customer satisfaction[2]. Therefore, regular bus maintenance and repair are a top priority for bus companies and repair shops.

Bus maintenance workshops help keep the bus fleet in top condition. Official workshops equipped with adequate tools, skilled labor, and efficient management systems can perform repairs quickly and accurately. However, in practice, many bus workshops face various obstacles that hinder repair efficiency. Repairs to the underside of buses, such as the suspension, brakes, transmission, power transfer, and exhaust systems, often require a great deal of time and effort because technicians have to work in non- ergonomic positions or use inadequate tools [3].

PT United Tractors Tbk (UT) is a leading company in Indonesia that distributes heavy equipment, construction machinery, and provides mining and energy services. A subsidiary of PT Astra International Tbk, it has been operating since 1972 and is the official distributor of well- known brands such as Komatsu, Scania, UD Trucks, and others. UT serves various sectors such as mining, construction, forestry, transportation, and plantations, and provides mining contractor services, mine management, infrastructure projects, and power plants.

UT Semarang Branch is located at Jl. Jenderal Urip Sumoharjo Km 12, Wonosari, Semarang, and serves the areas of Central Java, Yogyakarta, and Rembang (Fig. 1). Its facilities include an office, workshop, and warehouse complete with a washing area and unit parking. This branch provides regular and additional service to ensure heavy equipment operates optimally, with a strong commitment to productivity and customer satisfaction.

Figure 1. Workshop

One of the main services offered is a remanufacturing program, in which machine components that have reached the end of their useful life are repaired and restored to their original condition. This program aims to extend the life of components and improve operational efficiency. In addition, this workshop also provides training services for mechanics, including a safety talk program to increase awareness and understanding of work safety in the workshop environment [4].

Figure 2. Safety Talk

PT United Tractors Tbk (UT) provides official after-sales services, including servicing, repairs, and warranty claims, for 150 Scania buses operated by several bus companies (PO) in Central Java and the Special Region of Yogyakarta (DIY). These bus companies include Rosalia Indah, Agra Mas, Rimba Raya, Kencana, and Bejeu. This Scania bus fleet supports intercity transportation, tourism, and other services that prioritize comfort and efficiency. With proven engine quality, comfortable bodies, and premium facilities, Scania buses are the top choice for large PO companies in Indonesia. UT plays an important role in supporting and improving safe, comfortable, and efficient transportation services in the Central Java and DIY regions [5].

Based on field observations and interviews with technicians, the bus repair process at the PT. United Tractors Semarang Branch support point often takes longer than it should. One reason is the difficulty of accessing the underside of the bus. When the service pit is full, as there is only one available at PT. At United Tractors Semarang Branch, technicians often have to rely on jacks and wooden blocks to lift the bus, which is time-consuming, poses a risk to worker safety, and results in poor working conditions. These positions can cause fatigue and injury among technicians, ultimately affecting the efficiency and quality of repairs.

The focus of this study is on improving bus repair efficiency at PT. United Tractors Semarang Branch overcame the challenge of accessing the underside of the bus, which is often a major obstacle in the repair process. This obstacle significantly impacts repair time, work safety, and repair quality [6]. Therefore, an integrated solution is needed to overcome this problem. One proposed solution is to design a portable ramp. This tool can gradually lift the bus, making access to the underside easier and safer. This ramp is flexible and easy to move, so it can be used in various locations without requiring a service pit.

Suspension system repairs often take technicians about two working days just to reach the components that need repair or replacement [7]. This is due to the working position, which requires technicians to bend over or lie under the bus, which is very tiring. Replacing the exhaust pipe can also take up to one working day due to the difficulty of removing rusted bolts. Technicians must use various tools such as wrenches, hammers, and screwdrivers, which adds to their workload. In brake system repairs, technicians need about half a working day due to the difficulty of inspecting parts in narrow, dark spaces under the bus. These conditions worsen work comfort and safety. In addition, when repairing the power transmission system, space limitations hinder the use of tools such as jacks to lift heavy components, including propellers weighing 60-90 kg. All these cases show that the difficulty of accessing the underside of the bus significantly hinders the repair process, affecting work efficiency and safety.

The use of portable ramps is expected to provide various benefits for PT. United Tractors Semarang Branch. First, these ramps will speed up bus repairs, as technicians can access the underside of the bus more easily and quickly. Second, these ramps will improve work safety, as a stable and sturdy structure supports the bus. Third, these ramps will improve work efficiency, as technicians can work in a more comfortable, natural position. Fourth, this ramp will improve repair quality, as technicians can perform inspections and repairs more thoroughly.

The process of maintaining and inspecting large buses often encounters obstacles in accessing the underside of the vehicle due to limited service pits. The use of conventional methods, such as jacks and wooden blocks, not only requires more time and energy but also poses a significant safety risk. Therefore, there is a need for more effective, efficient, and safer tools to support the smooth running of vehicle maintenance processes. Portable ramps are essential because they can improve accessibility and safety, especially during maintenance or inspections. In addition, portable ramps support time and energy efficiency, enabling work to be done more effectively. Portability is a tool's ability to be easily moved and used in various locations as needed. Thus, portable ramps can be used flexibly in various places, both at the UT Semarang workshop and in the field.

The solution proposed in this study is to design and analyze portable ramps. Portable ramps are tools designed to provide a smooth, gradual change in height, making access to the underside of buses easier and safer. These ramps are portable, offering several advantages over conventional methods, such as jacks and wooden blocks. One of the main advantages is its ability to work faster and more efficiently. By using a portable ramp, technicians can lift buses more easily and quickly, avoiding the need to repeatedly pump jacks or arrange wooden blocks, which often takes time and energy [8].

The portable ramp is designed to provide greater safety. The ramp's structure is stable and sturdy, reducing the risk of the bus slipping or falling off its support. Additional safety features, such as stoppers, are also embedded in this ramp to protect technicians and prevent the bus from rolling off the ramp during use. Another advantage is the portable ramp's ergonomic design. By using this ramp, technicians can work in a more comfortable, natural position, avoiding the need to bend over or lie under the bus, as is necessary when using a jack or wooden blocks. This not only increases comfort but also reduces the risk of injuries from poor working posture. Portable ramps also improve the quality of vehicle repairs. By providing better access to the underside of the bus, these ramps enable technicians to perform more thorough, detailed inspections and repairs. The use of portable ramps makes the repair process more efficient, safe, and of higher quality.

By implementing a comprehensive, integrated solution, it is hoped to improve the efficiency of bus repairs at the PT. United Tractors Semarang Branch Workshop can be significantly improved. This is also expected to reduce the company's maintenance costs. In addition, this solution will help improve work safety for technicians involved in the repair process. The implementation is also expected to improve work posture, thereby reducing the risk of injury and fatigue. Thus, this increase in efficiency will contribute to greater customer satisfaction with the company's services.

In this study, the portable ramp design will be analyzed structurally to ensure it can safely support the bus's weight without excessive deformation. The analysis includes calculations of stress, strain, and safety factor under a total bus load of 28 tons. The materials used will also be examined to obtain a combination that is lightweight yet strong enough to support the load. The selection of materials considers tensile strength, weight, production costs, and availability. In addition, the ramp design will consider ease of use to ensure optimal field use [9].

2. Methodology

This study uses the DMADV process, which stands for "Define, Measure, Analyze, Design, and Verify." In the Six Sigma product development process, this model is an integral component of the framework. DMADV was chosen because of its comprehensive framework for integrating field requirements, data analysis, and design validation. The main reason for considering this is that it is the most important factor influencing the decision-making process.

The development process of the portable ramp in this study followed the DMADV methodology integrated with FEA. These stages were chosen to ensure that the ramp design met the technical, safety, and operational efficiency requirements at the PT. United Tractors Semarang Branch Workshop.

The indicators and assessment criteria for the portable ramp were designed to ensure that the design meets the technical, safety, and operational efficiency requirements at the PT. United Tractors Semarang Branch Workshop.

Tractors Semarang Branch Workshop. The portable ramp design refers to six main criteria: structural strength with a safety factor ≥3.0 and maximum deformation ≤5 mm in accordance with OSHA standards; safety through anti-slip surfaces and stoppers at least 10 cm high; portability with a ramp weight ≤150 kg so that four technicians can easily move it; selection of materials between ASTM A36 Steel, Stainless Steel, and Aluminum based on strength, strength- to-weight ratio, ease of production, and local costs; compliance with OSHA and ISO

12100 standards related to work safety; and design validity and reliability validated by PT. United Tractors was tested through repeated FEA simulations with load variations of ±5%.

This study uses a combination of quantitative and qualitative collection techniques to validate the design of the portable ramp and ensure compliance with safety standards and the operational requirements of the PT. United Tractors Semarang Branch Workshop. Data collection techniques in this study included four main approaches. First, a finite element analysis (FEA) was performed to evaluate the structural strength of the portable ramp using a 3D model in SolidWorks and a load of 88,750 Newtons. Second, literature reviews and international standards, such as ISO 12100 and OSHA 29 CFR 1926.451, were used to ensure that the ramp design met technical and occupational safety requirements. Third, interviews with technicians and direct observations in the workshop were conducted to understand operational needs and vehicle access challenges. Fourth, a material analysis was performed by comparing the strength-to-weight index of materials using the Ashby Material Chart to determine the best material based on strength, weight, cost, and availability.

The data collection instruments consisted of three main types. First, a standard compliance checklist containing technical parameters that portable ramps must meet, such as anti-slip surfaces, slip resistance, and a minimum safety factor of 3.0, based on OSHA and ISO standards. Second, FEA simulation using SolidWorks Simulation with distributed loading and fixed supports, with outputs including stress distribution, maximum deformation (≤5 mm), and safety factors. Third, technical material documents covering the mechanical and physical specifications of various types of metals, such as ASTM A36 carbon steel, stainless steel, and aluminum, including yield strength and density data from local suppliers.

The validity and reliability of the data collection instruments in this study were ensured through a systematic approach that guaranteed the accuracy of the FEA simulation and the compliance of the portable ramp design with OSHA and ISO 12100 safety standards. Validity in this study refers to the extent to which the instruments measure the parameters intended to be measured, with a focus on content validity. Validation was carried out through two main approaches: a standard-compliance checklist, validated by industry parties, to ensure that the ramp design meets load capacity and safety factor standards, and boundary conditions that are adjusted to the actual situation at the PT. United Tractors Semarang Branch workshop. Validity was also reinforced by references to ASTM A36 and AISI 304 steel material literature as the basis for material selection based on their respective tensile strengths.

Reliability measures the consistency of test results when instruments are used repeatedly. Reliability testing was conducted using the test-retest method with three FEA simulations using load variations of ±5%. Evaluation by industry experts was conducted using a design validation checklist based on structural strength, compliance with OSHA/ISO standards, and portability.

3. Result And Discussion

3.1 Results

This study successfully developed a portable ramp for bus repair access using the DMADV (Define, Measure, Analyze, Design, and Verify) methodology integrated with Finite Element Analysis (FEA). The results showed that the ramp design met all OSHA and ISO 12100 safety criteria, with a safety factor ≥ 3.0, maximum deformation ≤ 5 mm, and the ability to withstand an operational load of 88,750 Newtons, distributed at a 50:50 ratio between the right and left sides of the bus's rear axle.

1. **Define (Establishing Requirements)**

The following are the results obtained from the define stage. The functional criteria and technical specifications of the portable ramp were effectively described during the Define phase of this project. The operational conditions of the PT United Tractors Semarang Branch workshop were evaluated, which showed that the existing standards and specifications were not in accordance with these conditions. Based on the findings of the requirements analysis, it was determined that the workshop needed an alternative to the conventional service pit, which posed constraints on flexibility and operational efficiency.

Table 1. Work List

No	Date	Unit	Work
1	06-05-2025	K410CB-6X2	PS 60,000 KM
2	08-05-2025	K410CB-6X2	PS 60,000 KM
3	09-05-2025	K410CB-6X2	PS 60,000 KM
4	May 14, 2025	K410CB-6X2	PS 60,000 KM
5	May 20, 2025	K450CB-6X2	PS 60,000 KM
6	May 21, 2025	K450CB-6X2	PS 60,000 KM
7	May 23, 2025	K410CB-6X2	PS 60,000 KM
8	May 27, 2025	K410CB-6X2	PS 60,000 KM
9	May 28, 2025	K410CB-6X2	PS 60,000 KM
10	May 28, 2025	K410CB-6X2	PS 20,000 KM

The table above shows the unit's work history over one month, during which one job requires access to the undercarriage and engine compartment, so a portable ramp is required. This process involves understanding the purpose of maintenance or repair, as well as identifying the technical requirements, resources, and time needed. Considering that this service work is carried out over a month with a total of 10 units, it is important to ensure that time and resource allocation are optimally arranged for each unit. By establishing detailed requirements, service work can be carried out more efficiently and effectively, reducing the likelihood of errors and ensuring results meet the desired standards.

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(OSHA) 29 CFR 1926.451 provides a minimum safety factor of 3.0. At the same time, ISO 12100:2010 outlines a comprehensive risk assessment with a focus on surfaces designed to prevent slipping, even in wet or slippery conditions, both of which are referenced in the safety requirements. Both standards are referenced in the safety requirements. To ensure that the ramp can withstand static loads.

2. **Measure (Measuring Specifications)**

The Scania K410 is 13.60 meters long and is suitable for accommodating more passengers on both floors. At 4.15 meters tall, this bus is a double-decker model that offers comfortable seating on the upper deck. Its width of 2.54 meters, in accordance with intercity bus standards, provides adequate space for two rows of seats and maintains stability and comfort during the journey.

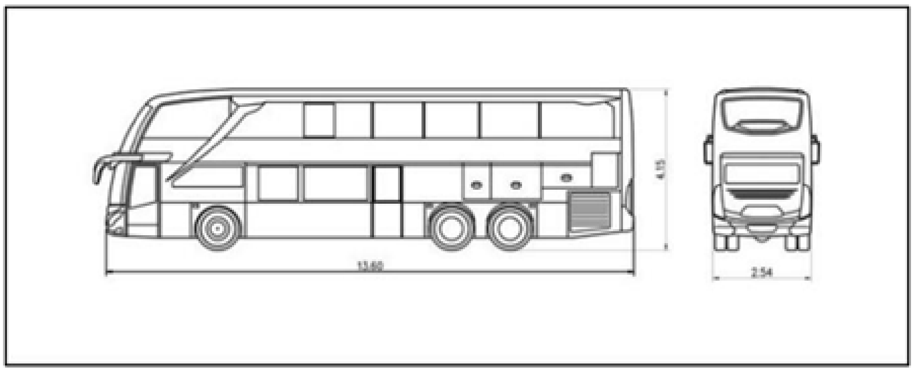


Figure 3. Bus Dimensions

The Scania K 410 bus has an uneven weight distribution across its rear axles, requiring a working load capacity of 18,100 kilograms (Fig. 3). This is one of the specifications that is effectively articulated. The load is allocated according to the bus's actual weight distribution, with 42% on axle 2 (7,602 kg) and 58% on axle 3 (10,498 kg). Portability requirements are critical, given the limited workspace and the need to move the ramp between repair areas.

The Measure phase compiles the technical data that forms the basis for the portable ramp design calculations. The Scania bus specifications show dimensions: length 13.60 meters, width 2.54 meters, and a total weight of 29 tons, with a load of 18,100 kg, distributed to axles 2 and 3 at 42%:58%, in accordance with the actual load distribution between the axles. Each load on the axle is assumed to be evenly distributed between the right and left sides (ratio 50:50), so that each ramp is designed to bear a load of 9,050 kg under maximum loading conditions.

Table 2. Bus Load

Load Condition (kg)	1st axle	2nd axle	3rd axle	Total
Gross vehicle weight GVW	7,000	10,000	12,000	28,000
Chassis Weight	2,036	1,702	5,540	9,278
Chassis with Body (theory)	5,712	7,521	10,580	23,813

The operational parameters that were successfully measured included the workshop working environment conditions, ramp usage frequency, and load characteristics that may occur during operation. This data shows that the ramp will be used with load variations between 70% and 100% of maximum capacity, depending on the type of repair being performed.

3. Analyze (Material Analysis)

After conducting a comprehensive material analysis using the Ashby Material Chart, it was concluded that there are three candidate materials: ASTM A36 Carbon Steel, SS 304 Stainless Steel, and Aluminum 6063, which emerged as the most suitable choices based on the strength-to-weight index. It was concluded that the materials in Table 3 below are the most suitable alternatives.

Table 3. List of Materials

Material	Yield Strength (MPa)	Density (kg/m³)	Index MPa/(kg/m³)
Stainless Steel 304	210	8000	0.02625
ASTM A36	250	7850	0.03185
Steel	250	7850	0.03185

Based on the specified material specifications, a comparison was made using a Fig. 4 to assess the relative performance of each material.

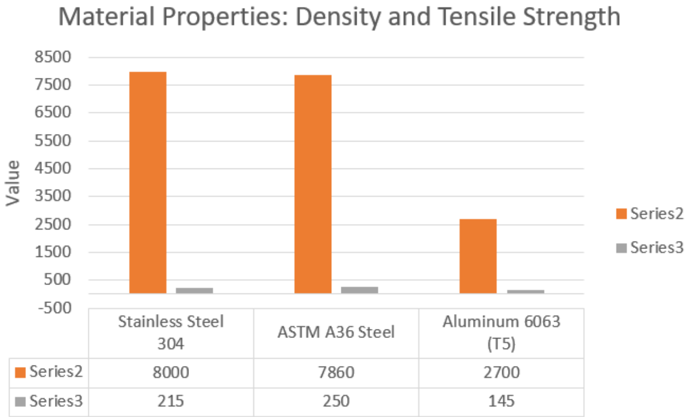


Figure 4. Material Graph

Next, the properties of these materials were entered into SOLIDWORKS Simulation to perform an in-depth numerical analysis of the structure's behavior under the given load.

4. Design (Design Analysis)

a. Geometric Optimization

Based on the results of the material analysis in the Design phase, geometric optimization and material selection were carried out to maximize the performance of the portable ramp. Design modifications included adding reinforcement ribs in critical areas, optimizing material thickness, and integrating safety features.

The final design features an optimized rib configuration for more even stress distribution. The ribs are strategically placed at intervals of 135- 230 mm along the length of the ramp to optimize the strength-to-weight ratio. Material thickness was optimized from 4 mm to 2 mm for selected materials, reducing the ramp's total weight without compromising structural integrity and accounting for market availability (Fig. 5).

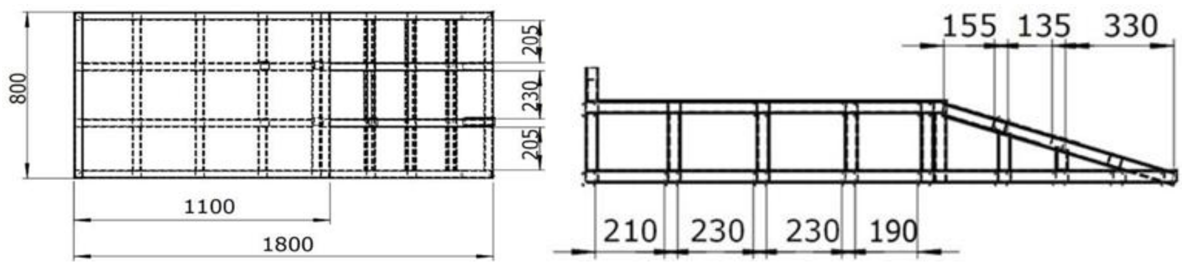


Figure 5. 2D Drawing

Safety barriers (stoppers) are 10 cm high and placed at the front of the ramp to prevent wheels from leaving the ramp area. The stopper design functions as a wheel guide and additional safety feature. The ramp surface features diamond-patterned steel plates to improve traction and prevent slipping in wet or oily conditions. The diamond pattern, with a height of 2 mm, provides optimal grip without damaging vehicle tires.

b. Design Weight Estimate

The portable system is designed with adjustable dimensions to fit in the trunk of a mechanical service vehicle, facilitating mobility and location adjustments to meet bus repair needs. This design aims to improve the efficiency of moving equipment to the repair site, enabling four technicians to move it flexibly. The total weight of the ramp is optimized at 110.019 kg, still within the tolerance limit of ≤ 150 kg specified in the design criteria.

Table 4. Material Weight

Material	Weight (kg)
Carbon Steel ASTM A36	110,019
Stainless Steel SS 304 Material	111,778
Aluminum 6063	49,641

In Table 4, the mass calculations were performed in SolidWorks using the Mass Properties feature. This feature provides complete data on the component's weight and volume. Using the Mass Properties menu, SolidWorks enables accurate calculations of the physical characteristics of 3D components, which are adjusted to the model's material and geometric design. The results shown in this table include the calculated mass values.

c. Production Cost Estimation and Material Calculation

The production cost, the total estimated cost required to manufacture this portable system, is Rp. 2,397,600, which is lower than the predetermined budget of Rp 10 million. This shows that this project can be carried out more efficiently and within the planned budget. Good cost management enables more flexible budget allocation for other project-related needs without exceeding predetermined cost limits.

Table 5. Material Calculation

No	Description	Requirement Stick	Length (m)	Total Length (m)
1	Outer frame	2 x 1.8 m + 2 x 0.8 m	5.2	5.2
2	Center brace	6 bars x 1 m	6.0	6.0
3	Cross transverse	20 bars x 0.8 m	16.0	16.0
4	Slanted support	4 bars x 75 cm	3.0	3.0
5	Vertical reinforcement main	24 bars x 0.17 m	4.08	4.08
6	Vertical inclined reinforcement (17 cm)	4 bars x 11 cm	0.44	0.44
7	Vertical inclined brace (11 cm)	4 bars x 7 cm	0.28	0.28
8	Vertical rod for a stopper	2 rods x 0.10 m	0.2	0.2
Total Length				44.8
Total Number of Bars				8 trunks

Another very important factor in smooth production is the availability of materials. To ensure the production process runs smoothly and on time, the materials used to manufacture this portable system can be readily sourced from the local market. The easy availability of materials provides a major advantage, reducing the potential for delays due to supply issues and associated costs. For transporting materials from outside the area. In addition, stable material availability supports cost efficiency, as there is no need to incur additional costs to procure materials outside the available area.

Table 6. Cost Estimates

No	Material	Estimated Cost (IDR)
1	ASTM A36 Carbon Steel	299,700
2	AISI 304 Stainless Steel	1,572,870
3	Aluminum 6063	1,243,200

The above production cost estimate does not include manufacturing service costs and border plate costs. These two components can be considered optional in budget planning.

Table 7. Estimated Other Costs

No	Work	Price (IDR)
1	Welding and labor	4,000,000
2	Painting & finishing	1,500,000
3	ASTM A36 plate (1.6 mm)	475,000

Bordes plate manufacturing and installation services are required to complete the manufacturing process. However, their use depends on decisions made based on requirements. The cost of these services may vary and is therefore calculated separately as optional in the total cost estimate.

Table 8. Total Cost Estimate

No	Material	Material Cost Estimate (IDR)	Fabrication Cost Estimate (IDR)	Total Estimate (IDR)
1	ASTM A36	3,934,600	5,500,000	9,434,600
2	AISI 304	14,119,960	5,500,000	19,619,960
3	Al 6063	11,482,600	5,500,000	16,982,600

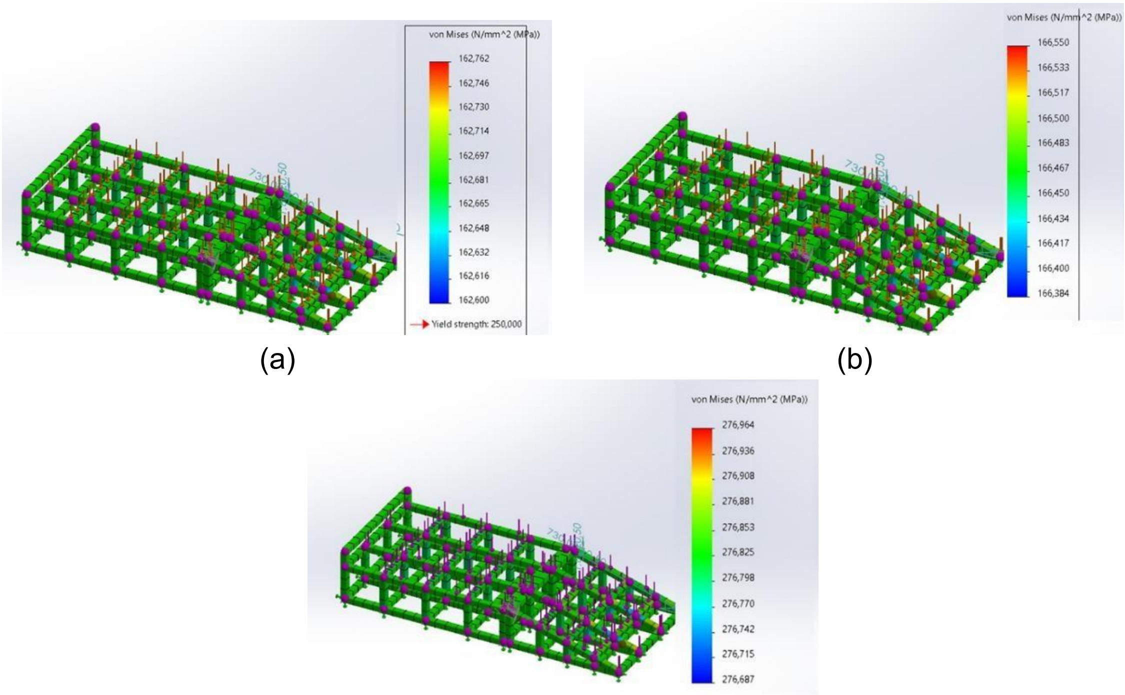
5. Verify

The Verify stage successfully validated the portable ramp design against all technical specifications and safety standards set. The verification process involved FEA simulation using SolidWorks Simulation and validation by industry parties, along with a standards-compliance checklist.

a. FEA Simulation Verification Results

FEA simulation using SolidWorks Simulation successfully validated the structural integrity of the portable ramp with a loading parameter of 88,750 Newtons distributed according to the operational load ratio. The 3D model of the ramp, measuring 180 cm in length, 80 cm in width, and 25 cm in height, is equipped with reinforcing ribs and 10 cm-high safety barriers to prevent wheels from rolling off the ramp.

The FEA simulation results show that the von Mises stress distribution (Fig. 6) is within safe limits for both candidate materials. The maximum stress occurs in the load-concentration area (the point of contact between the wheel and the surface ramp). It is significantly lower than the material's yield limit. For ASTM A36 Carbon Steel, the maximum von Mises stress recorded was 162.762 MPa, well below the 250 MPa limit.



(a) (b)

(c)

Figure 6. Von Mises stress of a) ASTM A36 Steel, b) Stainless Steel SS 304, and c) Aluminum 6063

Table 9. Stress analysis

No	Material	Stress		
		Specification (MPa)	Simulation (MPa)	Conclusion
1	Carbon steel ASTM A36	250	162.762	No plastic deformation occurred, and the material was in a safe condition
2	Stainless steel AISI 304	210	166.550	No plastic deformation occurred, and the material was in a safe condition
3	Aluminum 6063 (T5)	145	276.964	Plastic deformation occurred, and the material was in an unsafe condition

The deformation analysis shows that all material variants meet the maximum deformation criterion of ≤ 5 mm specified in the design standard. Maximum deformation occurs at the middle of the ramp, where the load concentration is highest, with deformation values ranging from 0.474 to 1.37 mm, depending on the material used.

Carbon Steel ASTM A36 exhibits deformation of 0.224 mm, Stainless Steel SS 304 experiences deformation of 0.237 mm. In comparison, Aluminum 6063 shows the largest deformation of 0.657 mm. The deformation pattern indicates a uniform distribution without excessive concentration or excessive deformation at a single point, indicating a stable and safe design.

Table 10. Deformation analysis

No	Material	Deformation		
		Specification (mm)	Simulation (mm)	Conclusion
1	Carbon steel ASTM A36	≤ 5	0.474	Material is safe and not deformed permanently
2	Stainless steel AISI 304	≤ 5	0.5	Material is safe and not deformed permanently
3	Aluminum 6063 (T5)	≤ 5	1.37	Material is safe and not deformed permanently

The safety factor obtained from the FEA simulation meets OSHA standards, with a minimum factor of 3.01. ASTM A36 Carbon Steel material produces a safety factor of 3.49, meeting the minimum standard. SS 304 Stainless Steel shows a safety factor of 3.30, providing a smaller safety margin. Aluminum 6063 has a safety factor of 2.02, which does not meet the minimum standard.

Table 11. Safety factors analysis

No	Material	Safety factors		
		Specification	Simulation	Conclusion
1	Carbon steel ASTM A36	3	3.49	This material is sufficiently safe to withstand loads and has an adequate safety margin.
2	Stainless steel AISI 304	3	3.30	This material is safe for use in applications involving loads slightly below the desired safety margin.
3	Aluminum 6063 (T5)	3	2.02	This material can withstand loads according to its capacity without any safety margin.

Sensitivity testing was conducted by varying the load by ±5% from the nominal value (88,750 Newton):

Table 12. Simulation results varying the load ±5%

No	Load (N)	Von mises stress (MPa)	Deformation (mm)
1	84,312	154.623	0.450
2	88,750	162.762	0.474
3	93,187	170.899	0.498

Deviations in von Mises stress and deformation indicate that the FEA model provides consistent predictions despite varying loads. The simulation shows that the increase in stress and deformation remains within safe limits, consistent with the material's characteristics. This indicates that the FEA model can be relied upon to predict material response to load changes without affecting design stability, and to ensure that the material continues to function properly without excessive deformation.

3.2 Discussion

The portable ramp design is intended to facilitate mobility and location adjustments for bus repairs at the PT. United Tractors Semarang Branch Workshop. This design ensures the ramp system can be loaded into the mechanical service vehicle's trunk, providing flexibility for the efficient movement of equipment by four technicians. Structural safety features, such as safety barriers and anti-slip surfaces, are designed to prevent slips and ensure safety during use. In this design, the maximum load generated by the ramp is 110,019 kg, which still meets the tolerance limit of ≤ 150 kg specified in the design criteria. ISO 12100:2010 is an international standard that outlines design principles for reducing the risk of injury in machinery and equipment. This standard emphasizes the importance of hazard identification, risk assessment, and the implementation of risk control measures in equipment design [10].

To ensure the ramp design can support the bus's weight without excessive deformation or structural failure, a Finite Element Analysis (FEA) was performed. The simulation results show that ASTM A36 Carbon Steel has a Safety Factor (SF) of 3.49, indicating that this material can withstand the applied stress without undergoing plastic deformation. This simulation also shows that the von Mises stress in this material is well below the yield stress limit of 162.762 MPa, compared to the specification limit of 250 MPa, indicating that the material can withstand loads optimally without structural failure. The study used Finite Element Analysis to ensure the ramp could withstand heavy loads without excessive deformation or structural failure. The von Mises stress, deformation, and safety factor values were analyzed and compared with the material's safety limits. As a result, the optimized ramp design met load capacity standards without exceeding material limits [10].

The selection of the right material for ramp fabrication is an important factor in achieving structural strength, weight efficiency, and cost efficiency. Based on analysis using the Ashby Material Chart, ASTM A36 Carbon Steel was selected because it has an optimal strength-to-weight index compared to SS304 Stainless Steel and 6063 (T5) Aluminum. This material is also more affordable and widely available in the local market, enabling quick, efficient procurement. In addition, ASTM A36 Carbon Steel meets the strength, ease of welding, and low cost criteria suitable for this project. The selection of this material ensures that the designed portable ramp has high structural strength and can be produced at an efficient cost. Research shows that stainless steel SS304 offers higher corrosion resistance and strength, but it is significantly more expensive and more difficult to fabricate in large quantities thanarbon steel such as A36 [11].

4. Conclusion

To optimize the design and analysis of the portable ramp, this study provides several relevant conclusions as a reference for further development. Research successfully designed an optimal portable ramp for PT. United Tractors Semarang Branch, weighing 110,019 kg, is easily movable by four technicians and equipped with safety features such as barriers and anti-slip surfaces. It can support an operational bus load of 88,750 N, making it safe for use in various locations. Finite Element Analysis (FEA) simulations show that the ramp design meets safety standards. ASTM A36 material has a maximum stress of 162.762 MPa (below the safe limit of 250 MPa) and deformation of 0.474 mm (within the tolerance of ≤ 5 mm) with a safety factor of 3.49. The ±5% load sensitivity test shows stable results. ASTM A36 Carbon Steel was chosen as the best material because it is strong, economical, and readily available. With an estimated cost of IDR 2,397,600, this material is superior to alternatives such as aluminum, which, despite being lightweight, does not meet safety standards.

Conflict of interest

The authors declare no conflict of interest.

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Design and Development of a Low-Power Motorcycle Camshaft Copying Machine: Feasibility and Accuracy Evaluation

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ABSTRACT

This research aims to design, develop, and evaluate the feasibility and accuracy of a motorcycle camshaft copy machine as an alternative to protect the privacy of modified camshafts from copying or duplication. This research used the ADDIE development model, involving: (1) problem analysis and needs analysis, which then produced a motorcycle camshaft copy machine; (2) the design phase, resulting in a Safety Factor of 1.23 with a load of 22.046 lb force or 10 kg; (3) the development phase, including the process of cutting the frame steel, welding to make the frame, drilling to make holes in the frame steel, assembling the motorcycle camshaft copy machine components, and painting; (4) the implementation phase, consisting of a feasibility test with a result of "very feasible," suggesting that the motorcycle camshaft copy machine can be used in workshops; and (5) the evaluation phase, which resulted in good accuracy of the camshaft copy machine. The results of this study indicate that: (1) the motorcycle camshaft copy machine has dimensions of 60 cm in length, 50 cm in width, and 75 cm in height, weighs 26.5 kg, and has a power of 245 watts. (2) The motorcycle camshaft copy machine is declared "very feasible", with a value of 89.23%. (3) The motorcycle camshaft copy machine has good accuracy with an accuracy of ± 0.13 mm.

1. Introduction

Indonesia has a very high rate of motor vehicle ownership. Based on data from the Indonesian National Police Traffic Corps on August 29, 2024, the number of motorcycles in Indonesia reached 137,350,299 units, with a population of 275 million. This figure shows that more than half of Indonesia's population uses motorcycles as their primary mode of transportation. East Java is recorded as the province with the highest number of motorcycles, followed by DKI Jakarta, Central Java, and West Java [1]. This data reflects the dominance of motorcycles as the most preferred means of transportation in Indonesia.

Technological developments and high demand for motorcycles in Indonesia have encouraged automotive companies to continue competing to deliver innovative technology in their latest products [2]. These innovations aim to offer motorcycles that appeal to consumers, with a focus on fuel efficiency and the lowest possible exhaust emissions. This forces manufacturers to develop more efficient, environmentally friendly engines, even though this often comes at the expense of performance [3]. Therefore, modification has become a common alternative for motorcycle users to increase power.

Modifications are usually made by replacing standard components with aftermarket or other-vehicle components. The area most often modified is the cylinder head component, which has an important role: first, it closes the cylinder block to form a tight combustion chamber and assists in the compression process; second, it houses components such as valves, camshafts, and valve springs; and third, it acts as an inlet for fuel and an outlet for combustion products [4].

The camshaft is one of the components that greatly affect engine performance because it regulates the movement of the intake and exhaust valves and influences the flow of the fuel-air mixture in the combustion chamber [3]. In the world of motorcycle racing, many workshops modify the camshaft to match the track's characteristics and improve engine performance.

Camshaft modifications must be carried out with a high degree of precision in order to meet engine specifications and competition requirements [5]. The main challenge for a workshop duplicating modified camshafts is privacy. Not all workshops or racing teams have direct access to expensive precision machines such as CNC (Computer Numerical Control) machines. Some workshops duplicate modified camshafts at partner workshops or other workshops, which, unfortunately, still offer low privacy protection for those camshafts.

This problem requires the development of a motorcycle camshaft copying machine that meets the needs of workshops and offers the advantages of space efficiency, light weight, and energy efficiency, without sacrificing functionality. A solution is needed through the research and design of a motorcycle camshaft copying machine with more compact dimensions and lower power consumption, to meet the needs of small workshops and medium-sized industries.

2. RESEARCH METHOD

This research uses the ADDIE development model to facilitate the development of the camshaft copying machine. ADDIE consists of five main stages, namely Analysis, Design, Development, Implementation, and Evaluation [6].

2.1 Analysis

The first stage of the ADDIE model, namely needs analysis, involves the researcher conducting a needs analysis through direct observation to determine the requirements for a motorcycle camshaft copying machine to solve existing problems. At this analysis stage, the following needs analysis will be carried out:

2.1.1. Needs analysis

A needs analysis is conducted to determine the requirements for a motorcycle camshaft copy machine.

2.1.2. Analysis of the camshaft copy machine specification plan.

The purpose is to determine the specification plan required to operate the motorcycle camshaft copy machine.

2.2 Design

After conducting a needs analysis for a camshaft copying machine, the next step is to design it in Autodesk Inventor.

2.3 Development

The third process is the development of the motorcycle camshaft copy machine. In this development stage, the first method used is welding to join two pieces of metal to form a strong structure. The second method is grinding, which is used to cut the iron on the camshaft of the copying machine frame. The third method is drilling, which creates holes in the iron so the components of the camshaft copying machine can be bolted together properly.

2.4 Implementation

After realizing the product from a design into a finished product, namely a motorcycle camshaft copy machine, the next step is to test the machine used to assess the feasibility of the motorcycle camshaft copy machine that has been made. By collecting data related to setup time and the accuracy level of the motorcycle camshaft copy machine.

2.5 Evaluation

The fifth stage is the assessment stage, after the assessment process on the motorcycle camshaft copy machine. The research data is analyzed to determine the accuracy and feasibility of the motorcycle camshaft copy machine. Based on the analysis results, it can be concluded whether the motorcycle camshaft copy machine is feasible.

3. Result and Discussion

3.1. Result

3.1.1. Analysis

This stage involves the analysis process and information related to the motorcycle camshaft copy machine. There are two analyses in this stage: problem analysis and needs analysis, which are used to solve problems.

3.1.2. Design

This stage involves designing the motorcycle camshaft copy machine based on the requirements analysis.

a. Camshaft copy machine design

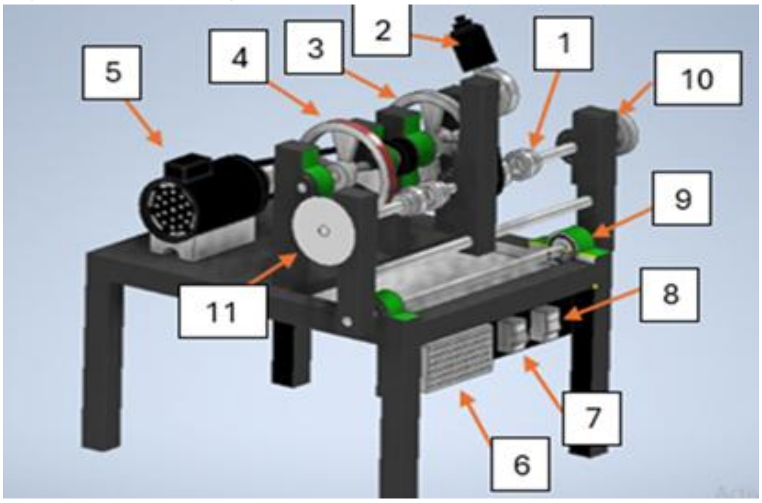

Figure 1. Camshaft Copy Machine Design

1. Clamp
2. Turning machine
3. Master pulley
4. Grinding pulley
5. Grinding machine
6. Power Supply Clamping
7. Machine power button
8. Grinding machine power button
9. Seat bearing
10. Manual clamping pulley
11. Camshaft degree arc

The camshaft copying machine design shown in the figure above has dimensions of 60 cm in length, 50 cm in width, and 75 cm in height. A 125-watt electric motor is mounted on the copying machine's camshaft to rotate the grinding pulley. Then, a 120-watt electric motor is added to rotate the clamp (Fig. 1). The selection of electric motors with these power ratings was made to ensure that the camshaft copying machine has low electrical power consumption.

b. Test results of the motorcycle camshaft copying machine design

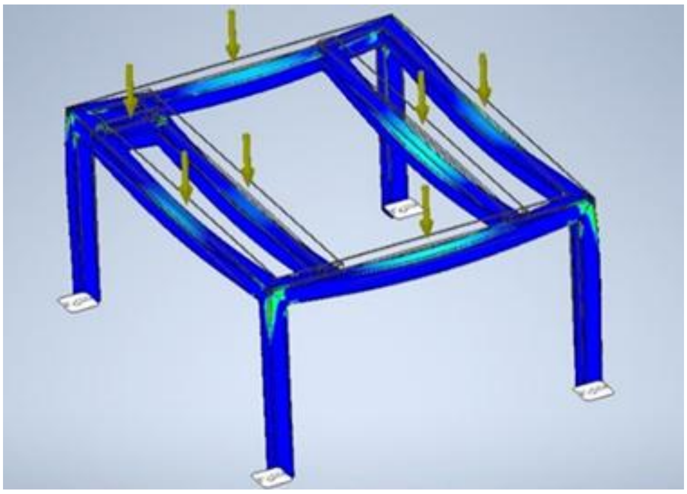

Figure 2. Frame Design Testing of the Camshaft Copying Machine

The safety factor obtained from the simulation results in Autodesk Inventor is 1.23, with a load of 22.046 lb-force (10 kg). This means that the copy camshaft engine frame is above the yield load and is capable of withstanding the permitted load of 10 kg, as can be seen in the Fig. 2, where most parts of the copy camshaft engine frame are blue, meaning that most parts of the copy camshaft engine frame have a safety factor above the permitted load.

3.1.3. Development

The development of the motorcycle camshaft copy machine resulted in specifications that can be seen in the table below:

` **Table 1.** Camshaft Copy Machine Specifications

No	Feature	Description
1	Product	Motorcycle camshaft copying machine
2	Developer	Raynaldi Prima Kurnia Putra
3	Electricity	AC (245 Watts)
4	Dimensions	a. Width: 50 cm b. Length: 60 cm c. Height: 75 cm
5	Total Weight	26.5 kg
6	Electric motor speed	11.2 RPM
7	Grinding pulley RPM	2,767 RPM
8	Key features	a. Adjustable clamping length Camshaft length b. Lighter machine weight c. Compact dimensions d. Lower power consumption

3.1.4. Implementation

a. Feasibility of the motorcycle copy camshaft engine.

Feasibility testing of the motorcycle camshaft copying machine was conducted by users and mechanics who use it. The summary of the feasibility testing results for the motorcycle camshaft copying machine is as follows:

Table 2. Feasibility Results of the Motorcycle Camshaft Copy Machine

	Criteria					
Respondents	Strongly Agree (5)	Agree (4)	Disagree (3)	Don't Agree (2)	Strongly Disagree (1)	Total
1	5	8				13
2	7	6				13
3	6	7				13
Konversi Skor	**90**	**84**				**174**

After the test results are compiled, the next step is to calculate the feasibility percentage using the formula below.

Calculating the maximum score:

$$Eligibility = \frac{Obtained\ score}{max\ score} \times 100\%$$

Notes:

Feasibility = Feasibility value in percentage (%)

Maximum score = (number of questions) x (maximum score) x (number of respondents)

$$Eligibility\ (\%) \frac{174}{13 \times 5 \times 3} \times 100\%$$
$$Eligibility\ (\%) \frac{174}{195} \times 100\%$$
$$Eligibility\ (\%) = 0{,}8923 \times 100\%$$
$$Eligibility\ (\%) = 89{,}23\%$$

The eligibility calculation result for the motorcycle camshaft copy machine is 89.23%

b. Accuracy of motorcycle camshaft copying machines.

Table 3. Camshaft Accuracy 1

Parameter	Degree		Accuracy (mm)
Camshaft 1	**0-45**	IN	0.07
		EX	0.01
	46-90	IN	0.12
		EX	0.02
	91-135	IN	0.13
		EX	0.02
	136-180	IN	0.12
		EX	0.11
	181-225	IN	0.09
		EX	0.09
	226-270	IN	0.04
		EX	0.09
	271-315	IN	0.01
		EX	0.09
	316-360	IN	0.01
		EX	0.01

Table 4. Camshaft Accuracy 2

Parameter	Degree		Accuracy (mm)
Camshaft 2	**0-45**	IN	0.06
		EX	0.02
	46-90	IN	0.09
		EX	0.02
	91-135	IN	0.1
		EX	0.01
	136-180	IN	0.08
		EX	0.1
	181-225	IN	0.07
		EX	0.11
	226-270	IN	0.01
		EX	0.08
	271-315	IN	0.01
		EX	0.08
	316-360	IN	0
		EX	0

Table 5. Camshaft Accuracy 3

Parameter	Degree		Accuracy (mm)
Camshaft 3	**0-45**	IN	0.06
		EX	0.01
	46-90	IN	0.09
		EX	0.02
	91-135	IN	0.08
		EX	0.02
	136-180	IN	0.06
		EX	0.12
	181-225	IN	0.07
		EX	0.07
	226-270	IN	0.04
		EX	0.06
	271-315	IN	0.01
		EX	0.07
	316-360	IN	0.01
		EX	0.01

c. Time analysis

This stage involves taking data three times, followed by calculating the average time for the camshaft copying process. Below is a summary table of the camshaft copying process time:

Table 6. Recap of Camshaft Copy Process Time

No	Parameter	Setup Time (minutes)	Camshaft Copy Processing Time (minutes) - Stage 1	Camshaft Copy Processing Time (minutes) - Stage 2	Total (minutes)
1	Camshaft 1	13.47	34.43	38.20	86.1
2	Camshaft 2	15.28	37.50	41.40	94.18
3	Camshaft 3	14.12	33.51	39.55	87.18

Notes:
1. Camshaft 1: the first camshaft copy result
2. Camshaft 2: the second camshaft copy result
3. Camshaft 3: the third camshaft copy result

Once the time is known, the average calculation process for the camshaft copy process is carried out using the formula below:

$$\underline{T} = \frac{T_1 + T_2 + T_3}{3}$$

Explanation:
T1, T2, T3: represent the times of the first, second, and third tests.

$$\underline{T} = \frac{86{,}1 + 94{,}18 + 87{,}18}{3} = 89{,}15$$

Based on the above calculation, the average time for the motorcycle camshaft copying process is 89.15 minutes.

3.2. Discussion

3.2.1. Development of the motorcycle camshaft copying machine.

The process of manufacturing a motorcycle camshaft copying machine was developed through the ADDIE stages (analysis, design, development, implementation, and evaluation). The first step in the ADDIE stage is analysis, which identifies problems in motorcycle camshaft copying machines and helps find the right solution. The results of the needs analysis form the basis for designing the motorcycle camshaft copy machine. This finding aligns with the literature, which states that tools are developed based on their needs and limitations of use. Sudheer & Reddy state that good design is not only about technology, but also how technology integrates with needs and usage [7]. Designing a motorcycle camshaft copy machine according to needs is not only technically efficient.

The second step in the ADDIE model is design, which is carried out using Autodesk Inventor. The design stage has produced a motorcycle camshaft copy machine design that meets the needs identified in the analysis stage. The motorcycle camshaft copy machine design needs to undergo a frame-strength test to ensure the frame can properly support the camshaft copy machine. The strength test results from the Autodesk Inventor application, using stress analysis simulation, focused on the safety factor. The safety factor obtained from the simulation in Autodesk Inventor was 1.23, with a load of 22.046 lb-force (10 kg). This means that the copy camshaft engine frame is above the yield load and can withstand the permissible load of 10 kg. This is in line with the research by Toding Bunga, which states that a value above 1 is safe for static loads [8].

The third step of the ADDIE stage is development, which covers the process of cutting the iron frame, welding the frame, drilling holes in the iron frame, assembling the components of the motorcycle camshaft copy machine, and painting the motorcycle camshaft copy machine. This stage ultimately produces a complete copy of the camshaft. The fourth step is implementation, the process of copying motorcycle camshafts using a camshaft copying machine. This process produces copies of camshafts intended to be close in size to the originals.

The design of the motorcycle camshaft copy machine produces a machine capable of copying camshafts. This camshaft copy machine requires 245 watts of AC power, making it suitable for use in small workshops and medium-sized industries with low power capacity. This supports the research by Rahman, which states that small-scale workshops have relatively low electrical power, namely 400-900 watts [9].

The motorcycle camshaft copying machine has dimensions of 50 cm wide, 60 cm long, and 75 cm high. The weight of this motorcycle camshaft copying machine is 26.5 kg, and the RPM of the copying process is 2,767 RPM for grinding and 11.2 RPM for clamping rotation. The advantages of this motorcycle camshaft copying machine are that the clamping length can be adjusted to fit the camshaft shaft, it has compact dimensions, it is lighter than other camshaft copying machines on the market, and it requires less electrical power to operate.

3.2.2. The suitability of the motorcycle camshaft copy machine.

The feasibility validation test conducted by mechanics or users involving three respondents examined several aspects, including ease of operation, ease of storage, visual appeal, suitability for workshop needs, and safety. Based on testing conducted using Google Forms as the validation tool, a score of 89.23% was obtained. Based on this score, the motorcycle camshaft copy machine falls into the "Highly Suitable" category. This is in line with Yanthi's research, which states that a validation success rate of 81%-100% falls into the highly suitable category [10].

3.2.3. Product accuracy of the motorcycle camshaft performance.

Accuracy copying level machine testing was conducted to determine the precision level of the motorcycle camshaft copy machine. The testing was conducted three times on three different camshafts, after which the measurement process was carried out using a dial gauge and a protractor at 45-degree intervals. After the measurement was completed, the calculation was performed to find the largest difference between the copied camshaft and the original camshaft.

This motorcycle camshaft copying machine had the largest difference of ± 0.13 in the first camshaft test. The value of ±0.13 was due to significant changes in the profile shape during the camshaft copying process. This supports the findings of Girawan in their study on "the design and performance testing of a duplicate camshaft grinding machine for motorcycle racing applications" that the highest value in camshaft testing can occur when the camshaft copying process involves significant profile changes but is not followed by a reduction in engine speed, resulting in a significant deviation [11].

4. Conclusion

The design and fabrication of the Motorcycle Camshaft Copying Machine was successful, resulting in a device optimized explicitly for small workshops and medium-sized industries. The final unit is compact and energy-efficient, weighing 26.5 kg, measuring 60 cm (W) x 50 cm (L) x 75 cm (H), and requiring only 245 watts of AC power. In terms of performance, the machine has proven to be highly viable and precise. Feasibility testing yielded a suitability rating of 89.23%, indicating the device is "highly suitable" for practical application. Operational tests confirmed the machine's capability to produce high-quality components with a precision accuracy of ± 0.13 mm. Furthermore, the machine balances precision with efficiency, achieving an average copying process time of 89.15 minutes.

Conflict of interest

The authors declare no conflict of interest.

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Design and Experimental Evaluation of a Light Cut-off (Baffle) Plate for Aftermarket LED Motorcycle Headlamps

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ABSTRACT

This study aims to determine the impact of replacing halogen lights with LED lights on two-wheeled vehicles, focusing on energy efficiency, light brightness levels, and operational temperatures of the lights to support road safety in areas with minimal road lighting, as well as on adjusting the light distribution of the applied LED lights. The method used was an experiment conducted on variables for which data were unavailable, necessitating manipulation of the research object. The experiment was conducted using a Honda Supra 125 FI motorcycle, with measurements of light intensity (lux), power consumption (watts), battery current (V), electric current (A), and operating temperature (°C). The known impact became a reference for regulating LED light distribution. The test shows that applying a barrier plate design to LED lights can provide focused lighting through its light distribution patterns. The application of the baffle plate design to LED lights provided focused lighting through its light distribution patterns. The use of LED lights provided a slightly higher intensity (6.4%) and an energy consumption efficiency 60% higher, with a reduction in operating temperature of 64%. The application results show that the light control plate successfully forms a bright-dark cut-off, with a uniform light distribution and consistent light intensity of 1854 lux. This indicates that the tested LED lamp maintains stable lighting performance without a decrease in brightness.

1. Introduction

Motorcycles are the most widely used means of transportation in Indonesia due to their efficiency in daily mobility. Based on data from the Indonesian Motorcycle Industry Association (AISI), national motorcycle sales reached more than 5 million units in 2023, far exceeding car sales of about 1 million units. In rural areas such as Gunungkidul Regency, Special Region of Yogyakarta, motorcycles are the primary mode of transportation for the community due to limited public transportation and varied road conditions. Data from the Gunungkidul Central Statistics Agency shows that more than 40% of households own at least one motorcycle, totaling 324,494 vehicles out of a population of 776,580. This high number makes motorcycles not only a means of transportation but also an important part of rural communities' social and economic activities.

In the context of driving safety, the lighting system plays a vital role because it serves not only as an illuminant but also as a medium of visual communication between road users. Previous studies have shown that light-emitting diode (LED) technology has been increasingly applied in various transportation lighting systems due to its potential to improve electrical efficiency compared to conventional lamps. Research on runway and airfield lighting systems indicates that LED lamps can reduce electrical power consumption while maintaining adequate illumination levels for safety applications [1], [2]. According to Rizki et al. [3], an optimal lighting system, including the use of stabilizer technology, can improve visibility and reduce light glare for other drivers, thereby increasing safety. This condition is critical in areas with minimal public street lighting, such as Gunungkidul, where drivers depend entirely on vehicle headlights for nighttime visibility. In areas with hilly topography and inadequate road access, such as Gunungkidul, a good lighting system is a necessity that cannot be ignored [4]. The limited availability of public street lighting facilities exacerbates the risk of accidents. The Jogja Daily Report states that the South Cross Road (JJLS) in Gunungkidul requires an additional 4,000 street lights to meet lighting needs. As a result, drivers must rely on motorcycle headlights with a limited light range. In such situations, a well-designed lighting system is crucial to reducing traffic accident rates.

Along with the development of automotive technology, vehicle lighting systems have also evolved, from incandescent, halogen, and HID lights to LEDs (Light Emitting Diodes). Halogen lights, which have been in use since the 1970s, are inefficient and have a short lifespan. In contrast, LED lights offer advantages in light intensity, energy efficiency, and lifespan. Previous studies have reported that the operational lifespan of LED lamps is influenced by their switching characteristics and operating conditions, indicating more stable long-term performance compared to conventional lighting technologies [5]. According to Vorlane (2023), LED lights can operate for 15,000-50,000 hours, far exceeding the 500-1,000 hours of halogen lights. However, using aftermarket LEDs is not always optimal due to differences in design and light beam direction, which can affect light distribution. Previous research has shown that the application of control systems in LED matrix headlamps can improve light beam direction and distribution, thereby enhancing visibility while reducing glare [6]. If the lighting is not focused, the driver's visibility will be reduced, potentially causing accidents. Data from Kompasiana shows that nighttime accidents account for up to 70% of all fatal accidents, with 80% involving dark-colored vehicles or insufficient lighting.

Thus, an effective and targeted lighting system is a key factor in supporting driver safety. The use of LED lights as a replacement for halogen lights is increasingly popular due to their ability to produce brighter light and save energy. However, additional designs, such as light diffusion plates, are needed to direct the spotlight in accordance with safety standards and to avoid disturbing other drivers. Several recent studies have evaluated the performance of different headlamp technologies, including halogen and LED lamps, under various operating conditions, emphasizing the importance of light distribution control and thermal considerations in practical applications [7]. Based on this background, the researchers sought to establish a solid foundation for identifying problems and formulating appropriate solutions to improve traffic safety. In motorcycle electrical systems, the stability of voltage and current supply affects the performance and reliability of lighting components. Studies have reported that improvements in charging systems and the use of stabilizer technologies can enhance electrical stability, thereby supporting more consistent lamp operation [8].

2. Methodology

2.1 Research Method.

This research method uses an experimental approach, which involves manipulating variables for which data do not yet exist by applying treatments to the research object, which is then observed and measured for its impact. According to Akbar & Saragi [9], the experimental method is important in research because it can show a direct cause-and-effect relationship through the manipulation and control of variables. In this study, a series of modifications were made to the main headlights of motorcycles. The main objective of this study was to analyze and understand the impact of these changes, particularly on the headlights (main lights). These changes were made by comparing the light distribution, energy consumption, and temperature of LED and halogen lights.

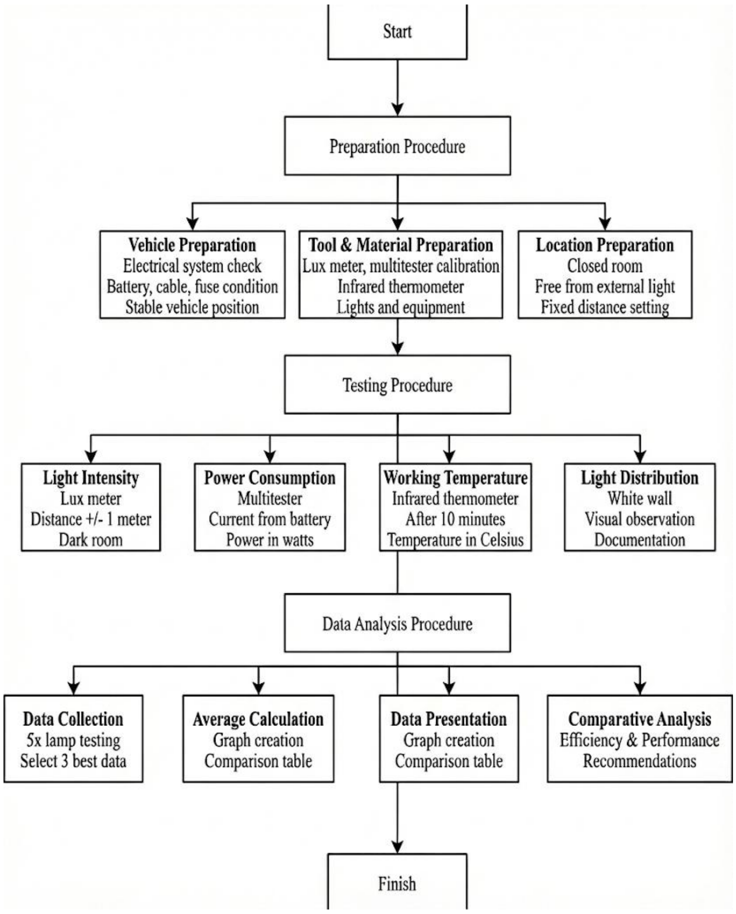


Figure 1. Research Procedure

2.2 Research Time and Place

The research was conducted at Mas Bagio's workshop, located at Keruk 4, Banjarejo Tanjungsari. The research was conducted from April to July 2025.

2.3 Research Subject

The subjects used in this study were Honda Supra 125 FI motorcycles, standard halogen lights, aftermarket LED lights, and LED lights with modified reflectors.

2.4 Technique, Data Collection Instruments, and Product Testing

Data collection techniques in this study were carried out by filling out measurement result tables according to the designed procedures. Data collection included measurements of light intensity (lux), power consumption (watts), lamp operating temperature (°C), and visual observations of light distribution. The data were then averaged to yield more objective and significant results.

Table 1. Data Collection

No	Type of Data	Instrument	Description
1	Light Distribution	White screen, Camera	To see the distribution pattern
2	Light Intensity	Digital Lux Meter	Distance 1 m, in a dark room
3	Power Consumption	Digital Multitester	Current from the motorcycle battery
4	Surface Temperature	Thermometer	15-minute measurement

2.5 Data Analysis Technique

Data analysis techniques in this study were carried out based on predetermined procedures. The data analyzed were the results of measurements of three main variables, namely light intensity (lux), power consumption (watts), and lamp operating temperature (°C). The processed data were then presented as comparisons between the types of lamps tested, namely standard halogen lamps and aftermarket LED lamps. Researchers were able to visually and systematically observe the performance patterns of each lamp type, resulting in an analysis that was more accurate, objective, and scientifically accountable.

3. Result and Discussion

3.1 Results

3.1.1 Light Distribution

The results show that LED lights have higher light intensity than halogen lights at the same distance. LED lights provide better illumination on the road, thereby improving driving visibility.

Table 2. Lux Meter Testing

No	Light Type	Distance	Lux
1	Halogen	1 Meter	1775 lux
2	LED	1 Meter	1854 lux

3.1.2 Power Consumption

Halogen lamps have very high power consumption, namely 101.16 watts and 145.2 watts. Meanwhile, LED lamps have much lower power consumption, namely 12 watts and 24 watts, indicating that LEDs are much more energy efficient than halogen lamps.

Table 3. Power Consumption Testing

Object	Volt	Amperes	Consumption
Halogen 1 lamp	12 V	8.43 A	101.16 W
Halogen 2 lamp		13.2 A	145.2 W
LED 1 lamp	12 V	1 A	12 W
LED 2 lamp		2 A	24 W

3.1.3 Temperature Results

Data were collected every 15 minutes up to the 75th minute, for a total of 6 observation points. Temperature measurements were taken with a digital thermometer, and power consumption was measured according to the lamp specifications. The LED lamp consumes 12 watts, demonstrating its efficiency and stability despite increased temperature.

Table 4. Temperature Testing

No	Time (Minutes)	Lamp Surface Temperature
1	0	0 °C
2	15	60 °C
3	30	83 °C
4	45	96 °C
5	60	100 °C
6	75	100 °C

3.1.4 Energy Efficiency Results

Overall, replacing halogen lamps with LED lamps shows a very high increase in energy efficiency. LED lamps can produce a slightly higher light intensity of 6.14% and consume about 60% less power than halogen lamps.

Table 5. Energy Efficiency Testing

Aspect	Halogen	LED	Efficiency (%)
Distribution	1775 lux	1884 lux	6.14
Energy Consumption	35 W	12 W	60

3.1.5 Adjusting the Height of the Light Beam on the Motor

Based on the LED light source being 1 meter above the road surface, and given a height of 7 meters due to space limitations, the concept of a straight line equation or a right triangle was used. The measurement results obtained a value of 0.825 meters from the road surface at a distance of 7 meters.

3.1.6 Light Barrier Design

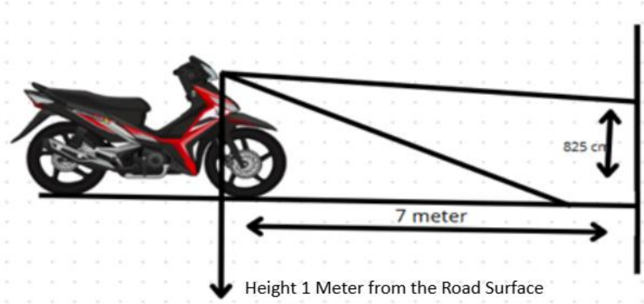


Figure 2. Adjusting the Height of the Spotlight

Adjusting the height of the spotlight, the application of LED lights requires an additional component in the form of a plate to regulate the lighting from the LED. The main objective is to create a clear lighting boundary so that the light is focused on the road surface and does not dazzle oncoming drivers. This plate is positioned so that it covers part of the LED surface and prevents light from spreading directly to the top of the reflector. Using this plate, only light directed downward toward the reflector is emitted, according to the lighting pattern. The following image shows the plate design for controlling the lighting.

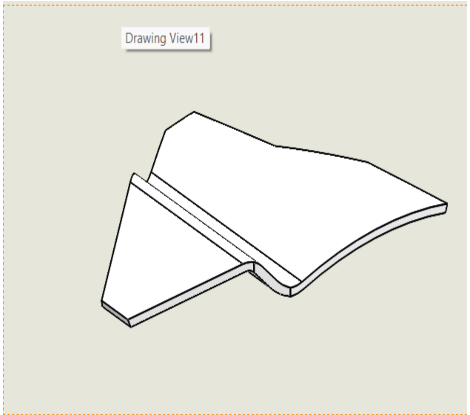


Figure 3. Light Limiting Plate Design

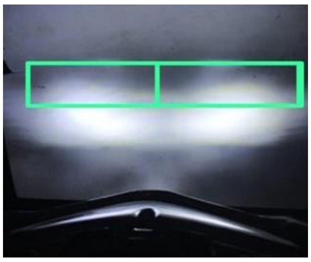
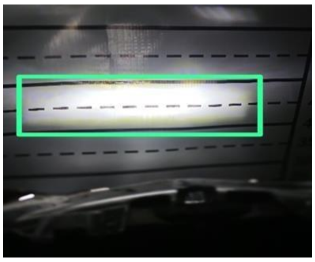
The light-limiting plate design consists of a large folded horizontally. The dimensions indicate that the plate is precisely designed to follow the shape inside the reflector housing.

a. Total height of the plate: ± 5.5 cm
b. Lower width: 2.5 cm – 2.5 cm (for the sloped side following the reflector's posture).
c. 1 cm horizontal fold: used as the mounting section to the reflector's inner bracket

3.1.7 Application of the Plate Design to the Reflector

The limiting plate is mounted on the reflector side near the light source to form the desired light-cutting or light-blocking surface.

Table 6. Light Pattern Produced

Light Distribution Pattern	
Before Limiting	After Limiting
	

After installing the light barrier plate, the light pattern becomes more focused and directed. The result shows a more even horizontal light distribution and a clearer cut-off line (light boundary line). The light no longer spreads freely upwards, thereby minimizing the potential for glare to drivers coming from the opposite direction.

3.2 Discussion

Test results for Halogen and LED lights were conducted to determine light intensity, power consumption, operating time without recharging, and operating temperature for each light. The objective was to determine the type of light that is safe to use, especially in electrical systems with limited power sources, such as a 12-volt 3-ampere battery.

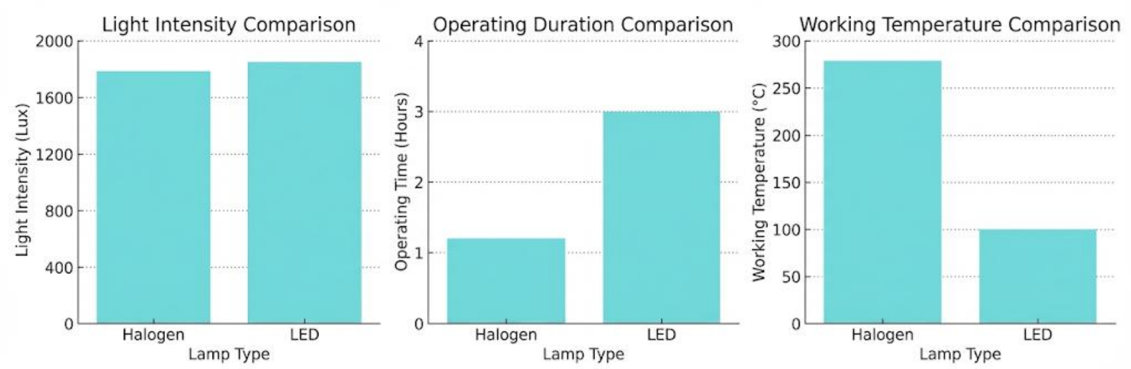


Figure 4. Test Graph

Test results show that halogen lamps have a light intensity of 1775 lux. Meanwhile, LEDs show an intensity of 1854 lux. Despite using less power, both LED lamps can produce higher illumination. This shows that LED lamps provide higher illumination than halogen lamps. LED lamps are more durable than halogen lamps. Halogen lamps last about 1.2 hours, while LEDs can last up to 3 hours without recharging. This shows that LEDs have 60% better energy efficiency, resulting in more efficient use of battery power. This supports the literature that LEDs are more energy-efficient and reduce heat load compared to halogens, which generate higher heat and consume more power [10]. Thus, LEDs are more advantageous in terms of operational duration and power savings.

Halogen lamps have a very high operating temperature of 278°C, while LEDs only reach 100°C. The high temperatures of halogen lamps can damage surrounding components, especially the built-in plastic reflector, which has a low melting point. On the other hand, LED lights are 64% safer because they generate less heat, thereby minimizing the risk of damage to the reflector. As discussed in the literature, LEDs face significant thermal challenges. However, with proper design and an appropriate cooling system, or by imposinghysical limits, temperatures can be controlled below hazardous levels [10].

4. Conclusion

The results of this study show that LED lights in motorcycle lighting systems provide better lighting performance and energy efficiency than halogen lights. The highest light intensity was measured with LED lights at 1854 lux, higher than halogen lights at 1775 lux, indicating that LED lights provide better visibility, especially in low-light conditions. In terms of power consumption, LED lights are highly energy-efficient, with 12 watts (one light) and 24 watts (two lights), which is much lower than halogen lights, which require 101.16 watts and 145.2 watts, respectively. Thus, LED lights have up to 60% higher energy efficiency and 6.4% greater light output than halogen lights. The application of a light diffusion limiter plate in the LED lighting system has been proven to produce a more focused lighting pattern with a clear cut-off, as well as a stable light distribution of 1854 lux without any decrease in intensity. Overall, it can be concluded that LED lights with a light-diffusion limiter plate design provide brighter lighting, higher energy efficiency, and lower operating temperatures, making them a safer, more efficient, and more energy-friendly choice than conventional halogen lighting systems.

Conflict of interest

The authors declare no conflict of interest.

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Design of an Electronic Control System for Automating the GMAW Welding Process

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ABSTRACT

This study aims to design and implement an electronic control system to automate the GMAW welding process, focusing on precise regulation of travel speed and travel length to improve repeatability, safety, and weld consistency. The methodology is organized into four stages: (1) needs analysis to define functional requirements, user constraints, and operating ranges; (2) system design covering hardware architecture, sensor and actuator selection, and embedded control logic; (3) implementation through microcontroller-based integration of a motion drive, user interface, and parameter-setting features; and (4) testing to verify accuracy, stability, and performance under realistic operating conditions. The results demonstrate that the system regulates welding speed with an accuracy of 92.54%–99.44%, while maintaining a maximum time standard deviation of 0.038 seconds, indicating stable motion over repeated trials. For welding length control, the system achieves an average absolute error of 0.35–0.5 mm, a percentage error of 0.17%–0.7%, and a standard deviation of 0.051 mm or less, supporting consistent endpoint positioning. In real-world welding tests, the actual weld length deviation ranges from 0.20 to 1.71 mm. It remains within ISO 13920 Class D tolerance limits, confirming practical applicability for general fabrication. The developed controller enables precise parameter control over a speed range of 100–800 mm/min and a length range of 50–300 mm, reducing the need for direct operator intervention and limiting human-induced variability. Overall, the system supports safer, more consistent welding operations and provides a scalable platform for integrating additional monitoring or adaptive control functions. Suitable for training, prototyping, and routine production trials. Future work will address adaptive control diagnostics.

1. Introduction

The fourth industrial revolution (Industry 4.0) is driving automation across various industrial sectors, including manufacturing, to improve production efficiency and quality [1], 2]. Automation is a technology that uses mechanical, electronic, and computer systems to replace human work [3][4]. Data from the Indonesian Ministry of Manpower shows that the manufacturing sector has the highest automation potential at 65%, including the welding industry. Gas Metal Arc Welding (GMAW) is one of the most widely used welding processes in industry due to its practicality and high-quality [5].

However, according to the American Society of Mechanical Engineers, manual welding still faces challenges, including welding defects. The two biggest factors are suboptimal welding processes (41%) and operator error (32%) [6]. The main causes of welding defects are shown in Table 1 below.

Table 1. Factors causing welding defects

No	Factors Causing Welding Defects	Percentage (%)
1	Suboptimal process	41
2	Operator error	32
3	Inappropriate methods	12
4	Incorrect selection of additives	10
5	Poor weld groove shape	5

(Source: American Society of Mechanical Engineers, 2001)

Based on these issues, it is necessary to optimize the welding process and reduce operator errors by mechanizing it and adding process parameters that can be set consistently. This is important because some parameters, such as current, voltage, and gas flow, can be controlled electronically. In contrast, welding speed (travel speed) is highly dependent on operator skill, making it prone to inconsistency [7].

In addition to technical factors, manual welding also poses health risks, particularly eye damage from exposure to UV radiation from the welding arc. Surveys show that most welders have experienced eye damage despite using protective equipment [8]. Based on these issues, there is a need for an automated GMAW welding system that can consistently regulate welding speed and length and reduce direct operator involvement. The purpose of this study is to design an electronic control system for GMAW welding that can regulate the direction of movement, speed, and weld length in response to desired inputs, thereby improving weld quality and reducing operator health risks.

2. Methodology

This research uses a design methodology with a process flow as shown in Fig. 1.

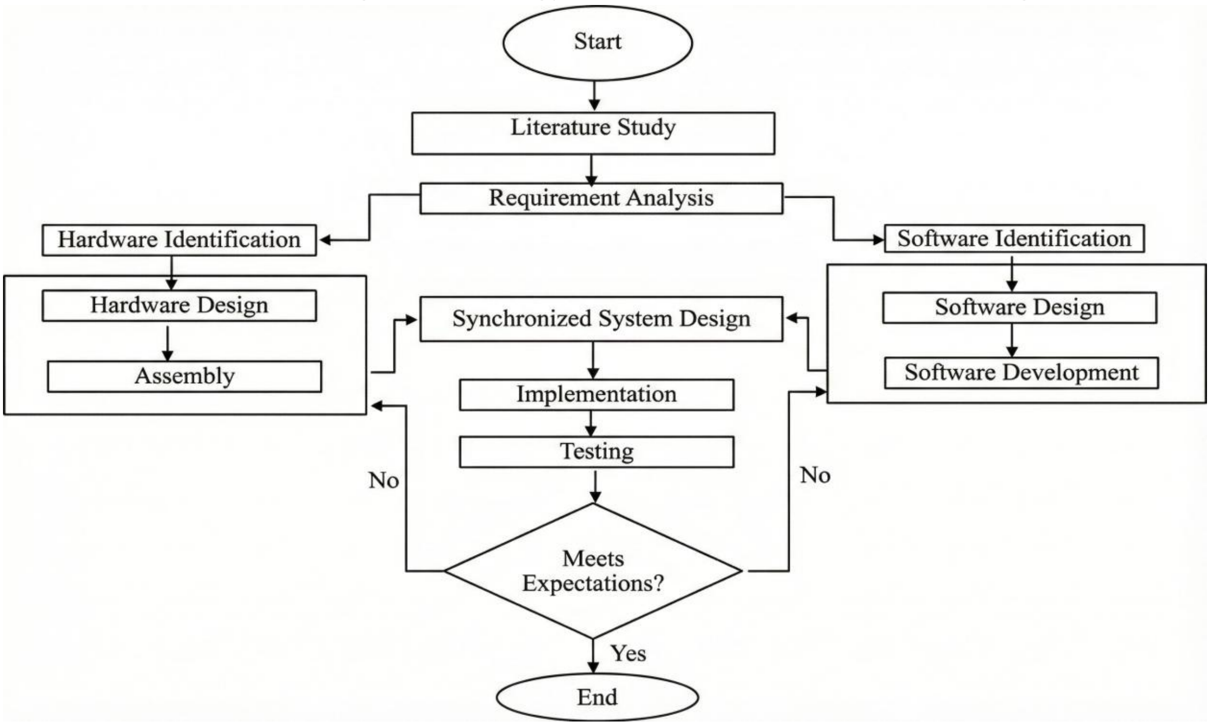

Figure 1. Product Design Flowchart

First, a literature review was conducted to gather existing information from various sources, including books, scientific journals, research articles, technical reports, and other relevant documents, with the aim of understanding the theoretical basis, concepts, and previous findings related to the research topic. Next, a needs analysis was conducted, and the tools and materials needed to design and realize the product were identified. The next stage included product design, implementation, and testing. Testing was carried out by collecting actual data and comparing it with the expected data. If the actual data matched expectations, the next step was to discuss and analyze the results. However, if the actual data did not match expectations, the software and hardware would be recalibrated.

3. Result and Discussion

This chapter on results and discussion presents the results of functional, performance, and welding tests of the electronic control system developed.

3.1 Design of the Electronic Control System Box

The construction of the control system box or casing is in accordance with the design concept described. The control system designed is shown in Fig. 2.

Figure 2. Electronic Control System Box

After all components were assembled in the control box, the next step was to create and input the instruction program into the Arduino Nano to conduct functional testing and determine whether the system ran according to the instructions.

3.2 Functional Testing

Based on the functional testing of the electronic control system for GMAW welding automation, all designed components and software functioned as expected. This test focused on verifying the basic functions of the system, including the user interface, stepper motor, relay as a substitute for the trigger switch on the welding rod, limit switch, and LCD. Based on the test results, the system has met the functional criteria specified in the system work diagram.

In the user interface test, the LCD functioned properly, displaying the necessary information, including system status, welding parameters, and navigation menus. The clarity and consistency of the words displayed on the LCD indicate that the user interface is well designed and easy for operators to understand. This shows that the system can provide accurate, relevant information to users, thereby facilitating the operation and monitoring of the welding process.

In addition to the LCD, user interface input components such as the left, right, and back buttons, as well as the rotary encoder for scrolling and entering, also functioned properly. This proves that the interface design meets user needs and provides accurate responses to user inputs. These buttons consistently control menu navigation and parameter settings, while the rotary encoder facilitates precise selection and confirmation of options. The combination of an informative LCD and responsive input components demonstrates that the user interface is ergonomically and intuitively designed.

Stepper motor testing shows that the motor can rotate clockwise (CW) and counterclockwise (CCW) in response to the button input. This proves that the control system can precisely control the stepper motor, a key component of this electronic control system.

3.3 Performance Testing

3.3.1 Accuracy and Precision of Travel Speed Parameters

Testing the performance of variable-speed control systems for GMAW (Gas Metal Arc Welding) process automation assesses the system's ability to follow a predetermined input speed. In this test, the theoretical time is calculated from the input speed and travel length, then compared with the actual time measured by the moving system.

Based on the test data, the average error percentage ranged from 0.56% to 7.46%, with the error increasing as the input speed increased. Using this average error value, the system's accuracy can be calculated by subtracting it from 100%. Thus, the system's accuracy ranges from 99.44% at 100 mm/min to 92.54% at 800 mm/min.

The graph of the error test results at various input speeds is shown in Fig. 3, which indicates that the error increases with increasing speed.

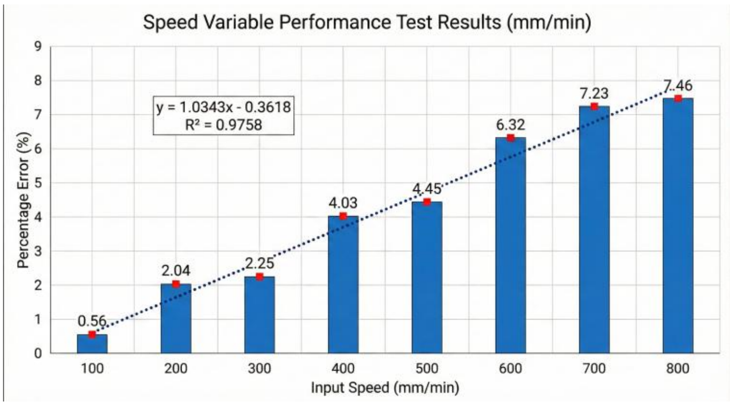

Figure 3. Graph of Error Test Results at Various Speed Inputs

The graph above also shows the linear regression equation $y = 1.0343x - 0.3618$. The regression results indicate a positive linear relationship between input speed and error, with a coefficient of determination (R^2) of 0.985, indicating that the regression model explains approximately 98.5% of the data variability. This indicates that higher input speed is associated with greater error.

This phenomenon can be caused by various factors, including limitations of the microcontroller used in the system, namely the Arduino Nano [9]. The Arduino Nano has limitations in processing speed and time resolution, so the higher the speed set, the more difficult it is for the system to maintain movement stability. In addition, mechanical factors, such as friction in the welding holder and actuator response delays, also contribute to increased errors at high speeds. The accuracy of this test is also an important factor in assessing the system's reliability. In this test, a time resolution of up to microseconds has been used to ensure that the difference between theoretical and actual times can be measured with high accuracy.

In addition to accuracy, the system's precision was analyzed using standard deviation. The standard deviation in this test indicates how consistently the system maintains the set input speed. From the graph in Fig. 4, the combined standard deviation per input ranges from 0.015 to 0.038, as indicated by the red dots. The relatively small standard deviation values indicate that, despite errors in accuracy, the system still has a good level of precision, as the variation between experiments is relatively small. In other words, the system may not consistently achieve the desired speed absolutely, but the deviation remains consistent.

In this test, researchers used a manual stopwatch to record the system's travel time over a certain distance. However, manual recording can lead to potential errors due to delayed responses when stopping the stopwatch. Human hands cannot always stop time exactly when the motor stops. This can lead to additional deviations in the data and contribute to the measured error rate.

Overall, this control system has fairly good accuracy and precision in tracking the input speed, though error increases at high speeds. The average accuracy is still above 90%, and the standard deviation is small. The main factors influencing the error are the control system's limitations, variations in motor performance, and limitations of the manual testing method.

3.3.2 Accuracy and Precision of Travel Length Parameters

In this test, the operator-entered length is compared with the actual length of the moving system from point 0 to the stop. Based on the test results, the average absolute error increased from 0.35 mm at a length of 50 mm to 0.5 mm at a length of 300 mm. However, the percentage error actually decreased from 0.7% to 0.17%. This shows that even though the absolute error increased, the error proportion relative to the input length decreased.

Errors in the test results can be caused by several technical factors related to the linear motion mechanism and control system. One of the main causes is backlash on the leadscrew, which is the gap or slack between the leadscrew thread and the nut that can cause inaccuracy in the system's movement. This backlash occurs due to mechanical wear or manufacturing tolerances in the leadscrew and nut components, so that when the system changes direction, there is a delay before the actual movement occurs. In addition, operators who perform measurements can contribute to errors due to variations in measurement techniques or subjective interpretation of results. Thus, the errors observed during testing are not only due to the electronic control system itself but also to mechanical factors and human error in the measurement process.

The test results graph shows the linear regression equation y = 0.0321x – 0.33083. The gradient of 0.0321 indicates that for every 1 mm increase in input length, the actual length increases by approximately 0.0321 mm.

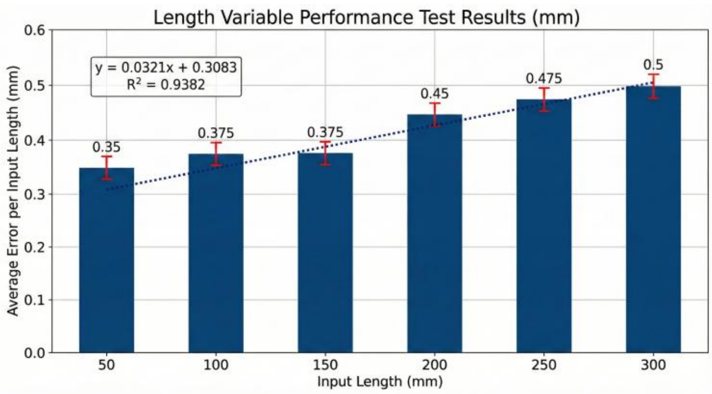

Figure 4. Error Test Results Graph for Various Input Lengths

In terms of precision, the low standard deviation of 0-0.051 mm indicates good consistency in repeated measurements. As seen in the Test Graph, the red dots representing the standard deviation show slight variations in the measurement results, indicating that the system maintains precision despite an increase in absolute error.

3.4 Welding Test

This test was conducted to determine the performance of the control system with a direct welding load, both on the surface of an iron plate and to join iron plates. A descriptive analysis of the welding results is presented in Table 2.

Table 2. Table of Plate Surface Welding Test Results

No	Input Welding Speed (mm/s)	Input Length (mm)	Weld Length (mm)	Mean Absolute Error (mm)	Mean Absolute Percentage Error (%)	Standard Deviation (mm)
1	200	100	102.50	1.66	1.66	1.75
			102.96			
			100.80			
2	250	100	102.40			
			102.50			
			98.44			
3	300	100	102.70			
			101.18			
			101.18			
4	350	100	98.60			
			97.62			
			100.10			
5	400	100	101.30			
			100.52			
			98.62			

The test results show that the developed GMAW welding automation system has an average absolute error of 1.66 mm, corresponding to an error percentage of 1.66% relative to the target weld length of 100 mm, and a data dispersion level (standard deviation) of 1.75 mm. These results indicate that the weld length produced ranges from 101.66 ± 1.75 mm to 103.41 mm. The precision level measured at a standard deviation of one sigma (1σ) has shown good consistency in the initial development phase. In addition to surface-welding tests, the researchers also conducted tests on joining materials using 5 mm steel plates and a joint length of 50 mm. The test results showed that this automation system was capable of joining materials with an actual weld length of 50.20 mm, indicating an error of 0.20 mm.

To evaluate the quality of welding results, this study uses ISO 13920, an international standard that specifies general tolerances for welded constructions [10]. The ISO 13920 tolerance classes are shown in Table 3.

Table 3. ISO 13920 for Linear Dimension Tolerances

Tolerance Class	Nominal Size Range (mm)					
	2 - 30	>30 - 120	>120 - 400	>400 - 1000	>1000 - 2000	>2000 - 4000
A	±1	±1	±1	±2	±3	±4
B		±2	±2	±3	±4	±6
C		±3	±4	±6	±8	±11
D		±4	±7	±9	±12	±16

In this evaluation, tolerance class D was selected, which provides a tolerance limit of ±4 mm for linear dimensions between 30 mm and 120 mm. Class D in this standard refers to rough tolerances intended for structures that do not require a high degree of accuracy. The selection of class was based on the fact that the welding automation system is still in the early stages of development, so the primary focus is on achieving basic stability before further improvements in accuracy and precision. The test results show that all data is within the tolerance range specified by ISO 13920 tolerance class D, indicating that the electronic control system for GMAW welding automation meets the quality requirements of ISO 13920 tolerance class D.

Further analysis shows that dimensional deviations are mainly due to thermal deformation, which causes the welding material to expand during welding. This phenomenon causes the weld material to expand, increasing the weld length. In addition, differences in weld length can occur due to differences in the height of the wire relative to the specimen to be welded or the arc length at the start of the welding process for each test sample, which can result in differences in the arc ignition time or a delay in the welding wire touching the workpiece when the stepper motor starts operating to run the welding rod, thereby affecting the final length of the weld, which can result in a weld length that is less than or exceeds the target length input by the operator. When the system was tested without a welding load, as previously done, the deviation ranged from 0.35 mm to 0.50 mm. These results indicate that the basic position control mechanism is functioning correctly, and the deviations observed during welding are primarily due to the physical characteristics of the welding process.

4. Conclusion

This research successfully designed and implemented an electronic control system for GMAW welding process automation that is capable of regulating travel speed parameters (welding speed) with a speed range of 100 to 800 mm/minute and travel length (welding length) with a welding length range of 50 to 300 mm with sufficient accuracy and precision. The system performs well and consistently, as demonstrated by functionality and performance testing, with all components, including stepper motors, relays, limit switches, and user interfaces, functioning as designed. Testing shows that the system has high accuracy at low speeds, reaching 99.44%, and minor errors in welding length settings with an error rate between 0.17% and 0.7%. Although accuracy decreases at high speeds, with an error of up to 7.46% due to microcontroller limitations and mechanical factors, precision remains stable, with a maximum standard deviation of 0.038 seconds. The welding results also meet the ISO 13920 Class D tolerance standard, with a tolerance of ±4 mm for lengths between 30 and 120 mm. Overall, this system reduces dependence on operator skills and lowers health risks due to exposure to welding light and fumes. The addition of continuously adjustable parameters improves welding quality and process efficiency, although improvements in mechanical aspects and speed control are still needed to achieve optimal performance.

Conflict of interest

The authors declare no conflict of interest.

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Development and Performance Evaluation of a Car Brake Bleeding Tool to Reduce Labor and Service Time at PT. UMC Suzuki Ahmad Yani Surabaya

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ABSTRACT

The objectives of this research are: (1) Designing a brake bleeding tool that will be used for the process of bleeding car brakes at the UMC Suzuki Ahmad Yani Surabaya workshop, (2) Knowing the effectiveness of the brake bleeding tool when used at the UMC Suzuki Ahmad Yani Surabaya workshop, (3) Finding out work efficiency after work is carried out using the brake bleeding tool at the UMC Suzuki Ahmad Yani Surabaya workshop. The design of the car brake bleeding tool was developed through analysis, design, development, implementation, and evaluation, resulting in a specialized tool that enhances the mechanic's work at the PT UMC Suzuki Ahmad Yani Surabaya workshop. This tool helps mechanics bleed car brakes, which previously required conventional tools and at least 2-3 additional mechanics. With the developed brake bleeding tool, mechanics only need to work with one person. This tool can also reduce the time required for brake bleeding, which is usually 17 minutes, to just 9 minutes. The development of a brake bleeding tool proved very effective in expediting brake bleeding maintenance at the UMC Suzuki Ahmad Yani Surabaya workshop. With this tool, manual bleeding tools are no longer required, making work more effective without additional labor. This tool produces a time efficiency of 55%. This tool makes the brake bleeding process more accurate and reliable, providing consistent quality assurance and, overall, increasing the productivity and effectiveness of workshop operations.

1. Introduction

The development of light vehicles has increasingly become a complex endeavor, consisting of thousands of components organized into dozens of systems. One system that plays an important role in a vehicle is the braking system [1]. The important role of the braking system is to slow and stop the vehicle and maintain its position when parked on an uneven surface. In addition, [2] states that a car's safety lies in its braking system, specifically that this system can affect driving safety and efficiency. The braking system is a vital component of a vehicle because driving safety depends on its proper functioning. Routine maintenance is necessary to ensure the braking system's quality of operation, including replacing the brake fluid.

Bleeding the brake fluid is an important step in brake system maintenance [3]. This step prevents air from entering and becoming trapped in the brake system. Air trapped in the brake system can make the vehicle's braking function suboptimal. Bleeding is also necessary after changing the brake fluid. Changing the brake fluid involves emptying the used fluid from the master cylinder and all brake lines, then refilling with new fluid [4].

PT United Motors Company was founded in Surabaya in 1952, located at Jalan Jendral Basuki Rakhmat No. 14. Due to regulations regarding the use of the name "Limited Liability Company," PT. United Motors Company changed its name to PT United Motors Centre in

2001. Initially, UMC distributed products from General Motors, Datsun, Chrysler, Simca, and Jeep. In line with the times and, of course, after going through several stages, in 1981, through PT. Indohero, UMC was entrusted to become the Main Dealer of Suzuki for the East Java and South Kalimantan regions, led by Jos Mardanus, with a network of sales, service, and spare parts, both managed by UMC branches and appointed sub-dealers [5].

There are several services offered at UMC Suzuki Ahmad Yani Surabaya, including new car sales, vehicle maintenance, and the sale of original Suzuki spare parts. As for vehicle maintenance, several services are available, including periodic servicing, tune-ups, general repairs, Suzuki home service, and booking service. One vehicle maintenance service available is periodic servicing [6]. Regular maintenance is vehicle maintenance that includes various actions, such as inspections, checks, and replacement of damaged components. Thanks to periodic maintenance, vehicles will continue to work properly and reduce the risk of accidents caused by damage or abnormal operation. One vehicle maintenance service is brake system maintenance. Brake bleeding is included in brake system maintenance, which aims to remove air trapped in the braking system [7].

This brake bleeding tool is an aid that can increase mechanics' efficiency when bleeding brake fluid. This brake bleeding aid is very much needed in the automotive industry and by mechanics because it makes the bleeding process easier. The process of bleeding brake fluid with this manual tool can cause brake fluid spills that can damage the car body if it comes into contact with the brake fluid and can also endanger mechanics if they slip on the spilled brake fluid. The brake bleeding work is carried out by two mechanics: one operates the brake pedal, and the other removes air from the system and adds new brake fluid. This technique is considered inefficient in terms of the number of technicians required and the time needed to complete the brake fluid bleeding process. The inefficient brake fluid bleeding technique can be improved by creating an innovative bleeding tool [8].

The benefits of using this brake bleeding tool include making the bleeding process safer and minimizing costs. This tool can help improve technicians' efficiency when bleeding brake fluid. It helps technicians bleed brake fluid efficiently, safely, and comfortably. If technicians can work safely and efficiently, their productivity will increase [8]. The advantages of this brake bleeding tool are that it is more time- and labor-efficient, as it simplifies the brake fluid bleeding process on cars, allowing it to be done relatively quickly and requiring only one person. The disadvantage of this brake bleeding tool is that the battery used for brake fluid suction power can run out at any time, so it must be recharged before it can be used again [9].

This brake bleeding tool makes the brake bleeding process more time- and labor-efficient, as it can be done by just one mechanic. Because this brake bleeding tool works with an automatic system, which eliminates the need to pump the brake pedal in the car. The mechanic only needs to press the on/off switch, and the bleeding tool will automatically suck the air out of the system. The mechanic can also fill the reservoir with new brake fluid, making the brake bleeding process faster [8, 10].

2. Methodology

This final project, entitled Development of a Car Brake Bleeding Tool to Improve Mechanic Work Efficiency at PT. UMC Suzuki Ahmad Yani Surabaya, uses the Research and Development (R&D) method. Research and development is a research method for developing and testing products that will later be developed in the world of education. One of the development models from R&D is ADDIE, which stands for Analysis, Design, Develop, Implement, and Evaluate. The ADDIE development model can be used to develop media, teaching materials, learning models, and learning strategies. This model enables the design and development of products in accordance with predetermined plans. In addition to its simple, systematic procedures, the ADDIE model allows repeated revisions and evaluations at each stage to produce valid and practical products [11]. The following is an explanation of how to use the ADDIE method:

2.1 Analysis

The first step in designing this tool is to conduct an analysis. This stage aims to identify development needs to ensure that the resulting product is optimal. In addition, the analysis aims to identify the obstacles mechanics face when performing brake bleeding and to determine the material specifications required to manufacture the bleeding tool.

This stage of the needs analysis is important for identifying the problems mechanics experience. The analysis process was carried out during industrial practice activities at PT. UMC Suzuki Ahmad Yani Surabaya. The manufacture of this brake bleeding tool requires important preparations. The first step was to coordinate with the industry to determine what was needed to manufacture this brake bleeding tool, including the tool's shape, the materials to be used, and the size of the tool to be made.

Table 1. Material and tool requirements

No	Material	Tools
1	12-volt DC pump	Measuring tape/Ruler
2	Battery	Hand Grinder
3	Container	Hand Drill
4	Wood or Board	Cutting Pliers
5	Clear Hose	Scissors
6	Nipple	Phillips Screwdriver
7	Hose clamp	Insulation
8	Switch	Glue G
9	Jumper Cable	Marker
10	Fuse	Varnish
11	Fuse box	Thinner
12	Sekun	Brush
13	Faucet	Sandpaper

2.2 Design

With the completion of process analysis, the next step is to design a brake bleeding tool. This tool is designed using Computer-Aided Design (CAD) technology. This modern approach integrates computational capabilities to produce precise, efficient digital designs. With CAD, the design process becomes more structured and controlled, enabling designers to produce models that are more detailed and accurate than with conventional methods. The tool model is created in three dimensions (3D), allowing for a complete representation of the tool's size, shape, features, and internal structure before entering the production stage. For a smooth design process, several steps must be taken, namely:

a. Creating a rough sketch or initial visual outline.
b. Determine the design dimensions.
c. The design creation process.
d. Design results.

2.3 Development

To ensure the design of this bleeding tool runs smoothly, several structured steps must be followed. These structured steps are intended to ensure that the tool to be implemented has a solid foundation during manufacture. The steps to be taken are as follows:

a. Tool and Material Preparation Stage
b. Material Cutting Stage
c. Plywood Gluing and Joining Stage
d. Box/Cover Hole Drilling Stage
e. Assembly Stage

2.4 Implementation

After the three stages of analysis, design, and development are completed, the next stage is to test the completed tool. At this stage, the researcher prepares the instrument to obtain assessments from the foreman and mechanic. This completed instrument is expected to be useful for foremen, mechanics, and industry. The purpose of testing this tool's performance is to obtain results and ensure it works properly and effectively.

Next, after testing this foreman and mechanical, the assessment is conducted by answering 25 questions. Tool testing consists of effectiveness and efficiency tests to determine the extent to which the brake bleeding tool works effectively and to identify any necessary corrections to the tool.

2.5 Evaluate

After completing the analysis, design, development, and implementation stages, the next step is evaluation. The purpose of this evaluation is to assess the effectiveness and efficiency of the developed tool. In the ADDIE model, the evaluation is formative, aimed at ensuring that the brake bleeding tool functions properly during the development and implementation stages and at obtaining feedback from foremen and mechanics. This feedback will later be used to evaluate and improve the parts of the tool that need improvement. Then, a summative evaluation is conducted after the implementation stage to assess the success of the bleeding tool by collecting data on its performance, conducting user satisfaction surveys, and comparing working time before and after using the bleeding tool. Thus, using these two types of evaluation can help ensure that the developed tool is successful and useful at PT. UMC Suzuki Ahmad Yani Surabaya.

This research was conducted at PT UMC Suzuki Ahmad Yani Surabaya during a field work program or internship. This final project is planned to begin in January 2024 and is targeted for completion in August 2024. To ensure the smooth running of the project and increase its effectiveness, an activity matrix was created to carry out the work as follows:

The first stage is the design and construction phase, which will be carried out at two locations: Kos Pak Sapto and Dna Kreasindo. These locations are situated at Kos Putra, Gorongan Jl. Wahid Hasyim No.173A, RT.7/RW.21, Ngropoh, Condongcatur, Depok District, Sleman Regency, Special Region of Yogyakarta 55281, and will run from January 1 to February 29, 2024.

The next stage is testing, which will be conducted at PT UMC Suzuki Ahmad Yani Surabaya. This location is at Jl. Ahmad Yani No.40–44, Ketintang, Kec. Gayungan, Surabaya City, East Java, 60231. Testing is scheduled for September 2, 2024. The division of stages and the schedule are expected to ensure that the project runs systematically to completion within the specified time target.

3. Result and Discussion

The following explains the results from the efficiency and effectiveness testing conducted during the research implementation phase.

Results

a. Efficiency Testing Results

Efficiency is a measure of how effectively an activity uses resources to achieve desired results. The fewer resources used to achieve the expected results, the more efficient the process is. After conducting efficiency testing during the implementation phase, it was clear that this special bleeding rem tool drastically reduced the time required for the bleeding rem maintenance process. Without this tool, the replacement process took about 17 minutes. However, with the help of this bleeding rem tool, the time required was significantly reduced to about half the normal working time, or only about 9 minutes. The following are the results obtained from the tests conducted during the implementation phase.

Table 2. Efficiency test results

No	Test	Bleeding brake time without using the tool	Brake bleeding time using tools	Conclusion
1	Test 1	17 Minutes	9 Minutes	Efficient
Difference		8 Minutes		

b. Effectiveness Testing Results

Effectiveness is the achievement of planned objectives within a specified time frame and with designated personnel. The higher the success rate, the greater the effectiveness. As explained in the effectiveness testing conducted during the implementation phase, the testing involved giving questionnaires to three mechanics. The following table shows the test results obtained:

Table 3. Effectiveness Testing Results

Aspect	Indicator	Item No.	Yes	No
Technical	Availability	1		3
		2	3	
		3		3
		4	3	
		5	3	
		6		3
		7	3	
	Performance	8	3	
		9	3	
		10		3
		11		3
		12	3	
		13	3	
		14	3	
		15		3
		16	3	
		17	3	
	Quality	18		3
		19	3	
		20	3	
		21		3

Aspect	Indicator	Item No.	Yes	No
		22	3	
		23	3	
		24	3	
		25	3	
		Total	51	24

Based on the results and calculations from the effectiveness test, a fairly strong association was found between the indicators of availability, performance, and quality and each respondent's perceptions. This fairly high percentage indicates that the indicators used effectively represented the expected availability, performance, and quality. It also shows that the tools or methods used in this study have sufficiently high validity in measuring the aspects identified.

Discussion

Brake bleeding is an important process in vehicle brake system maintenance that aims to remove air trapped in the hydraulic brake system. The presence of air can reduce brake performance, leading to a soft brake pedal and slower braking response. By bleeding the brakes regularly, users can maintain driving safety and ensure that the brake system operates efficiently. Brake bleeding maintenance requires precision, caution, and expertise from a mechanic. However, the old method, which relies solely on bottles and hoses to bleed brakes on vehicles, is time-consuming and labor-intensive and can sometimes cause accidents for mechanics.

Based on these issues, the development of a brake bleeding tool aims to provide an innovative solution that addresses the challenges mechanics face when bleeding car brakes. This tool is designed to improve work efficiency and effectiveness, reduce the risk of damage to other components, and facilitate the work and safety of mechanics. The development of this brake bleeding tool began with the design stage, taking into account various technical and functional aspects. The initial stage included sketching and creating a 3D model of the tool, followed by a detailed design that covered its dimensions and components. Once the design was completed, the assembly process involved cutting the materials, drilling holes, applying varnish and glue, and joining each component.

The assembly process was carried out precisely and thoroughly to ensure that each component met the specified requirements, using various industrial techniques and tools, including measuring instruments, hand grinders, and hand drills. Efficiency testing at UMC Suzuki Ahmad Yani Surabaya showed that using brake bleeding tools can reduce brake bleeding time from 17 minutes to 9 minutes, resulting in a 55% time efficiency. This efficiency helps reduce wasted time, increase productivity, and alleviate mechanics' workload.

In addition to measuring efficiency, the effectiveness of the brake bleeding tool was also evaluated through a questionnaire administered to mechanics to assess its availability, performance, and quality. The questionnaire results showed positive assessments, with the tool rated as easy to use, effective, and helpful in producing high-quality results. Based on testing, this brake bleeding tool has proven highly effective in improving operational efficiency and reducing work time.

In the brake maintenance industry for vehicles, particularly at PT. UMC Suzuki Ahmad Yani Surabaya, brake bleeding work is one of the complex technical challenges. Before the development of the brake bleeding tool, mechanics at the PT. UMC Suzuki Ahmad Yani Surabaya workshop typically relied on traditional bleeding tools. Although these tools appear simpler, they have several drawbacks.

Bleeding with this old tool has several disadvantages: it takes a long time to complete, requires additional manpower from other mechanics, and can cause leaks in the bottle, which can damage parts of the car if brake fluid from the bottle spills onto them. This means that brake bleeding takes longer, ultimately affecting the vehicle's operational productivity. The following is an image of the tool commonly used by mechanics at the UMC Suzuki Ahmad Yani Surabaya workshop to perform brake bleeding on cars:

Figure 1. Tool comparison

As an alternative solution, the brake bleeding tool offers advantages not found in current tools. This tool is designed with a minimalist shape, is lightweight, easy to use when moving between locations, and certainly simplifies the bleeding process, making it suitable for mechanics to perform their work. This tool also ensures greater safety and security when used for brake bleeding work.

The availability of this brake bleeding tool at PT. UMC Suzuki Ahmad Yani Surabaya can help mechanics shorten the brake bleeding maintenance process on vehicles and reduce the need for assistance from other mechanics, thereby minimizing disruptions to the mechanic's work. Overall, the development of this tool represents a significant step forward in enhancing the efficiency and effectiveness of vehicle maintenance at PT. UMC Suzuki Ahmad Yani Surabaya. This tool not only offers an alternative solution but also provides greater ease of use and safety than previous tools.

Figure 2. Innovation in car brake bleeding tools

4. Conclusion

The design of the car brake bleeding tool, from analysis through design, development, implementation, and evaluation, has resulted in a specialized tool that improves mechanics' work efficiency at the PT. UMC Suzuki Ahmad Yani Surabaya workshop. This tool helps mechanics perform car brake bleeding more quickly and accurately, thereby saving time and ensuring a safer, more comfortable work environment. The design of this tool also considers ease of access, allowing mechanics to work comfortably while performing their tasks. The development of this brake bleeding tool has proven to be very effective in streamlining the brake bleeding maintenance process at the UMC Suzuki Ahmad Yani Surabaya workshop. With this tool, manual bleeding tools are no longer necessary, and work becomes more efficient without requiring additional manpower. This tool makes the brake bleeding process more accurate and reliable, providing consistent quality assurance and thereby improving the overall productivity and operational effectiveness of the workshop. Work efficiency after using the brake bleeding tool at the UMC Suzuki Ahmad Yani Surabaya workshop has significantly accelerated the time required to complete vehicle maintenance tasks. Before using this brake bleeding tool, mechanics needed 17 minutes. However, after using this brake bleeding tool, mechanics can complete the task in just 9 minutes.

Conflict of interest

The authors declare no conflict of interest.

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Optimization of Production Process Activities in an Effort to Increase the Production Capacity of BZ 020 Cover Housing

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ABSTRACT

The objectives of this study are: (1) To optimize the production process activities of Cover Housing BZ 020 production by implementing an 8-step improvement to increase production capacity. (2) To determine the comparison of the production capacity value of Cover Housing BZ 020 before and after the improvement. (3) To determine the activities that can be optimized to increase the production capacity of Cover Housing BZ 020 production. The method used in this research is the 8-step improvement research method approach. The data collection techniques used are (1) Observation and (2) Documentation. Meanwhile, the research instruments used are (1) Logbook, (2) Observation Sheet, and (3) Cellphone. The data analysis used is descriptive, comparing production capacity and operator activities. The results of this study indicate that: (1) Implementation of the 8-step improvement can be done at PT. Gemala Kempa Daya and is in accordance with the applicable standard SOP. (2) The results obtained after the improvement of production capacity are from 360 units/hour to 468 units/hour, or an increase of 30%. As a result of this improvement, the company also recorded a profit of IDR 55,800,000.00 per year. (3) By adding an extension conveyor, it can shorten the duration of two of the four operator work activities. The decrease in cycle time from 10 seconds to 8 seconds is due to optimizing work activities.

1. Introduction

Indonesia is a country with rapid digital technology development in Southeast Asia. This rapid development has greatly influenced the economy in various fields. One sector that has benefited from advances in digital technology is the automotive industry. Digitalization has had a significant impact on several industries, including the automotive sector [1]. Advances in digital technology in the era of globalization have been very beneficial across various fields. With the conveniences provided by digital technology, many new companies have emerged. According to data from the Central Statistics Agency in 2022, the number of micro and small companies in the Motor Vehicles, Trailers, and Semi-Trailers field increased by 846 companies from the previous year. The impact of globalization is that many companies are working together, thereby increasing business competition [2].

Despite the development of the automotive industry in the era of globalization, the need for transportation, driven by people's increasing mobility in daily life, has become an important factor in competition among automotive companies. People's mobility between locations is increasing, resulting in a greater need for transportation [3]. This is because companies will face an increase in demand each year. This is reinforced by data from the Indonesian Motor Vehicle Industry Association (Gaikindo), which reports that domestic car sales increased by 11.8% in 2023. The increase in car sales is an opportunity for automotive companies, especially car manufacturers, to market their vehicles. Therefore, every company needs the right business strategy to compete and excel against competitors [4]. The increase in vehicle demand at each sole brand agent company (ATPM) also affects demand at vendor companies. In this case, companies must continue to meet consumer demand to maintain consumer satisfaction and loyalty [5]. To meet consumer demand, companies, both regionally and globally, must produce superior products or services [6].

PT. Gemala Kempa Daya is a company engaged in the manufacture of frame chassis and press products for the underbody of four-wheeled vehicles. Several customers with well-known vehicle brands, such as HINO, Toyota, Mitsubishi, and many others, place their complete trust in PT. Gemala Kempa Daya to supply the components needed for vehicle production. Based on 2023 customer demand data, there has been an increase from 7,880,048 units in 2022 to 8,069,429 units. This increase in demand will impact existing production capacity.

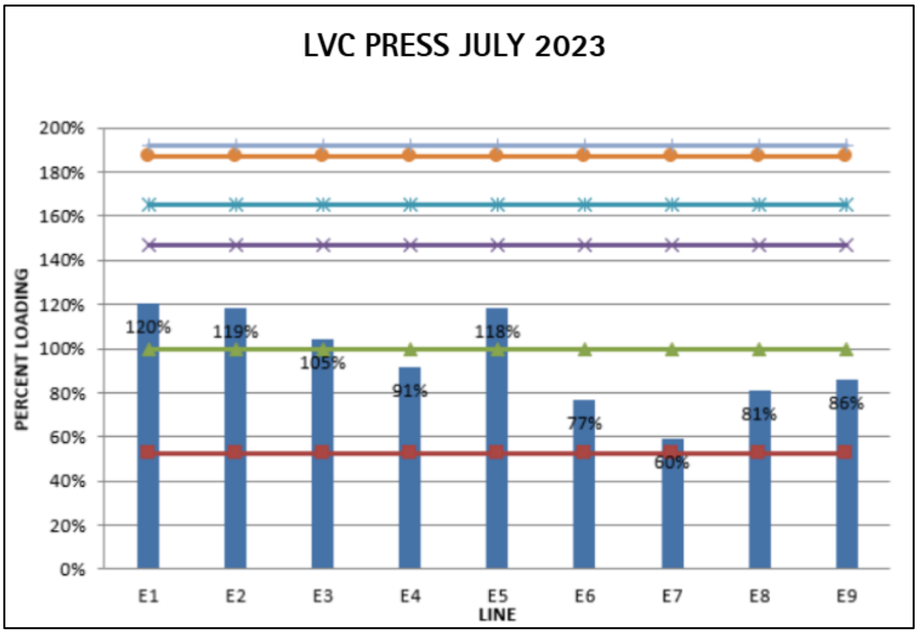

Figure 1. Loading vs. Capacity (LVC) line Stamping graph for July.

Based on the loading vs. capacity on Fig. 1, in July 2023, four machines on the stamping line had loading times exceeding the prepared time capacity. The two machines with the highest production hours were E1 and E2. As a result, the company needed to spend more money to provide additional wages to employees for performance outside working hours. Not only that, but the company also needs to spend more money to support production during overtime hours. Adding overtime hours can lead to a decline in productivity due to several factors, including disruptions to operator health, reduced workforce capabilities, and disruptions to project resources [7]. Machines E1 and E2 are designed with a tandem line layout. Therefore, the products manufactured on both machines are not significantly different. With the highest production time, the following is the total production time per product on machines E1 and E2 in July 2023.

Table 1. Total Production Time for Products on Machines E1 and E2

No	Product Name	Quantity Requested (pcs)	Cycle Time (s)	Total Production Time (h)
1	BRKT, ENGINE FR MTG, 2 RH/LH	3,366	18	17
2	Gusset C/MBR No. 6 (51361-EW011)	3,000	11	9
3	GUSSET 43	-	12	0
4	Reinforced Rear Axle Housing (BZ050)	13,508	9	34
5	BRKT, ENGINE FR MTG, 1	2,200	12	7
6	Cover Housing 640 SUV	5,601	19	14
7	C/M 101	274	12	1
8	Cover Housing D16D/BZ020	18,037	10	50
9	Bumper Stopper	-	12	0
10	Gusset C/MBR Frame No. 3	2,796	12	9
11	Housing RR Axle Upper/Lower MPV	7,873	15	33
12	C/MBR FRONT (51211-0W020) HMMI	754	14	3
13	Gusset C/M No. 3 FE 73/74/75	5,050	14	20
14	C/MBR, AUXILIARY (MK305222FM)	200	14	1
15	Reinforced Rear Axle Housing (BZ070)	8,369	10	23

Table 1 shows the results of calculating the total production time for several products manufactured by machines E1 and E2 in July 2023. Based on the above data, an analysis was conducted to identify the factors most influencing production time. The tool used is the Pareto Diagram. This diagram helps management to immediately determine which areas require extra care and attention at this time [8]. The following is a data analysis using the Pareto Diagram on Fig. 2.

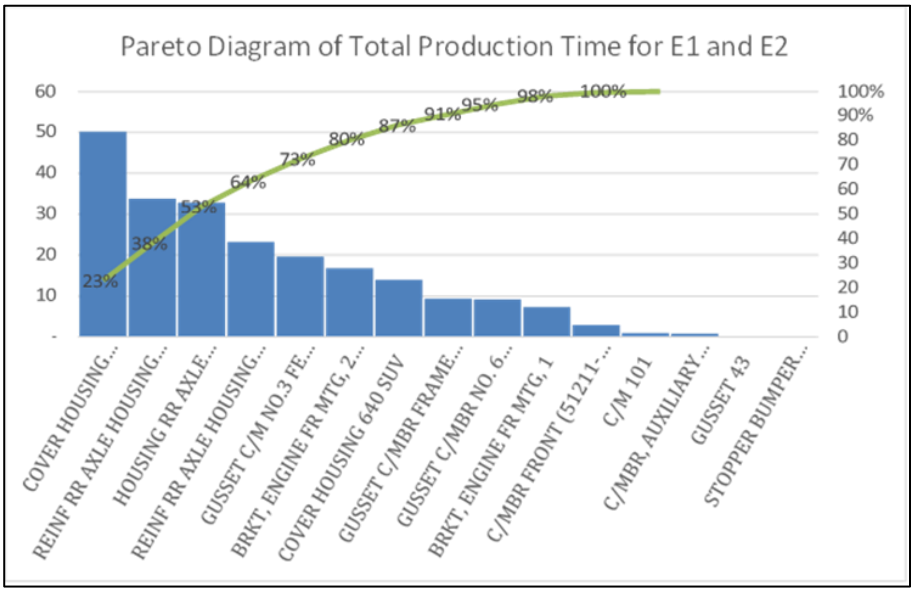

Figure 2. Pareto Diagram of Total Production Time for Machines E1 and E2

In the diagram above, Cover Housing BZ 020 has a total production time of up to 50 hours in one month. Therefore, improvement will be achieved by reducing the cycle time for Cover Housing BZ 020. This has a significant impact because demand for Cover Housing BZ 020 products is highest each month.

2. Methodology

2.1 Type of Research

The research method used is action research. Adopting the seven types of action research described by [9], Development Action Inquiry is the use of scientific methods in everyday life, emphasizing individual development to collaboratively solve problems. In this case, the research method will also use the 8-step improvement tool. This method consists of steps found in Quality Control Circle (QCC) activities, which are often used to empower all company assets to improve quality and productivity, add value, and increase company profits. The 8-step improvement method is the standard SOP used at PT. Gemala Kempa Daya.

2.2 Research Procedure

The 8-step process is grouped into Plan, Do, Check, Action (PDCA), with steps one to five in the plan, step six in the do stage, step seven in the check stage, and step eight in the action stage [9]. Table 2 show the following are the steps in the 8-step improvement.

Table 2. 8-step improvement steps

Group	Steps
Plan	Determine the Theme
	Determine the Target
	Analyzing Existing Conditions
	Cause and Effect Analysis
	Mitigation Plan
Do	Mitigation
Check	Evaluation of Results
Action	Standardization and Follow-up

2.3 Research Location and Time

The research was conducted at PT. Gemala Kempa Daya Plant Karawang, located at Kawasan Indotaisei Blok P4, Dawuan, Kalihurip, Cikampek, Karawang, West Java 41373. This research was conducted from September to December 2023.

2.4 Data Collection Methods and Instruments

The data collection methods used in this study were observation and documentation. The observation method was used to collect data on the production process cycle time and to document field conditions. Meanwhile, the documentation method focused on collecting data in the form of company documents and images. The observation and recording data collection methods were used to assess the quality of the collected data [10].

The data collection instruments used in this study were logbooks, observation sheets, and mobile phones. Logbooks were used to record progress at each step of the 8-step improvement process. Observation sheets were used to record the results of cycle time data collection. Mobile phones were used to record the production process of Cover Housing BZ 020.

2.5 Data Analysis Techniques

The analysis used for the implementation of the 8 steps of improvement focuses on monitoring the progress of the steps taken. Monitoring is carried out by providing an assessment of compliance with the standard SOPs applicable at PT. Gemala Kempa Daya regarding their implementation. The results of the improvement are analyzed by comparing the production capacity values before and after the improvement. The technique for analyzing the results of work activity optimization is to compare work activities before and after the improvement.

3. Result and Discussion

3.1 Result

3.1.1 Implementation of the 8 Steps Improvement

The analysis used for the implementation of the 8 steps of improvement focuses on monitoring the progress of the steps taken. Monitoring is carried out by providing an assessment of compliance with the standard SOPs applicable at PT. Gemala Kempa Daya regarding their implementation. The results of the improvement are analyzed by comparing the production capacity values before and after the improvement. The technique for analyzing the results of work activity optimization is to compare work activities before and after the improvement. The target is determined based on the SMART method (Table 3).

Table 3. Setting SMART Targets

1	Specific	Increasing capacity production Cover Housing BZ 020.
2	Measurable	Reducing cycle time from 10 seconds to 8 seconds.
3	Achievable	Previous improvements have been made, and the target has been achieved.
4	Reasonable	Improvements are needed, or overtime hours will continue to increase.
5	Time Base	The research period is 4 months, from September to December.

In this step, Standard Worktable data and actual Cycle Time data were collected, and the root causes of the problems were identified (Fig. 3). The results showed that there were non-value-added work activities that could be improved. Among these were back-and-forth movements when picking up products from the process and placing them on the conveyor.

Figure 3. Actual Conditions of OP 10

Create a countermeasure plan using the 5W+2H method as shown in Table 4.

Table 4. 5W + 2H Countermeasure Plan

What	Distance between dies and conveyor is 620 mm.
Why	A stepping motion is required when handling products onto the conveyor.
How	An extension conveyor is created.
Who	Syahrul.
When	October 5, 2023
Where	E1 Press Machine
How Much	IDR 0-,

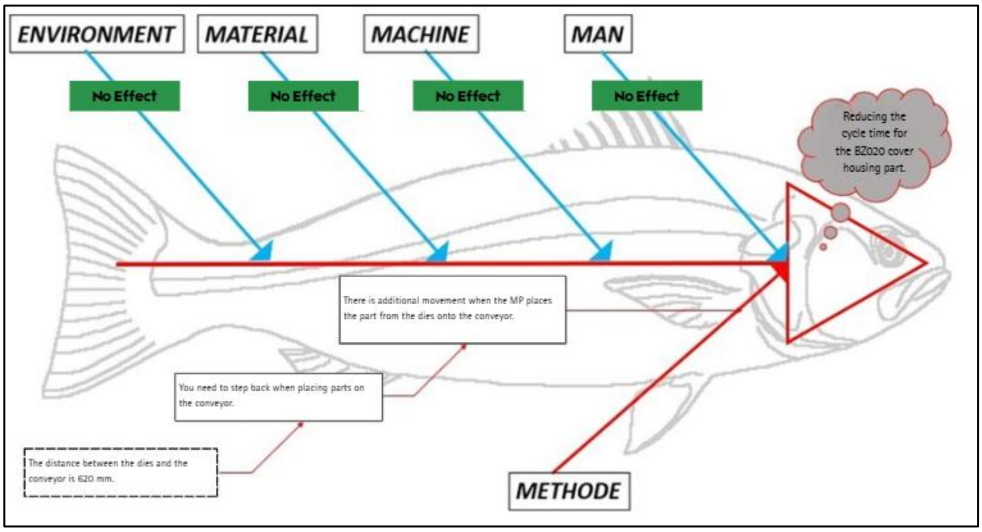

Figure 4. Fishbone Diagram

Analyzed possible causes that could be improved to reduce cycle time (Fig. 4). The results showed a considerable gap between the dies and the conveyor, measuring 620 mm. The first step in the solution is to create a 2D and 3D design for the extension conveyor (Fig. 5). The design was also consulted with the mentor, who is the section head of engineering.

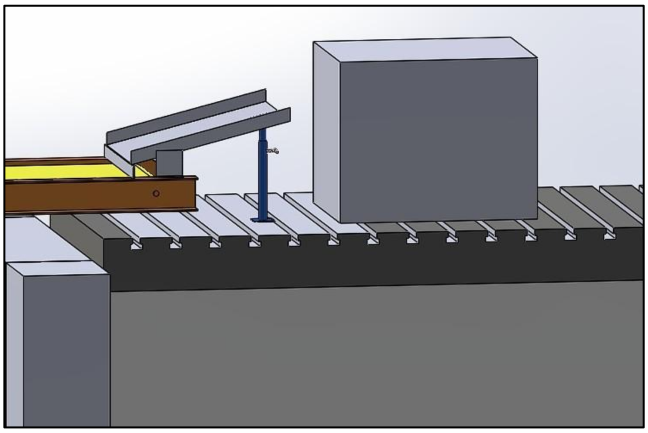

Figure 5. Extension Conveyor Simulation Design

After the 2D drawing is complete, the next step is to create the actual design (Fig. 6).

Figure 6. Extension Conveyor Painting Process

The maintenance department assists the manufacturing process itself to ensure its implementation. Of course, the manufacturing must comply with the drawings. The next step is to conduct a trial, the first of which is to fit the finished extension conveyor onto the conveyor. The results are in accordance with the layout of the dies and conveyor (Fig. 7).

Figure 7. Extension Conveyor Fitting Process

After the fitting process is complete, the next step is to conduct a trial process. The trial process involves taking 10 cycle-time samples (Fig. 8).

Figure 8. Trial Process

At this stage, data on cycle time is collected after the trial. The results of the cycle time data collection after the trial show that the cycle time for the production process of the Cover Housing BZ 020 product has decreased from 10 seconds to 8 seconds. At this stage, the Work Instruction (WI) for the Cover Housing BZ 020 product is standardized. The Work Instruction (WI) is revised and explained to the relevant operators. Meanwhile, the next improvement measure is to reduce the cycle time for products that exceed the takt time. These include Brkt, Engine Fr Mtg, 2 Rh/Lh, and Cover Housing 640 Suv products.

3.1.2 Production Capacity Value for Cover Housing BZ 020

After calculating the production capacity data before and after the improvement process, the next step is to calculate the difference between the two data sets. The calculation is as follows in Table 5.

Table 5. Production Capacity Data Results

Test No.	Production Capacity		Difference	Percentage Comparison
	Before	After		
1	340	439	99	29%
2	360	474	114	32%
3	360	461	101	28%
4	360	473	113	31%
5	336	444	108	32%
6	333	474	141	42%
7	346	461	115	33%
8	371	444	73	20%
9	360	456	96	27%
10	356	480	124	35%

After calculating the difference before and after the improvement, the next step is to calculate the 10 samples studied. The result of the calculation above is 108.4, or if rounded up, the difference in production per hour for the Cover Housing BZ 020 product is 108 units per hour.

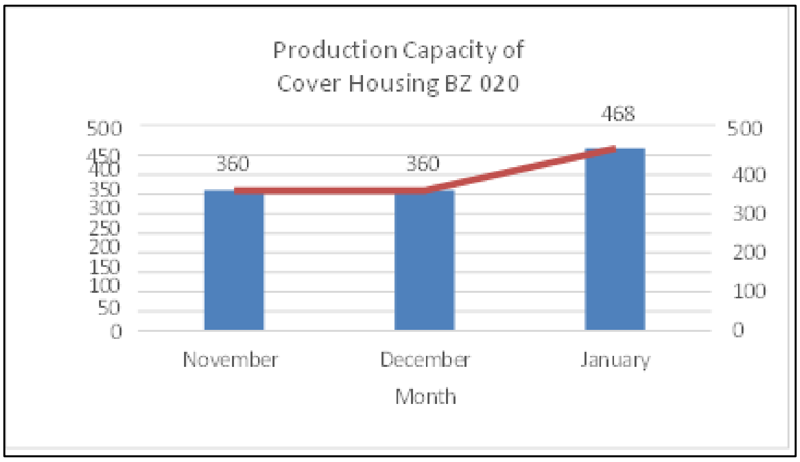

Figure 9. Production Capacity Chart for BZ 020 Housing Covers

As shown in the Fig. 9, the production capacity of Cover Housing BZ 020 increased in January, specifically after the improvement was implemented. Over the last two months, production capacity increased from 360 units/hour to 468 units/hour, a 30% increase. From this increase in production capacity, the company earned a profit of IDR 55,800,000.00 per year.

3.1.3 Optimization of Work Activities in the Cover Housing BZ 020 Production Process

The following is a comparison of work activities before and after the improvement was implemented. Since the improvement was carried out on OP 10, the comparison includes only work activities from that OP. The results are as follows:

The result of the improvement was a 2-second reduction in cycle time. The operator's work activity when handling the product involved only moving their hands while their body

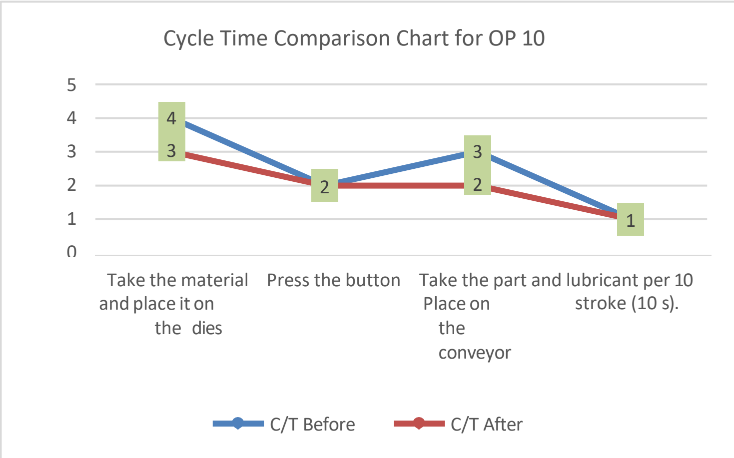

Figure 10. Cycle Time Comparison Chart for OP 10

remained in the original position. The impact was a reduction in cycle time for the BZ 020 Cover Housing product from 10 seconds to 8 seconds and an increase in production capacity.

3.2 Discussion

3.2.1 Implementation of the 8 Steps Improvement

The implementation of the 8-step improvement at PT. Gemala Kempa Daya Plant Karawang can be carried out within a period of 4 months. The implementation of the 8-step improvement process is in accordance with the standard operating procedures (SOP) of the Quality Control Circle (QCC) at PT. Gemala Kempa Daya. Additionally, the implementation of the 8-step improvement process aligns with the research titled "Implementation of the Quality Control Circle Method for Enhancing Propeller Shaft Production Capacity at PT XYZ" [11].

3.2.2 Improvement Results

After implementing the 8-step improvement, production capacity increased by 108 units/hour. The steps taken reduced the production process cycle time, thereby increasing production capacity. This aligns with the research, which found that the main cause of low production capacity was the relatively high cycle time in the production process. Therefore, improvements were made to the production process tools. The results obtained showed that the production process cycle time decreased from 5.5 seconds to 4.5 seconds. Production capacity increased from 506 units/hour to 557 units/hour.

3.2.3 Optimization of Work Activities

The improvement was to add a conveyor extension to OP 10, which affected the operator's handling of goods. Initially, the operator had to walk from the starting point to the conveyor. This increased the operator's activities and could increase the cycle time of non-value-added activities. This shows that there is a difference in work comfort when using the redesigned valve spring compressor compared to the conventional one. Thus, work productivity increases when using a redesigned alternative valve spring press tool. Additionally, according to [12], a company's optimization can be achieved by selecting, reducing, and eliminating activities that do not add value to the company.

4. Conclusion

The analysis confirms that the "8 Steps of Improvement" framework was successfully implemented at PT. Gemala Kempa Daya is in full compliance with existing Standard Operating Procedures (SOPs). This comprehensive process ranged from determining the initial theme and setting targets to analyzing root causes, implementing countermeasures, and finally standardizing the results. The primary technical intervention involved the installation of an extension conveyor. This modification significantly streamlined the workflow by reducing the distance and time required for operators to pick up and place materials, specifically at the OP 10 station. Consequently, the cycle time at OP 10 was optimized, dropping from 10 seconds to 8 seconds. These operational improvements increased production capacity by 30%, raising output from 360 to 468 units per hour. Finally, this efficiency gain translated into an annual profit increase of IDR 55,800,000.00 for the company.

Conflict of interest

The authors declare no conflict of interest.

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Optimizing the Exhaust System to Improve Air Quality in Vehicle Service Repair Shops

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ABSTRACT

Air pollution from vehicle emissions, including NO_2, SO_2, O_3, TSP, and CO, negatively impacts workers' health and reduces work efficiency and productivity. This study aims to (1) develop an exhaust system at the Nissan Mlati ATPM workshop, and (2) determine the effectiveness of the exhaust system. The process of optimizing the exhaust system to improve air quality in the vehicle service repair stall was carried out through a comprehensive design and development project, including design and development phases and tool use. Then, metric volume (theoretical), actual use, and performance efficiency calculations were used. The results of the study show that optimizing the exhaust system at the Nissan Mlati ATPM workshop has been proven effective in increasing airflow capacity, maintaining air quality, and improving performance efficiency. This system can reduce the concentrations of pollutants such as Carbon Monoxide (CO) and Total Suspended Particulate (TSP) and increase workshop productivity without requiring structural design changes. The overall percentage results show a 51.03% increase in value after exhaust system optimization. This exhaust system not only improves air quality but also increases work productivity, which is crucial in the automotive industry's competition.

1. Introduction

Transportation plays a vital role in modern life, especially in supporting community mobility. Motor vehicles are the dominant means of transportation used in various regions, including Indonesia. However, the annual increase in the number of motor vehicles has environmental consequences, particularly worsening air pollution. According to data released by the Central Statistics Agency [1] in 2023, the number of motor vehicles in Indonesia reached 157,080,504 units. This figure shows an increase of around 7,191,056 units compared to the previous year, indicating significant growth. In the Special Region of Yogyakarta (DIY), the number of registered motor vehicles reached 3,238,203 units, with an estimated annual growth of 4% for cars and 6% for motorcycles [2]. This increase in the number of vehicles certainly has implications for air quality in the region, especially in urban areas with high motor vehicle activity. There are two types of combustion in motor vehicle fuel: complete and incomplete. These two processes have different impacts on the environment.

Complete combustion occurs when hydrocarbon compounds (C_xHy) react with oxygen (O_2) in sufficient quantities, producing carbon dioxide (CO_2) and water vapor (H_2O) as the main products. A common chemical reaction that illustrates this process is C_8H_{18} + 12.5 O2 • 8 CO_2 + 9 H_2O, which shows that octane (C_8H_{18}), one of the main components of gasoline, undergoes complete combustion with higher energy output. This process also does not produce harmful substances such as carbon monoxide (CO) or unburned hydrocarbons. However, in practice, complete combustion is difficult to achieve in vehicle engines due to various constraints, such as an ideal air-fuel ratio and limitations in combustion system efficiency.

Air pollution is caused by various types of harmful gases emitted by vehicles, including nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), particulate matter (TSP), and carbon monoxide (CO). Based on research conducted by [3]. Motor vehicle emissions are known to contribute to nearly 100% of carbon monoxide (CO) levels, 100% of lead (Pb) levels, 70-89% of hydrocarbon (HC) levels, and 34-73% of nitrogen oxide (NOX) levels in the atmosphere. This situation is even more alarming when looking at data from IQAir.

According to IQAir data, Indonesia ranked 14th out of 134 countries with the worst air quality in 2023, with an average PM2.5 concentration of 37.13 µg/m³. This figure exceeds 7.4 times the annual PM2.5 (particles measuring 2.5 micrometers) guideline value recommended by the World Health Organization (WHO). In addition, real-time data from IQAir shows that several cities in Indonesia have high levels of air pollution. For example, on February 27, 2025, the city of Medan in North Sumatra recorded an Air Quality Index (AQI) of 163, which is categorized as "Unhealthy."

Measurements of motor vehicle emissions were conducted by [4] in the Sleman region, with a total of 528 vehicles tested, including 125 official vehicles and 403 public vehicles. The test results showed that 20% of government vehicles and 15% of public vehicles did not meet the Emission Quality Standards (BME). Overall, 84 vehicles, or 16% of the total tested, did not meet emission standards. Gasoline-fueled vehicles did not show significant changes in their level of compliance with emission standards.

Exhaust emission testing on Nissan D22 or Nissan Navara diesel engines using pure diesel fuel conducted by [5] showed that carbon monoxide (CO) emissions were in the range of 14% vol at 1000 rpm. It decreased to 12 vol at 3000 rpm. Carbon dioxide (CO_2) emissions increased from 6% vol to 14% vol, reflecting a more complete combustion process as engine speed increased. Oxygen (O_2) concentration was also recorded as higher at 8% vol, indicating excess air in the combustion process.

PT Wahana Sumber Baru Yogya (Nissan-Datsun Mlati) is an automotive company located at Jalan Magelang KM.10, Mlati, Sleman, Special Region of Yogyakarta. This company plays an important role in the motor vehicle industry by providing key services, namely the sale of Nissan, Datsun, KIA, Citroën, and AION vehicles; vehicle servicing; and the sale and ordering of original spare parts. However, the workshop's operational activities at this company have the potential to contribute to air pollution through exhaust emissions from vehicles being repaired and from the workshop itself.

Based on observations and interviews conducted at the Nissan Mlati ATPM workshop, several issues related to working conditions were identified. Several mechanics complained of frequent vision problems from exposure to thick exhaust fumes. This was evident from the workshop's air exhaust system not functioning optimally. These observations also revealed problems with the ventilation system, including narrowing of the ventilation holes due to dirt buildup and damage to the exhaust fan. As a result, smoke from vehicle engines can settle in the room, especially in areas with suboptimal ventilation.

The accumulation of pollutants indoors not only harms workers' health but also reduces work efficiency and productivity. Vehicles that have undergone combustion chamber cleaning require mechanics to leave the workshop area to revise the engine, as this process produces white smoke. This activity impacts work effectiveness and efficiency, as mechanics must move to a different location each time they perform this procedure. If this activity is carried out in the workshop, the smoke produced can pose health risks to mechanics and other workers.

Therefore, efforts are needed to improve the air management system by optimizing ventilation, regularly maintaining air exhaust devices, and adopting more effective filtration technology to enhance air quality in the workshop environment. These measures are expected to reduce the negative impact on workers' health and minimize discomfort for customers.

In addition, regular maintenance of the exhaust system has been proven to reduce exhaust emissions by up to 25% and improve vehicle fuel efficiency [6]. However, at the Nissan Mlati ATPM workshop, a more effective exhaust system still faces several challenges, including limited infrastructure and a lack of accurate air quality data within the workshop. The exhaust system was damaged in the fan and electrical circuit, including burnt 3-phase capacitors and insulators.

This study aims to fill this gap by conducting an air quality analysis at the Nissan Mlati ATPM workshop to obtain actual data on indoor pollutant concentrations and assess the effectiveness of the ventilation system in use. More accurate data from this study is expected to serve as a basis for recommendations to improve the exhaust or blower system. In addition, this study aims to educate the public and repair shops about the importance of controlling exhaust emissions to create a healthier, more environmentally friendly work environment. The findings from this study are expected to make a significant contribution to improving the quality of the working environment in repair shops and to supporting emission-reduction policies in the automotive industry.

2. Methodology

The method used in this study was development research, using the Design and Development Research stages [7]. Product or tool development yielded comprehensive, practical results in accordance with field conditions. This study focuses on optimizing the exhaust system in workshops exposed to pollution due to work activities, especially during the vehicle combustion chamber cleaning process. To achieve an effective and efficient system, direct testing of the object under study and measurement of variables that reflect the success of exhaust system optimization are required. This study sets two main focuses: air as the object and air quality as the research variable, both systematically observed.

The object of this study is the air inside the workshop. Air pollution in workshops can take the form of micron-sized particles (PM2.5 and PM10), exhaust gases such as carbon monoxide (CO) and nitrogen oxides (NOx), and volatile organic compounds (VOCs). Long-term exposure to these substances can cause various health problems for workers, including respiratory disorders, eye irritation, and even the risk of chronic diseases.

The main variable in this study is Air Quality, which serves as a related variable. Air quality is used as a benchmark to assess the extent to which an optimized exhaust system can improve the working environment in a workshop. Since this study focuses on the development of ventilation systems, air quality measurements are an important aspect in evaluating the effectiveness of the designed product, both in terms of technical aspects and its impact on health and work productivity.

Particulate concentration measurements were conducted using a MiniVolt Air Sampler, which detects dust or smoke particles in micrograms per cubic meter ($\mu g/m^3$). These particulates originate from incomplete combustion and can cause respiratory problems at high concentrations. Meanwhile, an Impinger is used to measure the content of hazardous gases such as carbon monoxide (CO), nitrogen dioxide (NO_2), and hydrocarbon compounds (HC) in parts per million (ppm) or milligrams per cubic meter (mg/m^3), which are important indicators of toxic air pollution [8, 9].

Accurate, relevant data-acquisition techniques are used to support the development of air management systems in workshops. Quantitative data collection methods are used with a direct observation approach. Various measuring instruments are used to measure important parameters, such as air particle concentration, pollutant gas content, air flow velocity, and the physical dimensions of the workshop room. Measurements are carried out in accordance with Indonesian National Standard (SNI) 7119:2017 to ensure accuracy and compliance with national ambient air quality standards. Each tool has a specific function that supports objective and measurable data collection in accordance with standards.

Calibration of measuring instruments is a crucial aspect in maintaining the accuracy and traceability of measurement results against national and international standards. According to the Calibration Certificate issued by Greenlab Indonesia, the calibration was conducted on February 27, 2024. The calibration process was carried out in accordance with applicable standard procedures, using reference equipment that has been verified and meets international standards. This calibration covered various measuring instruments, including the MiniVol Air Sampler, Impinger, and Handheld Anemometer, to ensure they are in optimal condition and capable of providing consistent, scientifically accountable results. In general, the research stages and activities are described in detail in the diagram below.

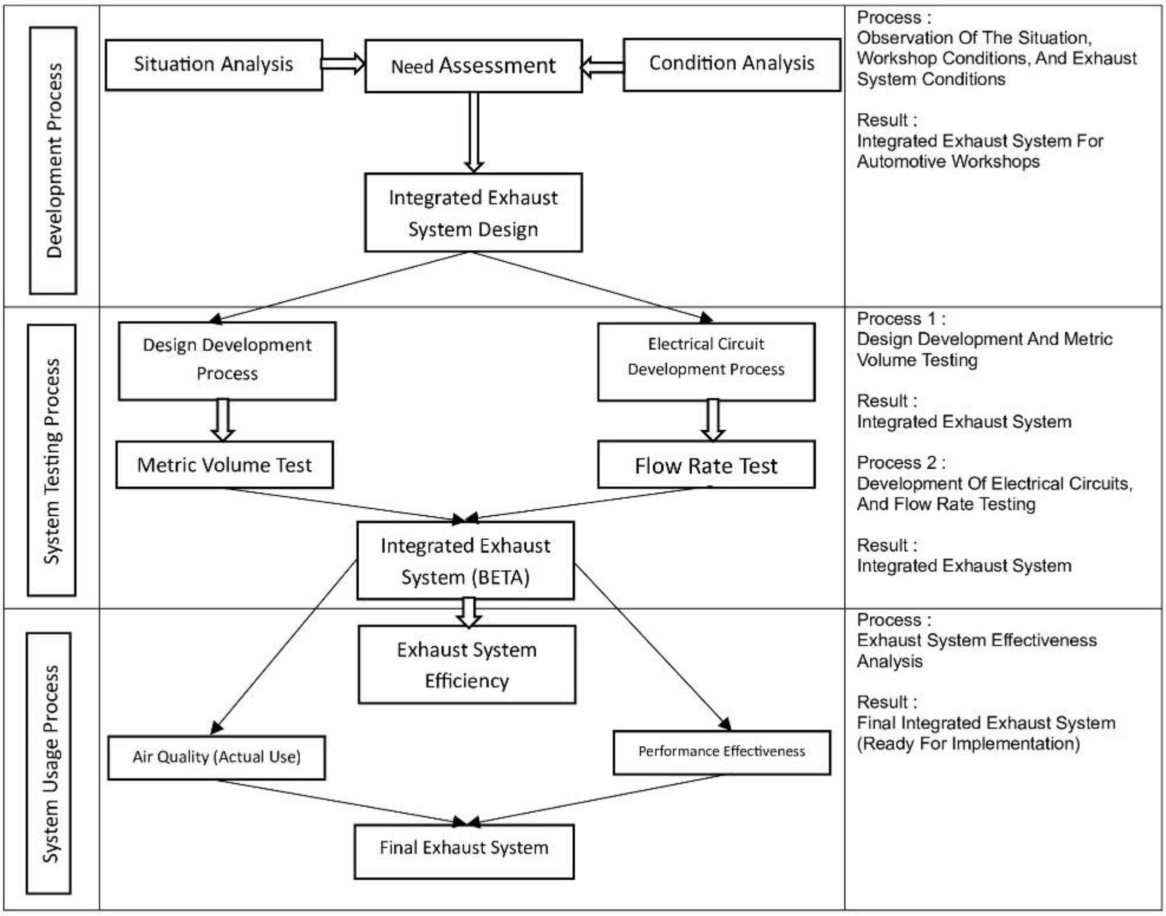

Figure 1. Research Process

3. Result and Discussion

3.1 Result

3.1.1 Pre-Product Development Stage

The pre-product development stage in this study aims to identify major problems in the exhaust system before the repair and optimization process is carried out. Activities in this stage include observing blockages in the exhaust system pipes, observing damage to the exhaust system's electrical circuitry, and measuring air quality before repairing the exhaust system. This pre-product development stage is an important foundation for designing targeted repair strategies, so that the resulting solutions are truly effective in improving the performance of the exhaust system and air quality in the surrounding environment.

The Nissan Mlati ATPM workshop is a high-activity vehicle service center that produces significant exhaust emissions, especially during testing and post-service engine revving. Initial observations indicate that indoor air quality in the workshop is suboptimal, as evidenced by mechanics' complaints of vision impairment and discomfort from exposure to thick smoke. This condition is exacerbated by damage to the ventilation system, such as broken fans, faulty capacitors, and clogged ventilation holes. The accumulation of pollutants hurts health and work productivity. Therefore, the pre-development stage focused on evaluating the ventilation system and collecting pollutant concentration data to formulate appropriate improvement measures to create a healthier work environment that supports mechanical performance.

Conditions at the Nissan Mlati ATPM workshop pose serious air-quality challenges due to an exhaust system that is not functioning optimally. Technical problems such as clogged ventilation holes from dirt buildup, damaged electrical capacitors, and broken fans block airflow, allowing vehicle exhaust to settle in the work area. As a result, mechanics experience health problems such as shortness of breath and vision impairment and must run vehicles outside the workshop to avoid exposure to exhaust fumes, which actually reduces work efficiency. In addition, emission test results show that some vehicles do not meet standards, exacerbating air pollution in the workshop. Therefore, an in-depth analysis of pollutant concentrations, such as CO and NOx, and a comprehensive evaluation of the ventilation system are needed to design solutions that create a healthy working environment while improving operational efficiency. The following is the design before and after the exhaust system optimization.

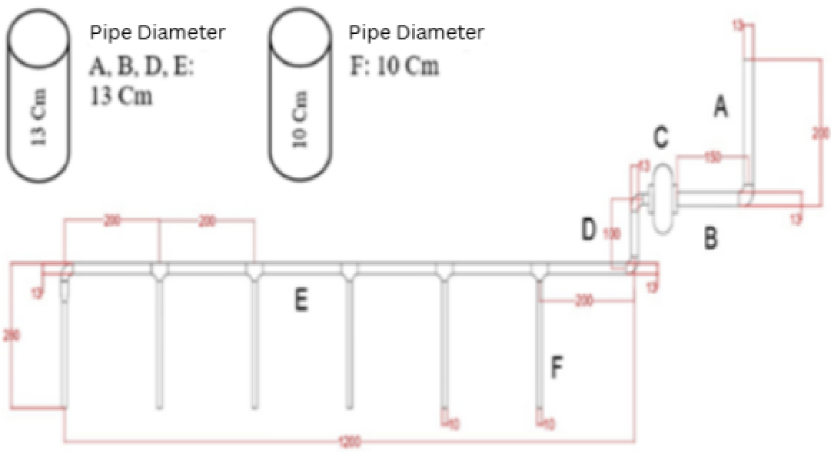

Figure 2. Design Before Exhaust System Optimization

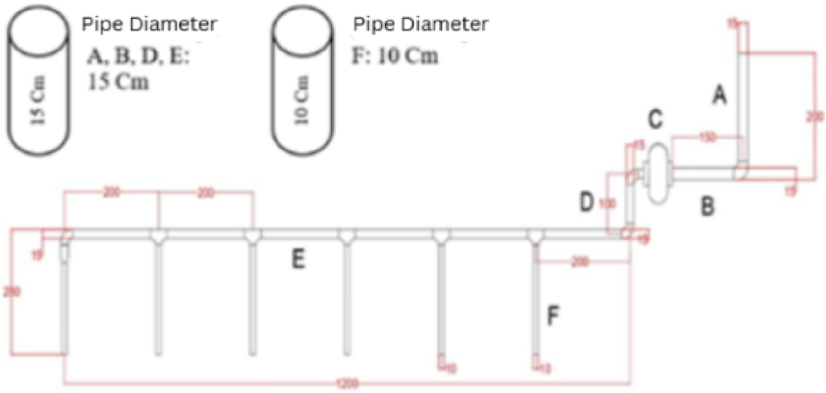

Figure 3. Design After Exhaust System Optimization

3.1.2 Product Development Stage

The product development stage in this study focused on optimizing the exhaust system without changing the main structural design. This process involved three main steps: modifying the pipe diameter to increase airflow capacity, repairing the electrical circuit due to damage to the capacitor and 3-phase insulator switch, and adjusting the control system to ensure more reliable, efficient system performance.

The final step is to measure air quality after repairs to assess the system's effectiveness in accordance with Permenaker No. 5 of 2018. The results of these measurements indicate the system's success in improving air quality and work comfort. These three stages are expected to yield an optimal, efficient exhaust system that can be implemented without major changes to the existing structure.

After evaluation and repair, the exhaust system at the Nissan Mlati ATPM workshop retained its main structural design, with a focus on functional improvements to maximize performance. The improvements included thoroughly cleaning the exhaust ducts of dust, dirt, and lint that were clogging them, as well as replacing the main connecting pipe with a capacity of 35.34 liters to restore air flow efficiency. Additionally, the damaged fan was replaced with a new, more efficient and durable unit. At the same time, the burnt capacitor was also replaced with a new component according to system specifications, all carried out in accordance with industry technical and electrical standards.

Figure 4. Image After Exhaust System Optimization

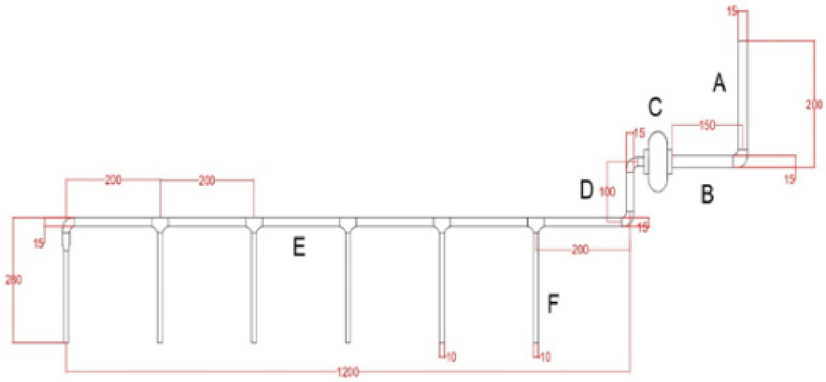

Figure 5. Exhaust System Design after Optimization

The exhaust system has been optimized through several technical improvements that remain consistent with the original design. Optimization was carried out by replacing burnt capacitors with new capacitors with specifications suitable for the fan motor load. The 3-phase isolator switch, which had been damaged by overcurrent, was also replaced. To ensure system reliability, electrical connections on the control panel were checked and reinforced to prevent potential current surges caused by loose contacts. All these repairs were also accompanied by a re-check of the current protection system and safety adjustments to ensure optimal protection under maximum load conditions.

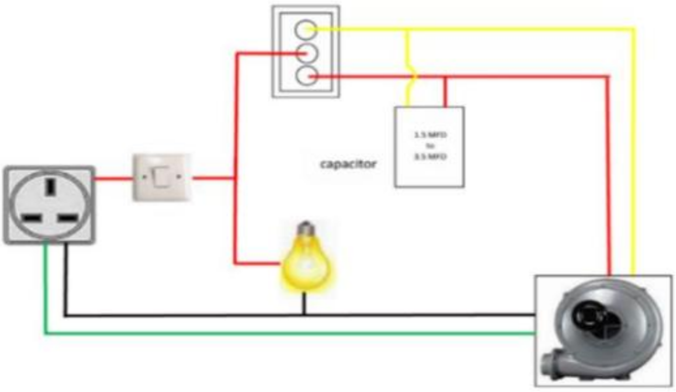

Figure 6. Electrical Circuitry of the Exhaust System After Optimization

The exhaust system at the Nissan Mlati ATPM workshop is now functioning optimally again after functional repairs: 6-inch pipe, 130 W/ 220 V motor rotating at 2,500 RPM, and a capacity of 720 CMH in a unit measuring 40 × 40 × 27 cm and weighing 5.25 kg, it efficiently vents exhaust gases again thanks to the replacement of the main pipe, fan, and capacitor according to specifications; Three-phase voltage distribution is stable without the need to change the basic structure, resulting in a longer system lifespan and daily operations that continue to meet occupational safety and health (OSH) standards.

After repairs to the exhaust system, air quality measurements were taken again in the area surrounding the workshop to determine current emissions and air pollution levels. These measurements aim to evaluate the effectiveness of the repairs and compare the results with data before the repairs. In addition, these measurements are used to ensure that the optimized exhaust system maintains the quality of the working environment air in accordance with the standards set by Permenaker No. 5 of 2018.

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by Environesia Company Group

LABORATORY TEST RESULT
HASIL PENGUJIAN LABORATORIUM
No. Report: 622.1284/LHU-GIG/III/2025

CUSTOMER *Nama Pelanggan*	: MAHASISWA UNIVERSITAS NEGERI YOGYAKARTA - M HERNANDA IQBAL
SAMPLE DESCRIPTION *Deskripsi Sampel*	: INDUSTRIAL HYGIENE (WORKSHOP BENGKEL (SESUDAH EXHAUST DINYALAKAN))
LABORATORY SAMPLE ID *Nomor Sampel Lab*	: IH-02
TIME OF RECIEPT *Waktu Penerimaan Sampel*	: 20 FEBRUARY 2025
COORDINATE *Koordinat*	: S 7° 46'10.632" E 110° 30'12.637"
TIME OF ANALYSIS *Waktu Analisis*	: 20 FEBRUARY - 05 MARCH 2025
SAMPLED BY *Pengambil Sampel*	: GREENLAB TECHNICAL TEAM (SYUHADA)
GOVERNMENT STANDART *Baku Mutu*	: PERATURAN MENTERI KETENAGAKERJAAN REPUBLIK INDONESIA NOMOR 5 TAHUN 2018 TENTANG KESELAMATAN DAN KESEHATAN KERJA LINGKUNGAN KERJA

No	PARAMETERS *Parameter*	UNIT *Satuan*	RESULT *Hasil*	STD. (MAX) *Baku Mutu*	TEST METHOD *Metode Uji*	CAL. RESULT OF MUE* *Hasil Perhitungan Estimasi Ketidakpastian Pengukuran*
1	Sulfur Dioksida (SO_2)	mg/m³	0.011	0.25	GSP. W-LAB-TS.089	0.001
2	Karbon Monoksida (CO)(*)	ppm	14,3	-	GSP W-LAB-TL.031	-
3	Nitrogen Dioksida (NO_2)(*)	BDS	0.006	0.2	SNI 7119-2 tahun 2017	0,0002
4	Oksidan (O_3)(*)	BDS	0,006	0.08	SNI 7119-8 tahun 2017	0,0002
5	Debu (TSP)	mg/m³	13,3	-	SNI 7119-3 tahun 2017	-

INFORMATION *Keterangan* : - *MUE : Measurement Uncertainty Estimation*
- (*) : Parameter Belum Terakreditasi
- "" : < Limit Deteksi

SAMPLING METHOD *Metode Pengambilan Sampel* : SNI 7230 tahun 2009

METEOROLOGICAL CONDITION		
1	Temperature	31,6 °C
2	Tekanan Udara	745,5 mmHg
3	Kelembaban	57,3 %RH
4	Kecepatan Angin	0,1 m/s
5	Arah Angin	Selatan ke Utara
6	Cuaca	Cerah

Yogyakarta, 05 March 2025
Technical Manager

Page 3 of 3

Figure 7. Air Quality Measurement Results After System Optimization

After repairing the exhaust system by cleaning the ducts, replacing the fan, and replacing the capacitor, laboratory test results showed a significant improvement in air quality. CO concentration dropped from 16.4 ppm to 14.3 ppm and TSP from 18.1 mg/m³ to 13.3 mg/m³. Other pollutant parameters, such as SO_2, NO_2, and O_3, also remained well below the thresholds set by Permenaker No. 5 of 2018. This proves that repairs without structural design changes can effectively restore exhaust function, creating a healthier and safer working environment.

3.1.3 Product Effectiveness Testing Stage

Metric volume testing (theoretical) was conducted to determine changes in system performance before and after the optimization process. Most parameters, such as stall volume, total workshop volume, and metric volume per minute for the east stall and the entire workshop, remained unchanged. This shows that optimization focused more on improving flow efficiency than on changing room volume. For certain variables, such as connecting pipes, the flow volume increased significantly after optimization. This data forms the basis for further analysis of the success of optimization in improving the performance of the flow distribution system in the workshop.

Applied air quality testing was conducted to evaluate the impact of the optimization process on the working environment, particularly the exhaust system and air pollutant levels in the workshop area. A comparison of test results between pre- and post-optimization conditions was conducted. After optimization, the exhaust system's speed and flow rate were measured correctly, indicating that the ventilation system was beginning to function effectively. In addition, the concentrations of several air pollutants, such as sulfur dioxide (SO2), carbon monoxide (NO2), and total suspended particulates (TSP), decreased, indicating an improvement in air quality. This is an early indicator that the optimization has had a positive impact on improving the health and comfort of the working environment.

Performance effectiveness testing was conducted to assess the extent of productivity improvements after optimizing the exhaust system in the workshop area. Based on the table below, a comparison was made between the conditions before and after optimization by measuring working time, hours worked per day, and the number of cars serviced.

Table 1. Performance Effectiveness Testing

No	Before Optimization		After Optimization	
	Combustion chamber cleaning unit	Time	Combustion chamber cleaning unit	Time
1	Nissan Navara	2 hours 15 minutes	Nissan March	1 hour 30 minutes
2	Nissan Livina	1 hours 50 minutes	Nissan Kicks	1 hour 30 minutes
3	Nissan Terra	2 hours 10 minutes	Nissan Juke	1 hour 40 minutes
4	Nissan X-Trail	2 hours 20 minutes	Nissan Serena	1 hour 50 minutes
5	Nissan March	1 hour 40 minutes	Nissan Livina	1 hour 20 minutes

Table 2. Performance Effectiveness Test Results

Condition	Processing Time	Working hours/day	Number Of Cars That Can Be Serviced
Before Exhaust Optimization	2 hours 3 minutes	8 hours	4 cars
After Exhaust Optimization	1 hour 34 minutes	4 hours	6 cars

The test results showed a significant difference: the processing time per vehicle unit decreased, and the number of cars serviced in a day increased. This data indicates that system optimization not only improves efficiency but also positively affects the workshop's overall service capacity.

3.2 Discussion

3.2.1 How to Optimize the Exhaust System at the Nissan Mlati ATPM Workshop?

Optimization of the exhaust system at the Nissan Mlati ATPM workshop was carried out in several stages, from problem identification to the repair of damaged components, such as broken fans and clogged ducts. The main objective of this process was to reduce the negative impact of exhaust gases on mechanics' health, such as shortness of breath and blurred vision. The optimization focuses on increasing airflow capacity and smoothness without altering the system's overall structural design. One important step is to increase the main pipe radius from 6.5 cm to 7.5 cm, increasing the pipe volume from 26.54 liters to 35.34 liters and resulting in smoother, more efficient air circulation.

The airflow rate was increased to 12 m³/minute in the eastern area and 24 m³/minute for the entire workshop, while maintaining air circulation time within the ideal standard. Although the airflow time increased slightly, the system's efficiency was maintained. This process aligns with the research by Roihan Muhammad Iqbal [10], which emphasizes the importance of functional design in exhaust systems, and with the research by Orisha Yuhan [11], which highlights the importance of regular maintenance and air distribution design. By adding a direct exhaust path from the vehicle to the exhaust system without altering the pipe dimensions at each stall, this workshop has successfully improved air efficiency significantly while meeting Occupational Safety and Health (OSH) standards.

Initially, the electrical exhaust system at the Nissan Mlati ATPM workshop sustained significant damage, including burned capacitors and 3-phase insulator switches. This problem indicated inadequate current protection due to voltage instability and excessive load. During the optimization process, repairs focused on replacing key components, namely capacitors and 3-phase isolator switches, with new versions that are compatible with the blower motor load. In addition, electrical connections on the control panel were checked and reinforced to prevent current surges caused by loose contacts, which could damage the system.

This optimization was carried out with reference to the technical specifications of the 130 Watt exhaust blower motor, 220 Volt voltage, 2500-RPM speed, 720-CMH airflow capacity, and a 6-inch-diameter pipe, ensuring the selection of new components was right on target. As a result, the voltage distribution became more stable, and the blower motor operated within its design capacity. This improvement significantly increases efficiency, extends the system's lifespan, and ensures workshop operations remain compliant with standards (K3). This comprehensive approach aligns with the findings of Comoglio [10], who emphasizes the importance of measuring environmental parameters as the basis for comprehensive improvements in workshop systems.

3.2.2 How effective is the optimized exhaust system at the Nissan Mlati ATPM workshop?

Metric volume testing on the exhaust system of the Nissan Mlati ATPM workshop is a crucial step in assessing the effectiveness of air circulation and the quality of the working environment. The test results show that after optimization, the volume of the main connecting pipe increased to 35.34 liters, and the volume of each pipe in the stall remained at 21.99 liters. The air volume for the six eastern stalls was recorded at 1,008 m³ and for the entire workshop at 2,184 m³. With flow capacities of 12 m³/minute and 24 m³/minute, respectively, this system efficiently removes vehicle exhaust gases and maintains air quality in the workspace.

The calculation of a fast airflow time of 0.002945 minutes for the eastern area and 0.0014725 minutes overall indicates the speed of the system's response in removing dirty air. This not only improves circulation but also reduces air resistance in the pipes. This optimization complies with ASHRAE (2003) and SNI 03-6572-2001 standards [11], which regulate artificial ventilation requirements based on room volume and pollution levels. Therefore, the optimized exhaust system is technically feasible and has created a healthier, more comfortable working environment for mechanics.

Testing the effectiveness of the exhaust system through actual use provides a realistic picture of its performance in workshop operating conditions. By simulating vehicle service activities, this test enables a comprehensive evaluation of the system's ability to manage exhaust gas and particulate emissions. Laboratory results show a significant decrease in carbon monoxide (CO) concentration from 16.4 ppm to 14.3 ppm, which remains well below the safe limit of 25 ppm set by Permenaker No. 5 of 2018. Additionally, the Total Suspended Particulate (TSP) level also decreased from 18.1 mg/m³ to 13.3 mg/m³, indicating a noticeable improvement in air quality. Other parameters, such as SO_2,

NO_2, and O_3, remained within safe limits, reinforcing that the system is operating optimally overall.

The application of this approach demonstrates that simple optimizations, such as replacing capacitors and 3-phase isolator switches, as well as adjusting pipe sizes, can have a significant impact without requiring major changes to the system structure. Air flow efficiency has increased, pipe resistance has decreased, and electrical stability supports consistent system performance. Overall, in terms of effectiveness and air quality, the optimized exhaust system is considered suitable for implementation because it not only meets technical and regulatory standards but also has been proven to improve workplace comfort and health significantly.

Optimizing the exhaust system at the Nissan Mlati ATPM workshop not only improves air quality but also significantly increases operational efficiency and work productivity. Before optimization, the average service time per vehicle was 2 hours, meaning that only four vehicles could be serviced in an 8-hour workday. Poor air quality caused health and comfort issues for mechanics, slowing down their work pace. After the exhaust system was improved, the processing time dropped to 1 hour and 30 minutes per vehicle, allowing up to 6 vehicles to be completed per day. This represents a 51.03% increase in productivity without additional working hours.

This improvement not only reflects time efficiency, but also a significant improvement in work comfort. Cleaner air contributes to concentration and physical endurance, thus directly impacting work effectiveness. These results reinforce those of Orisha Yuhan [12], who found that the effectiveness of air pollution control systems depends heavily on adequate maintenance and exhaust infrastructure. Thus, the optimization of the exhaust system in this workshop has proven feasible to implement, as it provides dual benefits: improved operational performance and worker health protection.

4. Conclusion

Based on the results of research and optimization of the exhaust system at the Nissan Mlati ATPM Workshop, it can be concluded that the optimized product, namely "an integrated exhaust system for automotive workshops," has been proven to improve air quality in the work environment significantly. The optimization of the system was carried out through several important stages, including:

1) Replacing the main connecting pipe from 6.5 cm to 7.5 cm increased the volume from 26.54 to 35.34 liters, and cleaning the pipe channels ensured smooth airflow. Replacement of fans and capacitors that can support motor performance and repair of the electrical system without changing the main structural design.
2) The results of this system optimization show a significant reduction in pollutant levels, such as carbon monoxide (CO), which decreased from 16.4 ppm to 14.3 ppm, and total suspended particulates (TSP), which decreased from 18.1 mg/m3 to 13.3 mg/m3. This reduction in pollutant levels is significant, given the negative impact that air pollution can have on worker health and the quality of the working environment.
3) The optimized exhaust system has had a positive impact on operational performance. Vehicle processing time has been reduced from 2 hours and 3 minutes to 1 hour and 34 minutes, enabling the workshop to increase the number of vehicles serviced from 4 to 6 per day. This optimization has resulted in a 51.03% increase. The exhaust system not only improves air quality but also increases work productivity, which is crucial in the competitive automotive industry.

4) The exhaust system product developed in this study is deemed suitable for implementation in supporting occupational safety and health (OSH) and workshop operational efficiency. The implementation of this system is expected to serve as a model for other workshops in creating a healthier, more productive work environment, as well as to contribute positively to worker safety and operational sustainability.

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