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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.

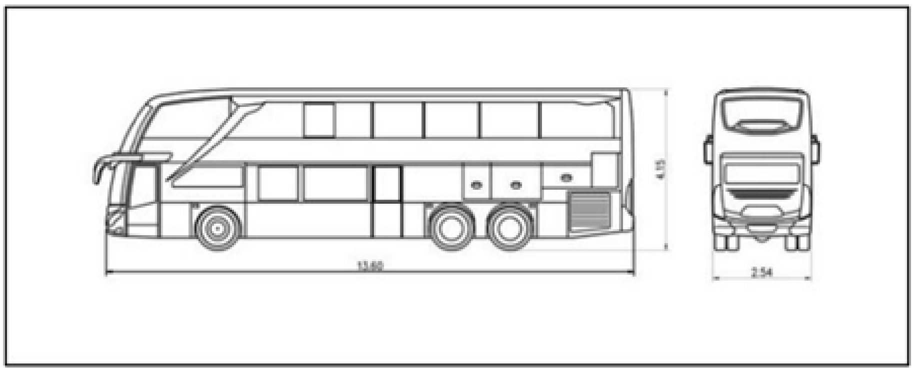

Figure 3. Bus Dimensions

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/m^3)	Index $MPa/(kg/m^3)$
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.

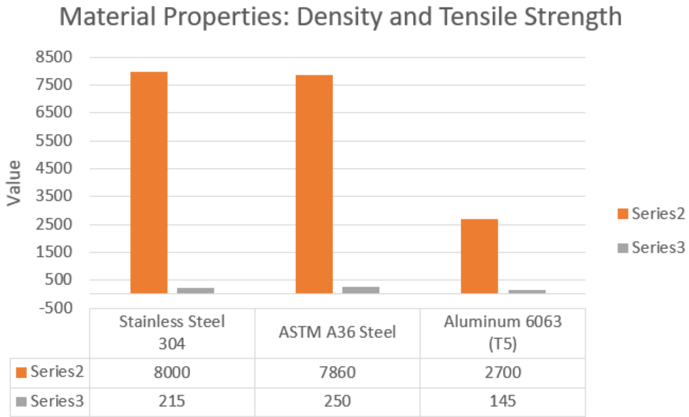

Figure 4. Material Graph

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).

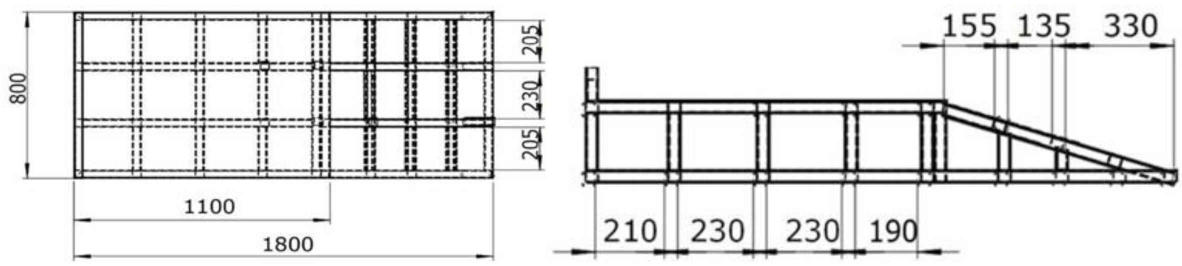

Figure 5. 2D Drawing

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.

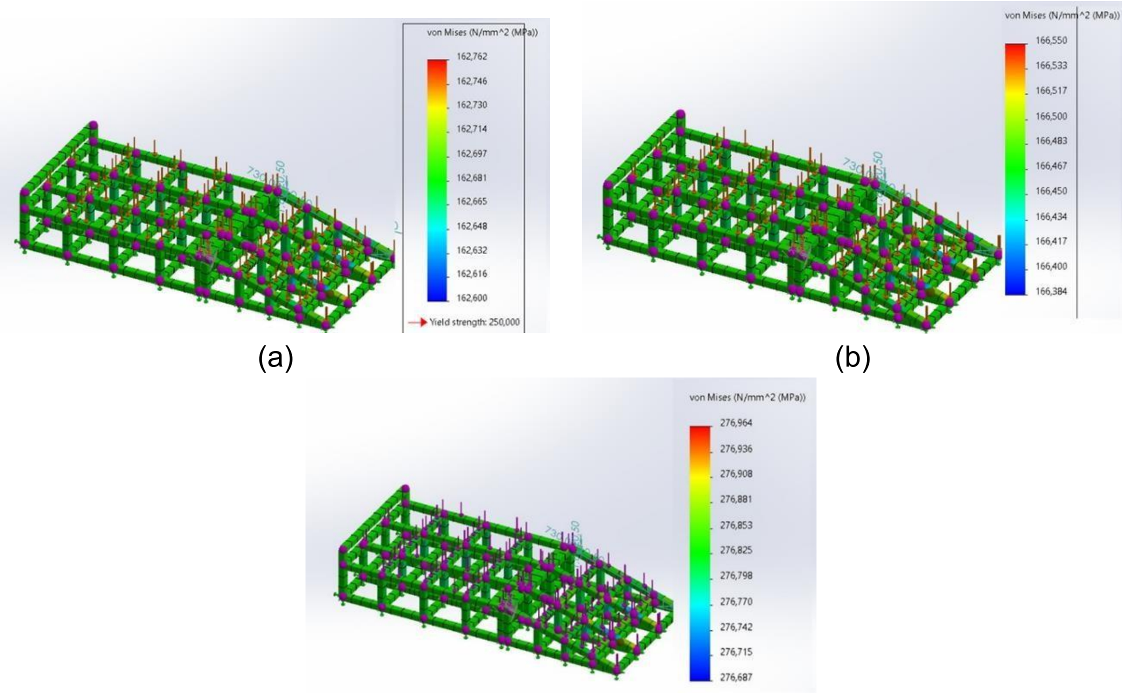

Figure 6. Von Mises stress of a) ASTM A36 Steel, b) Stainless Steel SS 304, and c) Aluminum 6063

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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