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Research paper

Analysis of Road Conditions Using the PCI and Bina Marga Methods on the Sanggau-Sekadau Section, West Kalimantan

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ABSTRACT

Purpose: This study aims to analyze the types of damage occurring on the national road section of the Sanggau-Sekadau city boundary and to determine the pavement condition using the Pavement Condition Index (PCI) method and the Bina Marga method. Additionally, this research seeks to identify suitable repair alternatives for the detected road damage, ensuring optimal road maintenance and serviceability.

Methods/Design: A quantitative research approach was applied, utilizing field surveys to collect direct data on pavement damage. The PCI method and the Bina Marga method were used to assess the severity and classification of road damage. Statistical analysis was conducted to determine the pavement condition and recommend the most effective repair strategies.

Findings: The results showed that potholes were the most dominant type of damage, contributing 36% of the total identified damage. Analysis using the PCI method resulted in an average score of 65.5, categorizing the pavement condition as Fair and requiring periodic rehabilitation. Meanwhile, the Bina Marga method gave the road section a priority rating of 5, indicating the need for scheduled maintenance. Repair recommendations based on the PCI method were patching and surface repair, while the Bina Marga method recommended asphalting (P2), crack sealing (P4), and patching (P5), adjusted according to the severity of the damage.

Practical implication: The findings of this study provide valuable insights for road maintenance agencies and policymakers in optimizing pavement management strategies. By utilizing both the PCI and Bina Marga methods, road authorities can make data-driven decisions to enhance road serviceability, minimize deterioration, and allocate maintenance resources efficiently.

INTRODUCTION

Infrastructure, defined as the physical structures that enable a society to function socially and economically, is the backbone of development. Its components include transportation networks (such as roads, bridges, and railways), energy systems, water supply and sanitation systems, and communication facilities (Wei *et al.*, 2015, 2018). These critical assets are highly vulnerable to the impacts of various natural disasters, such as earthquakes, floods, storms, and even climate change phenomena that exacerbate the intensity of extreme events (Intergovernmental Panel on Climate Change (IPCC), 2022). Infrastructure damage not only causes direct physical losses but also leads to cascading disruptions in the social and economic life of communities. For example, damage to road and bridge networks can isolate regions, disrupt supply chains and the distribution of goods, and impede access to emergency services, resulting in significant economic losses (Reed, Powell and Westerman, 2010). Furthermore, research in the Indonesian context shows that infrastructure damage due to disasters often exacerbates social inequality, with vulnerable groups experiencing the most severe impacts (Farid, Ellyzan and Oktavera, 2023). Therefore, building infrastructure resilience through adaptive design and risk-mitigating planning is very urgent (Wibisino *et al.*, 2022).

Roads, as land transportation infrastructure, play a crucial role in supporting economic activity and community mobility. Their function as interregional links, from villages to cities, between cities, and to centers of economic growth, makes roads a fundamental infrastructure for the distribution of goods, services, and people (Sudarno *et al.*, 2017). Legally, in Indonesia, roads are defined as land transportation infrastructure that encompasses all sections of the road, including complementary buildings and equipment, intended for traffic. This definition includes roads above, below, and on the ground surface, as well as over water, but excludes railways and cableways (Pemerintah Republik Indonesia, 2022). More than just a physical structure, the road network plays a key role in enabling regional economic growth and market integration (Bhattacharyay, 2010). However, the existence and condition of roads are not without challenges, such as premature damage due to excessive loads and environmental factors, which can significantly reduce their performance (Suroso, 2008). Therefore, sustainable road planning and management are essential to ensure reliable connectivity and support inclusive development (Litman, 2010).

In addition to serving as interregional connections, the existence and condition of roads directly facilitate economic activity, impacting three main pillars: the government (through tax revenue and service effectiveness), the community (through accessibility and mobility), and the business world (through logistical efficiency and market expansion). These positive impacts can only be optimally realized if roads are built and maintained to adequate technical standards, particularly in terms of pavement structural strength. Pavement structural strength is crucial to ensure adequate load-bearing capacity for passing vehicles without causing premature damage (Setiadi and Setyawan, 2017). In other words, good road performance is characterized by the use of appropriate materials, proper structural planning based on road class, and a level and durable surface that can serve the traffic load according to its intended use (Santhosh and Sridhar, 2024). Furthermore, poor pavement quality has been shown to significantly increase vehicle operating costs (VOC) and hamper regional economic productivity (Fahlevi, 2018).

Therefore, investment in the construction and maintenance of roads that meet standards is not only a technical issue, but also a strategic investment to encourage sustainable economic growth (German-Soto, Flores, and Bustillos, 2017).

Class III roads are one of the collector road classes that function as connectors in the road network system. In accordance with their functional classification, Class III roads serve motorized vehicle traffic at the arterial and collector service levels. In terms of technical specifications, Class III roads have limitations on dimensions and permitted vehicle axle loads, generally with a vehicle width of no more than 2,500 mm, a height of no more than 1,800 mm, and a maximum axle load of 8 tons (Maulana, Erwan and Sulandari, 2017). In addition to functional and technical classifications, the selection of pavement types is an important aspect in road planning. There are two main types of pavements commonly used: flexible pavements, which use asphalt as the surface layer, and rigid pavements, which use cement concrete (Taher, Alyousify and Hassan, 2020). The choice between flexible and rigid pavements for Class III roads must consider several factors, such as traffic intensity, local material availability, construction costs, and long-term maintenance costs (Rachmayati, 2014). A comprehensive technical-economic analysis is required to determine the optimal pavement type for the performance and design life of the road (Huang, 2004).

A pavement layer laid on compacted subgrade is known as road pavement. The primary factor in determining the level of safety and comfort is the structure used as the base, such as potholes in the subgrade (Wibowo and Endaryanta, 2017). West Kalimantan utilizes flexible pavement extensively as a road surface. Generally, asphalt and a layer of granular material are laid on top of each other to form flexible pavement (Maharani and Wasono, 2018). Through road maintenance activities, one can ensure the road is in prime condition. Good results must be achieved by organizing repair work according to a comprehensive road maintenance plan. Data collection, organization, and storage; asset management; and project management for road repairs are necessary examples (Fatah and Mulyono, 2014).

Road pavement layers will increasingly lose their serviceability and become damaged over time, and with the ongoing construction process (Daud, 2016). The increasing number of cars passing through the roads every day, and vehicle overloading, when the weight and volume of the load exceed the vehicle's capacity, can cause damage. Furthermore, natural factors such as rain can affect the stability of the soil, thus affecting and damaging the pavement layers. This is why roads must be built in accordance with applicable standards and requirements (Rahmawati, Iqbal and Adly, 2020). When certain sections of a road are damaged, this can slow down traffic in that area. The physical condition of the road surface, including the structural and functional properties that influence it, can provide detailed information about the extent of pavement damage (Arsyad and Ahmad, 2018).

Common damages include potholes, cracks, grain detachment, and collapse. Lack of maintenance will result in more severe damage. This will cause traffic to become less smooth and reduce comfort and safety when driving (Jalal *et al.*, 2023). Various factors can damage roads. Substandard subgrade compaction techniques, water, weather, air temperature, materials used to construct sidewalks, dangerous subgrade conditions, and vehicles passing on the road are some of them. Whether maintenance, improvement, or rehabilitation, road pavement construction will be handled depending on whether the cause of the damage can be identified (Yudaningrum and Ikhwanudin, 2017).

Pavement damage in Indonesia is caused by several main factors. One of the main causes is the heavy loads carried by heavy vehicles. This excessive load causes permanent deformation of the road pavement that does not comply with the equivalent axle load (EAL) calculations used in road planning in Indonesia (Prastyanto and Hidayat, 2023). Furthermore, damage is also caused by the failure of the subgrade bearing capacity. Expansive soils, which are commonly found in Indonesia, have large swelling and shrinking properties that are strongly influenced by water. When the soil expands, the road surface becomes uneven and bumpy, which causes damage to the pavement structure. One of the provinces in Indonesia experiencing quite severe road damage is West Kalimantan (Kumalasari, Prayogo and Febriansya, 2020).

Data from the Central Statistics Agency (BPS) of West Kalimantan Province in 2014 showed that 37.64% of the total road length in the province was in poor condition: 5,209.22 km. On the other hand, 8,630.69 km, or 62.36% of the roads, were in very good condition, a combination of good and moderate conditions. Equivalent to 4,551.20 km, district and city roads accounted for 91.28% of the total road conditions that did not meet standards. As a result, the overall road condition in West Kalimantan Province is highly dependent on the status of district and city roads. The national road section of the Sanggau-Sekadau city boundary is the only connecting route between cities in West Kalimantan and the city that experienced damage in Sanggau city, Potholes 2.19 km of severe damage, 59.55 km of damaged condition, 51.02 km of moderate condition, and 36.55 km of Good condition, and in Sekadau city the condition of severe damage is 3.29 km, 70.73 km of damaged condition, 45.58 km of moderate condition, and 42.52 km of Good condition then from the central axis of the Kalimantan cross-road or the Sanggau-Sekadau City Boundary road, many damages were found such as potholes, all of which will greatly affect the comfort and safety of road users: often flooded during the rain; Alligator Cracking; loose road legranules; need for patching. Field studies show that the Sanggau-Sekadau City border road is experiencing very serious damage. This route is often crossed and passed, especially during the holiday season when traffic on this road increases rapidly. Therefore, the condition of the road surface is getting worse.

From the observation results, there are four types of damage with a road width of 5 m, then the observation starts from Sta 20 + 000-23 + 000 to Sta 32 + 000- Sta 39 + 000 and the data obtained on the types of damage that occurred on this road are alligator cracking as many as 29 points of damage, Potholes as many as 50 points of damage, Raveling as many as 39 points of damage, patches as many as 22 points of damage. To find out the value of the road pavement and the steps that should be taken in handling damage to the national road on the Sanggau-Sekadau City boundary section, an in-depth analysis of the road damage that occurred must be taken to know the actions that should be taken by the authorities in handling damage to the central axis of the Kalimantan cross-road or the Sanggau-Sekadau city boundary road so that community mobilization and economic activities in the city run well.

METHODS

This study employs a quantitative approach aimed at analysing the road damage condition on the Kalimantan Tengah main highway, specifically on the Sanggau-Sekadau border segment in West Kalimantan. A quantitative approach was chosen for this research because it focuses on collecting numerical data to objectively describe the road damage conditions and provide a solid foundation for prioritizing road repairs. Through this approach, it is expected that precise and measurable data will be collected regarding road damage, which can then be analysed using statistical methods to generate appropriate recommendations for infrastructure improvements.

The research procedure begins with the selection of the study location, which focuses on the national road segment connecting the Sanggau and Sekadau regencies. This particular location was chosen due to its importance as a primary route linking these two regencies, making it crucial to assess the road conditions as part of the infrastructure development efforts. The study covers a 10-kilometer segment, specifically from STA 20+000 to STA 23+000, and from STA 32+000 to STA 39+000. This selection was made because the road serves as a vital transport corridor. The road has a total width of 5 meters, with each lane measuring 2.5 meters. To ensure representativeness, data collection was carried out every 500 meters along the specified segments, thereby obtaining data that accurately reflects the road damage conditions across different sections.

The data collection process involves both primary and secondary data. Primary data is collected through field surveys, where researchers directly observe and measure road conditions. The field surveys are intended to identify the types of road damage and their dimensions in each surveyed segment. The instruments used in this survey include measuring tapes for measuring the extent of damage, a push meter for distance measurement, and spray paint for marking the damage locations. Additionally, survey forms and written notes are used to record relevant information about the types of damage, such as potholes, Alligator Cracking, aggregate loss, and patch repairs. A camera is also utilized to document the road conditions visually. The survey is carried out with great care and systematic attention to ensure that the data collected is valid and reliable for further analysis.

Secondary data is also utilized to supplement and enhance the analysis. This data is obtained from various sources, such as the Public Works and Housing Department of West Kalimantan, which provides information on the Average Daily Traffic (ADT) for the studied road section, as well as maps of the road segment, road classification, and existing documentation of prior road damage. The ADT data is crucial for understanding traffic density and its potential impact on road conditions. The road maps and classification details offer additional context about the physical and structural characteristics of the studied road, while the existing damage documentation helps identify previously recorded issues. These secondary data sources complement the primary data, providing a more comprehensive understanding of the road's condition.

The data analysis procedure begins once the primary and secondary data have been collected. Two main analysis methods are employed: the Pavement Condition Index (PCI) method and the

Bina Marga method. The PCI method is used to assess the extent of road damage based on the type and severity of the observed damage. The analysis process begins by classifying the different types of damage observed in the field into categories of low, medium, and high severity. The damage extent is then measured and quantified, and a deduction value is applied based on the severity of the damage, following the PCI guidelines. The deduction value is further adjusted to account for specific road conditions, resulting in a corrected deduction value (CDV). The PCI score is then calculated for each road segment. Based on the PCI score, the road's condition is classified into various categories, ranging from very poor to very good. A table defining the condition categories based on PCI scores is used to provide a clear picture of the severity of road damage across the different sections of the road.

In addition to the PCI method, the Bina Marga method is also applied to analyze the road damage. This analysis method begins with the measurement of the Average Daily Traffic (ADT), which helps determine the road's traffic class. Traffic density data is important for understanding the potential impact on the road's structural integrity. The severity of the damage is also measured according to Bina Marga's criteria for road maintenance. This includes assessing the damage type and calculating the necessary repair actions. After assessing the damage, priority is assigned to the sections of the road most in need of repair, based on the severity of the damage and the traffic impact.

Once the damage analysis is completed, the next step is to determine appropriate repair alternatives based on the damage type and severity. Under the PCI method, the types of damage, such as potholes, Alligator Cracking, or aggregate loss, are categorized according to their severity. Based on these classifications, suitable repair alternatives are selected, such as patch repairs for low-severity damage or structural rehabilitation for high-severity damage. The Bina Marga method helps determine whether the required maintenance is routine or rehabilitation, considering the extent of the damage and the necessary intervention level. The results of the analysis will provide recommendations for repairs aimed at improving the road's condition.

FINDINGS

The damage observed in Sanggau-Sekadau at STA 20+000-22+000 and 32+000-39+000 can be categorized into four different types of damage. Potholes, Raveling, Alligator Cracking, and patches, and the Raveling that occurred on the road section can be seen in Figure 1 that most of the damage is dominated by Pothole damage, Potholes 36%, then Raveling 27%, Alligator Cracking 21%, and finally Patches 16% of the total road damage samples.

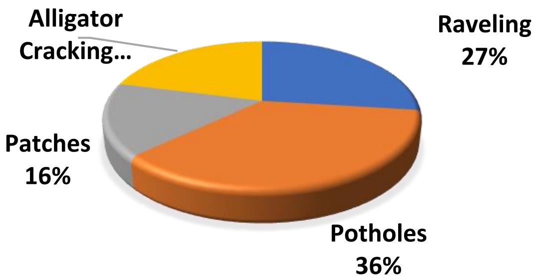

Figure 1. Diagram Percentage Road Damage

Patches on the surface of the road happen because of various factors that are mutually related. First, the pressure of heavy vehicle Which passing by can damage the surface road. Then, use material of low or Improper mixing of road layers also worsens the situation. Environmental factors, like extreme weather, are also influential because changes in temperature and rainfall accelerate damage. In addition, the system drainage causes water to flood, so that it speeds up the damage to the surface. Combining all factor This results in damage in the form of patches in the road. Damage to patches is measured according to their diameter. example Wrong One patches damage. This happened on the road limit in Sanggau-Sekadau city, West Kalimantan. STA 2+000 damage happen edge of the pavement

Damage patches happen throughout STA 20+000-24+000, and STA 32+000-39+000, with total damage. Potholes, 50-point patches from the results of the patches analysis, are the most dominant damage with 36%, compared to other example damage, which can be seen in Figure 2 below.

Figure 2. Damage Patches

Cracks on the road surface often occur due to the use of coating materials that do not meet quality standards. In addition, unstable or low-moisture base soil, Which No in accordance Also can also become the cause. Other factors that play a role include extreme temperature changes, vehicle load, as well as the influence of the weather and environment around. The interaction between these various factors can worsen road conditions, so analysis is needed. in-depth to identify the root cause and find the right solution. An example of one of the Alligator Cracking damages occurred on the Sanggau-Sekadau city boundary road in Kalimantan city, west STA 2+000 damage happen edge of the pavement.

Table 1. Damage Alligator Cracking

Level of Damage	Damage Identification
Medium	Crack pattern is parallel to each other, with lines connecting and random cracks. For damage road, this is classified as damage currently

Alligator Cracking Damage occurs throughout STA 20+000- 24+000 and STA 32+000-39+000 with total damage that is 29 poin Alligator Cracking, which can be seen on Table 1. The results of the analysis showed quite a lot of damage, Potholes 21% of the total damage. For example, damage can be seen in Figure 3, following this.

Figure 3. Damage Alligator Cracking

One of the causes of patch damage is the application of an inappropriate installation method, so that the patch surface becomes uneven or not parallel to the surrounding area. This imperfection can occur due to a lack of compliance with the correct installation procedures or the use of materials that do not meet standards. As a result, the patch becomes unstable, reducing the comfort of road users and triggering further damage to the road infrastructure. An example of one of these patch damages occurred on the Sanggau-Sekadau city boundary road, Kalimantan West. STA 2+000 damage happen edge pavement, which can be seen in Figure 4 and the description in Table 2 below.

Table 2. Patch Damage and Excavation

Level of Damage	Damage Identification
High	The patch is slightly damaged, and the comfort of the driver is disturbed. For the patch on the BTS Sanggau-Sekadau STA 2+000 road with an area of 1.3 m, it is categorized as High Severe damage

Patch damage occurred along STA 20+000-24+000 and STA 32+000-39+000, with a total damage of 22 patch points from the analysis results, which is quite a lot of damage, with 16% of the total damage. An example of the damage can be seen in Figure 4 below.

Figure 4. Patch Damage and excavation

Granular Detachment is damage to the road surface caused by various factors, one of which is high traffic load. This excessive load inhibits the optimal integration process in the road foundation layer. As a result, the asphalt layer on the top is damaged until the asphalt is released from the wearing layer. Condition: This impact on the decline in quality and overall road safety, so evaluation and repair are needed to prevent further damage in the future. an example of one of these granular release damages occurred on the Sanggau-Sekadau city boundary road, West Kalimantan City. STA 2+000 damage occurred at the edge of the pavement, which can be seen in Figure 5 and the description in Table 3 as follows.

Table 3. Damage Release Details

Level of Damage	Damage Identification
High	In the form of Surface Paving Which Rough Texture Many also lose the grain between >10%, the area lost, aggregate type damage, this goes into the level Heavy

Raveling Damage occurs along STA 20+000- 24+000, and STA 32+000-39+000 with total damage that is 38. The point of grain release from the analysis results shows quite dominant damage, with Potholes 27% of the total damage.

Figure 4. Damage Release Details

In Table 4, there is a recapitulation of the results of the analysis and calculations. use method PCI (*Pavement Condition Index*), which shows the overall value of the road is 65.5. According to the PCI method, pavement quality qualification includes seven categories of condition assessment with a value range of 0-100, from the worst to perfect. With a PCI value of 65.5 on the Sanggau-Sekadau road STA 20+000-24+000 and 32+000-39+000, the condition of the road pavement is stated to be in the Fair category. *Fair* condition means that the road has a relatively moderate level of damage, so it requires periodic maintenance to maintain its quality.

Road damage analysis after calculating traffic volume survey data, determining road class values, measuring damage dimensions, determining parameters for each damage, and based on the Bina Marga method, a priority order value of 5 has been established, which leads to the inclusion of roads in a certain order in the periodic repair program. Every year, we carry out routine maintenance, and at certain intervals, we carry out periodic maintenance. On the other hand, road improvement programs are implemented to handle unforeseen conditions, such as repairing roads that have been severely damaged by natural disasters.

Table 4. Results Analysis Method PCI

STA	Mark PCIS	Condition
0+000-1+000	76	Enough Good
1+000-2+000	56	Currently
2+000-3+000	70	Currently
3+000-4+000	69	Currently
4+000-5+000	54	Bad
5+000-6+000	55	Bad
6+000-7+000	53	Bad
7+000-8+000	75	Enough Good
8+000-9+000	80	Enough Good
9+000-10+000	66	Currently
Average	65.5	Currently

The PCI method determines the handling of damage on flexible pavement roads based on the road class and the type of damage that occurs. As an illustration, analysis and calculations on the Sanggau-Sekadau road section at STA 20+000-24+000, STA 32+000-39+000, and Km 1+000 identified damage in the form of Alligator Cracks with a damage level of Medium (M). In accordance with the PCI method, the appropriate treatment for this condition is partial patching. Different types of damage, such as potholes, alligator cracks, patches, and granular detachment, require different treatment methods, and the results guide several treatment procedures, Potholes patch replacement, not yet necessary for repair, partial patching, patching at all depths, and patching and covering the layer. Then, for the type of activity from the entire Sanggau-Sekadau sample area, there are two types of activities, Potholes rehabilitation maintenance and routine maintenance, where there is more routine maintenance.

The Bina Marga procedure follows the standard repair protocol established by the Directorate General of Bina Marga in 1995, Volume II, for addressing pavement damage in flexible layers. P1 refers to sand spreading techniques, while P2 relates to asphalting. P3 indicates crack sealing, P4 relates to crack patching, P5 relates to pothole patching, and P6 involves leveling. These six methods are tailored to address the various forms of damage found on road surfaces. For example, on the Sanggau–Sekadau road section at Km 1+000, a pothole was found with an area of 0.14 m^2 and a depth of 0.059 m. The appropriate treatment type for this damage is P5 (Pothole Patching), as the pothole depth is >50 mm. On the Sanggau-Sekadau Section STA 20+000-24+000 and 32+000-39+000, there are several types of repairs, Potholes P2 and P5, then for the types of activities carried out for all sections according to the periodic maintenance program for all sample sections.

PRACTICAL IMPLICATION

The practical implications of this study are far-reaching, particularly when considering the importance of infrastructure development and effective road maintenance in Indonesia. As a growing nation with a rapidly expanding population, the road infrastructure in Indonesia plays a crucial role in connecting people, facilitating trade, and ensuring public safety. This research on the road conditions of the Sanggau-Sekadau national road offers valuable insights that can be utilized by policymakers, urban planners, and local authorities to address road deterioration issues effectively. Road damage, especially in areas critical to economic activities and transportation, not only impacts safety but also leads to an increase in transportation costs, delays, and accidents, which can undermine the economic stability and social well-being of communities. This study provides a solid foundation for informed decision-making regarding road repair and maintenance strategies, emphasizing the need for prioritized interventions based on the severity of the damage.

A major practical implication of this research is the identification of road damage across various sections of the Sanggau-Sekadau national road. Using established methodologies like the Pavement Condition Index (PCI) and Bina Marga assessments, the research effectively categorizes the severity and extent of road damage. This systematic approach allows for a more precise understanding of where immediate repairs are needed, which in turn ensures that limited resources are allocated to the most critical areas first. This approach reduces the risks associated with road failure, such as accidents and further damage, and optimizes the use of available maintenance budgets. For example, sections of the road with severe damage, such as large potholes or cracking, may require immediate rehabilitation to prevent deterioration and maintain a safe and functional road network. By identifying and prioritizing these high-risk areas, the study provides a clear framework for road authorities to follow when planning repairs.

This study's practical contributions go beyond road repair prioritization; it also emphasizes the significance of traffic data in determining maintenance strategies. High-traffic roads tend to deteriorate faster due to increased wear and tear from the daily movement of vehicles. By incorporating traffic data such as the Average Daily Traffic (ADT) and vehicle load, this study provides a comprehensive analysis of how traffic density influences the rate of road damage. Roads with heavy traffic volumes are at a higher risk of rapid deterioration and may require more frequent maintenance. Consequently, this research allows infrastructure planners to take traffic patterns into account when allocating resources for repairs and maintenance. By combining damage data with traffic information, policymakers can ensure that the most critical roads, those that experience high traffic volumes, are prioritized for repair, preventing accidents and improving the safety and efficiency of the transportation network. Moreover, this data-driven approach enables future forecasting, helping authorities anticipate future maintenance needs based on traffic growth projections.

One of the key practical implications of the study is its contribution to road safety. Poorly maintained roads are a significant factor in the increasing number of road accidents, as they often feature hazards such as potholes, cracks, and uneven surfaces. These conditions not only lead to vehicle damage but also pose a direct threat to drivers and pedestrians. In regions with high traffic density, the risks associated with road damage are amplified. By pinpointing the specific areas of the Sanggau-Sekadau road with severe damage, this study provides actionable insights for road authorities to enhance safety measures. For instance, these findings can guide the implementation of safer road surfaces, improved signage, proper drainage solutions, and more effective road repairs. By addressing these critical safety concerns, the study can help mitigate accident rates, reduce vehicle repair costs, and ultimately save lives. These safety improvements not only benefit local commuters but also create a safer environment for businesses, tourists, and other road users.

The practical implications of this research also extend to the broader community, including residents and businesses. Well-maintained roads ensure smoother transportation, reduce travel time, and improve access to essential services such as healthcare, education, and markets. When roads are properly repaired and maintained, businesses benefit from reduced logistics costs, more reliable transportation for goods, and better access to a wider range of customers. This has a positive impact on the local economy, as transportation is a key factor in driving economic activity. Small and medium-sized enterprises (SMEs) in particular stand to benefit from lower operational costs, leading to increased profits and job opportunities. Additionally, improved road quality contributes to regional development by fostering better connectivity between urban and rural areas. Rural communities, in particular, benefit from enhanced mobility, enabling them to engage in economic activities, access public services, and improve their standard of living. Thus, this study indirectly supports broader socioeconomic development by promoting better infrastructure.

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