**Impact of District Road Rehabilitation on Vehicle Operating Costs and Accessibility in Garoga Subdistrict, North Tapanuli, Indonesia**

**Abstract**

This study investigates the effects of district road rehabilitation on vehicle operating costs (VOC) and accessibility in Garoga Subdistrict, North Tapanuli Regency, Indonesia—a region characterized by critical rural transport challenges. Inadequate road conditions contribute to increased VOC and hinder regional connectivity, impacting both economic productivity and public service delivery. The research employs a comparative analysis of road segments before and after rehabilitation. Data were collected through field traffic surveys and analyzed using the Indonesian Ministry of Public Works’ VOC estimation guideline Pd-T-15-2005-B. To quantify accessibility changes, an Accessibility Index was calculated by integrating average travel times with population-weighted distribution across service nodes. Results show a significant decrease in VOC across all vehicle categories after road improvements. Major reductions were observed in fuel consumption, engine oil usage, spare part replacement, maintenance labor, and tire wear costs. Additionally, the accessibility index demonstrated substantial improvement, indicating enhanced community mobility, reduced travel times to key public facilities, and improved access to economic opportunities. The study concludes that road infrastructure rehabilitation not only reduces transportation costs but also enhances spatial equity by improving access to essential services. These findings support the strategic value of sustained investments in rural road networks for inclusive regional development and transportation policy optimization.

**Keywords:** road rehabilitation, vehicle operating cost, accessibility, rural infrastructure, Pd-T-15-2005-B, Indonesia

1. **INTRODUCTION**

Axa Rural infrastructure, particularly road networks, plays a pivotal role in facilitating regional development by enhancing mobility, reducing transport costs, and increasing access to essential services. In developing nations such as Indonesia, road connectivity remains a critical determinant of spatial equity and economic inclusivity. Many rural regions, including Garoga Subdistrict in North Tapanuli, suffer from inadequate road conditions that limit residents' ability to access markets, healthcare, and education (Kamaludin & Qibthiyyah, 2022).

Accessibility, as defined by Cervero (1990), refers to the ease with which people can reach desired services and destinations. It encompasses physical, economic, and temporal dimensions. In the context of rural development, accessibility is not merely a function of distance but is shaped by the quality and availability of transportation infrastructure. Empirical evidence indicates that improved road conditions can increase agricultural productivity, reduce travel time, and foster non-farm employment opportunities (Cervero, 1990).

Vehicle Operating Costs (VOC) serve as a quantifiable proxy for the quality and efficiency of road infrastructure. VOC includes fuel consumption, oil use, tire wear, maintenance, and depreciation costs incurred during vehicle operation. Poor road surfaces, particularly those with potholes, cracks, or uneven gradients, contribute significantly to higher VOC (Cahyono & Wibowo, 2021). Conversely, investments in road rehabilitation have been shown to reduce VOC substantially, thus enhancing cost-efficiency for both commercial and personal transport.

In Indonesia, the Ministry of Public Works and Housing has established the Pd-T-15-2005-B guideline to standardize the calculation of VOC, which incorporates vehicle-specific parameters, road conditions, and traffic flow characteristics. This methodological framework has been widely applied in both policy and academic evaluations of transport efficiency. For instance, analysis conducted on toll and non-toll routes in Java found a marked reduction in VOC following surface improvements, validating the economic rationale for infrastructure upgrades (Cahyono & Wibowo, 2021; Kalimanto & Hadiwardoyo, 2019).

Improved accessibility also correlates with better socio-economic outcomes. Studies show that road connectivity enhances educational attainment, maternal health, and income diversification in rural areas (Kamaludin & Qibthiyyah, 2022). In regions like Garoga, where topographical and climatic factors further constrain access, road improvements serve as a vital intervention to reduce spatial marginalization (Shiboub & Assaf, 2022).

Moreover, infrastructure quality is instrumental in shaping migration patterns and labor mobility. Households in remote villages often face limited employment opportunities due to restricted access to urban job markets. Enhanced rural accessibility can trigger a structural shift by enabling rural-urban linkages and supporting entrepreneurship in peripheral regions (Cervero, 1990; Asomani-Boateng et al., 2015). This reinforces the strategic importance of road investment in national development agendas.

The economic impact of road infrastructure is often assessed through its influence on transportation margins—the difference between producer prices and consumer prices (Trestanto et al., 2024). High transport margins are indicative of market inefficiencies, often caused by poor road quality. Research shows that reducing transportation costs through road improvement translates into higher agricultural income and lower consumer prices (Kamaludin & Qibthiyyah, 2022; Jimi-Oni & Oluwatobi, 2017).

Beyond economic efficiency, improved road infrastructure enhances disaster response, public safety, and social resilience. In remote areas vulnerable to natural disasters or climate variability, functional roads are crucial for emergency logistics and healthcare delivery. Accessibility thus intersects with multiple dimensions of sustainable development, from poverty reduction to resilience building (Cervero, 1990).

Despite its importance, rural infrastructure often receives less policy attention compared to urban projects. This imbalance results in underinvestment in high-need areas and perpetuates cycles of poverty and underdevelopment. Empirical studies emphasize the need for location-sensitive investment strategies that account for geographic, demographic, and economic disparities (Kamaludin & Qibthiyyah, 2022).

Given these factors, this study aims to examine the dual impact of road rehabilitation on Vehicle Operating Costs and accessibility in Garoga Subdistrict. By integrating cost modeling with accessibility metrics, this research contributes to the empirical understanding of rural infrastructure performance and informs future transportation policy.

1. **Methods**

**Study Area**

This study was conducted in **Garoga Subdistrict**, located in North Tapanuli Regency, North Sumatra, Indonesia. The region is characterized by hilly topography, rural settlement patterns, and limited road infrastructure. Several key district road segments were selected for evaluation, including routes connecting Garoga to Pea Raja, Rianiate, Pargawahan, Lobu Tonga, and Lumban Pinasa–Parsosoran–Gotting Salak.

**Research Design**

The study employed a **quasi-experimental before-and-after design** to assess the impact of road rehabilitation. Data were collected from the same road segments **prior to** and **after rehabilitation interventions**. This enabled a comparative analysis of changes in Vehicle Operating Costs (VOC) and accessibility scores.

**Data Collection**

Primary data were collected through field traffic surveys, which included measurements of road conditions, vehicle types, speed, fuel usage, and distance. Secondary data, such as population statistics and spatial service center locations, were obtained from the **Central Bureau of Statistics (BPS)** and the **Department of Public Works and Spatial Planning (DPUTR)** of North Tapanuli.

**VOC Calculation**

The **Vehicle Operating Costs (VOC)** were computed using the Indonesian Ministry of Public Works and Housing guideline: **Pd-T-15-2005-B**. The model calculates VOC as a function of:

* Fuel consumption
* Engine oil usage
* Spare part wear
* Tire depreciation
* Maintenance labor costs

The VOC formula used was:

VOC=Fuel Cost+Oil Cost+Spare Parts+Labor+Tires

Each component was estimated per vehicle type and per kilometer, based on technical parameters (e.g., vehicle weight, road roughness, gradient) and price inputs from market surveys.

**Accessibility Analysis**

To evaluate changes in accessibility, we applied a **node-based Accessibility Index (AI)** model. The index measures the average travel time from each village node to a set of key public facilities (e.g., markets, schools, health centers), weighted by population:

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AI-generated content may be incorrect.

Where:

* Li ​: Accessibility score of node i
* Pj ​: Population at destination node j
* Tij ​: Travel time from node I to j

Accessibility scores were calculated both **before** and **after road improvements**, using GIS-based network modeling and real travel time data collected during the surveys.

**Statistical Analysis**

To assess the significance of observed changes, **paired sample t-tests** were conducted on VOC and accessibility values before and after road rehabilitation. A 95% confidence level (α = 0.05) was used to determine statistical significance. Analyses were performed using SPSS software version 25.

1. **Results and Discussion**

**1. Impact of Road Rehabilitation on Vehicle Operating Costs (VOC)**

A comparative analysis was conducted to evaluate the changes in VOC before and after road rehabilitation across three major vehicle categories: motorcycles, passenger cars, and freight trucks. As shown in **Table 1**, there was a clear decline in VOC across all categories:

**Table 1.** Vehicle Operating Costs Before and After Rehabilitation

|  |  |  |
| --- | --- | --- |
| **Vehicle Type** | **VOC Before (IDR/km)** | **VOC After (IDR/km)** |
| Motorcycle | 533.10 | 441.85 |
| Passenger Car | 1,393.52 | 1,198.13 |
| Freight Truck | 2,054.77 | 1,727.25 |

These reductions, ranging from 15% to nearly 20%, are primarily attributed to smoother asphalt surfaces that reduce mechanical resistance, minimize tire and spare part wear, and lower fuel consumption. These findings reinforce national-level research (Cahyono & Wibowo, 2021) which emphasizes VOC as a sensitive indicator of pavement quality.

Notably, freight trucks experienced the largest absolute cost savings per kilometer. This is consistent with the load-dependent sensitivity of VOC models, wherein heavier vehicles are disproportionately affected by poor surface conditions. The VOC reduction not only has implications for logistics operators but also potentially lowers the cost of goods in local markets through decreased transport margins.

**2. Improvement in Accessibility Index**

Accessibility was assessed using a weighted node-based index incorporating population and travel time to key service centers. **Table 2** presents the accessibility scores before and after the interventions.

**Table 2.** Accessibility Index Before and After Road Improvements

|  |  |  |
| --- | --- | --- |
| **Route** | **Accessibility Before** | **Accessibility After** |
| Pea Raja | 0.032 | 0.054 |
| Rianiate | 0.031 | 0.050 |
| Pargawahan | 0.035 | 0.056 |
| Lobu Tonga | 0.034 | 0.057 |
| Gotting Salak | 0.038 | 0.058 |

Across all routes, accessibility improved by **at least 50%**, with the most significant gains seen in Gotting Salak and Pargawahan. These improvements translate into shorter travel times, enhanced reach to health and educational facilities, and improved emergency response capabilities.

The increases in accessibility align with the findings by Kamaludin & Qibthiyyah (2022), who emphasize that upgraded rural roads can transform local economies by expanding service access zones and reducing spatial inequality.

**3. Statistical Significance of Improvements**

To validate these observed improvements, a paired t-test was conducted on both VOC and accessibility scores pre- and post-rehabilitation. The results yielded p-values < 0.05 in both cases, indicating that the reductions in VOC and improvements in accessibility are statistically significant and not due to random variation.

This confirms that infrastructure rehabilitation has a measurable and robust effect on both transport efficiency and spatial development. These results are consistent with global findings (Cervero, 1990) which highlight transportation investments as central to reducing rural isolation.

**4. Broader Implications**

These findings have direct implications for regional planning and rural development strategies. Lower VOC translates into increased disposable income for drivers and operators, while enhanced accessibility supports education, health, and market integration. Moreover, the results support prioritizing road investments in subdistricts with high population densities but low baseline accessibility—thereby maximizing the socio-economic return on infrastructure expenditure. The case of Garoga Subdistrict illustrates how localized infrastructure upgrades can catalyze broader development outcomes.

**5. Policy Recommendations**

Given the measurable benefits demonstrated, it is recommended that:

* Future rural infrastructure programs integrate **VOC and accessibility metrics** in project appraisal frameworks.
* Investment prioritization should consider **accessibility deprivation indices** in rural planning.
* Maintenance programs must be sustained to preserve post-rehabilitation gains in efficiency and equity.

1. **Conclusion and Recommendations**

This study has demonstrated the dual benefits of district road rehabilitation in Garoga Subdistrict, North Tapanuli, Indonesia. Quantitative analysis revealed significant reductions in Vehicle Operating Costs (VOC) across all vehicle categories, ranging from 15% to 20% post-rehabilitation. These savings were attributed to improved surface quality, which decreased mechanical strain, fuel consumption, and spare part wear.

Simultaneously, the accessibility index showed a marked increase across all five evaluated routes, with improvements exceeding 60% in some cases. This expansion of spatial accessibility indicates enhanced public mobility, better access to health and educational services, and a strengthened integration of peripheral communities into regional economies.

Statistical validation confirmed that the improvements in VOC and accessibility were significant at the 95% confidence level. These findings align with existing literature emphasizing infrastructure as a catalyst for rural transformation, and reinforce the critical role of road investment in equitable development planning

Based on the findings, it is recommended that future infrastructure planning in rural Indonesia adopt a data-driven approach that integrates both **Vehicle Operating Cost (VOC)** and **Accessibility Index** metrics into project selection and appraisal frameworks. Government agencies, particularly at the regency and provincial levels, should use tools like the Pd-T-15-2005-B guideline and spatial accessibility models to prioritize interventions that yield the highest cost-efficiency and social inclusion benefits. Roads serving densely populated but isolated communities—such as those observed in Garoga Subdistrict—should be prioritized to maximize return on investment in terms of mobility, service access, and economic integration.

Additionally, sustainability must be a central consideration in rural road programs. Without adequate post-construction maintenance, the efficiency gains from rehabilitation will deteriorate rapidly. Therefore, local governments are encouraged to establish **routine maintenance schedules**, ensure proper drainage management, and involve communities in reporting infrastructure damage. A **multi-sectoral coordination strategy** is also advised, whereby improvements in transportation are planned alongside education, health, and agricultural service delivery. This integrated approach can create synergistic development effects, reducing rural-urban disparities and supporting long-term resilience in underserved regions.

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