**Impact of District Road Rehabilitation on Vehicle Operating Costs and Accessibility in Garoga district, North Tapanuli Regency, 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 facing critical rural transport challenges. Guided by a positivist research philosophy and employing a quantitative approach, the study used purposive sampling to select key road segments. Field traffic surveys and spatial data analysis were conducted before and after the rehabilitation in 2022–2023. VOC was calculated using the Indonesian Ministry of Public Works’ Pd-T-15-2005-B guideline, while accessibility was measured through a population-weighted Accessibility Index based on travel time to service centers. Findings show significant reductions in VOC across motorcycles, passenger cars, and freight trucks—attributed to smoother road surfaces that reduced fuel use, spare part wear, and maintenance labor. Accessibility scores improved by over 50%, reflecting enhanced mobility and access to healthcare, education, and markets. These outcomes were statistically significant (p < 0.05). The study recommends integrating VOC and accessibility metrics in rural infrastructure appraisals, prioritizing investment in high-need, underserved communities, and ensuring post-rehabilitation road maintenance to sustain long-term development benefits.

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

1. **INTRODUCTION**

Rural infrastructure, particularly road networks, plays an essential role in enabling socio-economic development. In developing countries like Indonesia, the condition and availability of district roads significantly influence the well-being of rural populations (Wahyuni, 2022). Roads are not merely transportation conduits—they are development enablers, facilitating access to health care, education, markets, and employment opportunities. Their quality, extent, and maintenance status can either bridge or deepen the rural-urban divide (Kalimanto & Hadiwardoyo, 2019).

Inadequate road infrastructure imposes economic burdens on communities by increasing travel time, limiting market access, and inflating transportation costs (Trestanto et al., 2024). For many rural residents in Indonesia, poor road conditions are a daily barrier to reaching schools, clinics, and commercial hubs. This is particularly evident in geographically challenging regions such as Garoga Subdistrict in North Tapanuli Regency, where rugged topography and limited infrastructure exacerbate rural isolation (Yanti, 2023). These conditions have motivated local governments to explore road rehabilitation as a tool for inclusive regional development.

One of the primary metrics used to evaluate road quality and transport efficiency is Vehicle Operating Cost (VOC). VOC includes all recurring costs incurred during vehicle usage—fuel consumption, engine oil, spare parts, tire wear, and labor for maintenance (Wibisono, 2020). These costs tend to rise sharply in response to poor road conditions characterized by rough surfaces, frequent potholes, and inadequate drainage systems. Studies in Java and other parts of Indonesia have shown that road upgrades can significantly reduce VOC, benefiting transport operators and consumers alike

VOC is particularly critical in rural areas, where low-income populations are often more vulnerable to increases in transportation costs. A reduction in VOC following road rehabilitation can translate into lower freight charges, reduced prices for consumer goods, and greater affordability for personal mobility (Steyn, 2011). This underscores the role of road rehabilitation not only as an engineering intervention but as a policy tool for economic justice and spatial equity. Heavier vehicles, such as freight trucks, often experience greater cost savings due to their sensitivity to surface conditions, making VOC a valuable indicator for evaluating investment returns.

While VOC captures economic efficiency, accessibility captures social equity. Defined as the ease with which people can reach essential destinations, accessibility includes physical, economic, and temporal dimensions. In rural regions like Garoga, accessibility is not only a function of distance but also of road quality and connectivity to public services (Soseco, 2016; Mukerji, 2013). Poor accessibility can lead to missed educational opportunities, delayed medical care, and restricted participation in economic life—consequences that collectively undermine rural resilience.

Improvements in accessibility following road rehabilitation have been linked to better health outcomes, higher school attendance rates, and increased employment in non-farm sectors (Shimamura, 2022; Idei, 2022). Accessibility indices, which integrate population data with travel time to service centers, offer a quantifiable measure of these improvements. By applying such indices, researchers can identify underserved areas and prioritize road investments to maximize social impact. Studies have emphasized the need for governments to address these disparities through location-sensitive infrastructure planning (Kamaludin & Qibthiyyah, 2022).

In light of these dynamics, road rehabilitation emerges as a dual-impact intervention—enhancing both economic efficiency through reduced VOC and social inclusion through improved accessibility. This duality aligns with systems theory, which views infrastructure as part of an interconnected social, economic, and spatial system. Changes in road conditions produce ripple effects, influencing not just individual travel behavior but also patterns of regional development, migration, and investment.

Despite the known benefits, rural infrastructure projects often receive less attention and funding compared to urban development initiatives. The lack of empirical data and standardized evaluation methods further complicates infrastructure decision-making. Therefore, studies that quantify the effects of rural road improvements are essential to inform evidence-based policymaking. Metrics such as VOC and accessibility indices can help demonstrate the cost-effectiveness and long-term value of rural transport investments.

Garoga Subdistrict offers a representative case for such an evaluation. Its diverse terrain, scattered settlements, and historically underdeveloped road system make it a critical testing ground for infrastructure interventions. By conducting a before-and-after analysis of road rehabilitation projects across multiple routes in Garoga, this study provides empirical insights into how localized improvements can yield broad developmental benefits.

This research employs a quantitative case study approach within a positivist philosophical framework, focusing on measurable impacts using standardized models. VOC is calculated using the Ministry of Public Works' Pd-T-15-2005-B guidelines, while accessibility is analyzed through a GIS-enabled node-based index. By combining these metrics, the study contributes to a more integrated understanding of rural infrastructure performance. The findings aim to support policy design, infrastructure prioritization, and sustainable development planning, especially for communities facing geographic and socio-economic marginalization.

1. **Methods**

**2.1. Research Design and Philosophical Approach**

This study adopts a positivist philosophical framework which emphasizes objectivity, quantification, and empirical observation. The research follows a quantitative case study approach, suitable for examining specific impacts within a defined spatial and temporal context. A quasi-experimental before-and-after design was employed to measure changes in road performance indicators—specifically Vehicle Operating Costs (VOC) and Accessibility Index—before and after road rehabilitation projects

2.2 **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.

**2.3 Sampling Strategy**

The sampling employed a **purposive sampling technique**, selecting road segments that met specific criteria:

* Previously documented as in poor condition by local Public Works reports.
* Scheduled for rehabilitation within the 2022–2023 period.
* Serving communities with populations greater than 1,000 residents.

This approach ensured that the selected sites would yield significant variation in VOC and accessibility before and after the intervention, making the study suitable for inferential analysis.

**2.4 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:

Each component was calculated per vehicle type and per kilometer based on:

* Technical specifications (vehicle weight, engine capacity)
* Road condition parameters (surface type, roughness index)
* Local price inputs from market surveys

VOC data were collected for each route under both pre- and post-rehabilitation conditions and averaged across vehicle categories.

**2.5 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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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.

**2.6 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 scores improved significantly across all five evaluated road routes, reflecting better connectivity to public services (see Table 2).

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

|  |  |  |  |
| --- | --- | --- | --- |
| **Route** | **Index Before** | **Index After** | **% Increase** |
| Pea Raja | 0.032 | 0.054 | 68.8% |
| Rianiate | 0.031 | 0.050 | 61.3% |
| Pargawahan | 0.035 | 0.056 | 60.0% |
| Lobu Tonga | 0.034 | 0.057 | 67.6% |
| Gotting Salak | 0.038 | 0.058 | 52.6% |

These accessibility improvements reflect:

* Reduced travel time to schools, markets, and health centers.
* Expanded service zones, improving spatial equity.
* Better emergency response reach and utility access.

The largest relative gain was recorded in **Pea Raja**, where rehabilitation opened access to a previously underserved cluster of villages.

**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 and Planning Implications**

The findings have critical implications for regional planning:

* **Targeted Investment:** Routes with high population but low baseline accessibility should be prioritized for rehabilitation to yield high social returns.
* **VOC as a Planning Tool:** Inclusion of VOC metrics in road evaluation frameworks can quantify economic efficiency gains.
* **Sustainability:** Post-rehabilitation benefits may erode without adequate maintenance—emphasizing the need for routine upkeep and community-based monitoring.
* **Integrated Development:** Road investments should be coordinated with education, health, and agricultural policies to produce synergistic outcomes.

**6. Comparative Insight and Broader Relevance**

These results resonate with similar studies across the Global South. For example, Obeti et al. (2024) reported comparable VOC reductions in Uganda from rural road mechanization. The Garoga case thus offers a transferable model for evaluating road upgrades in geographically constrained, economically marginalized regions.

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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