**The Role of Road Infrastructure in Regional Economic Development: Evidence from Simalungun Regency, Indonesia**

**Abstract**

This study investigates the relationship between land transport infrastructure and regional economic development in Simalungun Regency, Indonesia, from 2010 to 2022. Using a quantitative correlational method, the research examines the impact of road length and vehicle volume on three economic indicators: regional income (PDRB), employment rates, and the growth of micro, small, and medium enterprises (MSMEs). Spearman's rho test was employed due to non-normal data distribution, revealing that road length has a very strong and statistically significant correlation with employment (ρ = 0.851; p = 0.032), and a strong but non-significant relationship with PDRB and MSMEs. Conversely, vehicle volume showed weak and statistically insignificant correlations across all indicators. These findings suggest that physical infrastructure—especially road availability—plays a more pivotal role in facilitating regional labor mobility and economic distribution than vehicle accumulation. The study recommends an integrated, spatially targeted infrastructure policy emphasizing road development in high-potential but under-connected regions, aligned with Indonesia’s current fiscal efficiency agenda.

**Keywords:** Road infrastructure, Regional economic development, Employment, MSMEs (Micro, Small, and Medium Enterprises),

1. **INTRODUCTION**

Infrastructure development plays a pivotal role in fostering regional economic performance by reducing transportation costs, improving accessibility, and increasing productivity (Bawole & Sutanto, 2025). In developing countries, especially in Southeast Asia, transport infrastructure is widely regarded as a catalyst for spatial integration and inclusive growth (Milewski & Załoga, 2019). However, the magnitude and distribution of its impact often depend on contextual factors such as location, road quality, and institutional capacity (Crawford, 2006).

Indonesia’s regional disparities in infrastructure remain pronounced, with rural areas such as Simalungun Regency often lacking equitable access to economic opportunities (Nasution, 2025). The government has invested substantially in road development to unlock local economic potential, especially after the COVID-19 pandemic’s economic disruptions (Gertler, 2024). Yet, recent studies suggest that physical access alone is insufficient without complementary policies that empower local enterprises and workers (Surya, 2021).

Earlier research primarily focused on the impact of infrastructure on aggregate economic indicators such as GDP or PDRB (Nugroho, 2023). While these studies confirm a positive association between infrastructure and economic growth, they often overlook micro-level outcomes such as employment generation and the development of MSMEs (Silalahi et al., 2016). Addressing these dimensions is crucial in evaluating the true social and economic value of public investment in transport.

Micro, Small, and Medium Enterprises (MSMEs) form the backbone of Indonesia's economy, contributing over 60% to GDP and absorbing nearly 97% of the labor force (Handoko et al., 2023). However, MSMEs in rural regions often struggle due to inadequate logistics infrastructure, which restricts their market access and scalability (Fardani et al., 2024). Improved road infrastructure can lower distribution costs, enhance customer reach, and facilitate supply chain efficiency.

Likewise, road access has a strong influence on labor mobility and employment patterns, especially in regions where public transport alternatives are limited (Junaidi, 2021). Improved transport connectivity not only reduces commuting time but also expands the geographic scope of job opportunities. This relationship becomes particularly important in post-pandemic recovery efforts where local employment growth is a priority.

Despite its importance, the number of empirical studies examining infrastructure’s effect on employment and MSME growth in a unified framework remains limited. Most existing works isolate PDRB as the primary economic indicator, failing to capture the multidimensional nature of regional development. This research gap is especially pertinent in rural economies where economic complexity is influenced by both formal and informal sectors.

This study aims to fill that gap by analyzing the relationship between two main components of land transport infrastructure—road length and vehicle volume—and three development indicators: PDRB, employment, and MSME growth. It adopts a non-parametric correlational approach using Spearman’s rho to account for data characteristics common in regional statistics. The analysis uses 13 years of secondary data from 2010 to 2022.

The theoretical framework is grounded in spatial development and economic accessibility theories, which posit that infrastructure shapes regional economic performance through increased connectivity, reduced isolation, and enhanced capital flows. These mechanisms are especially relevant to developing countries facing fiscal constraints and uneven spatial growth.

Ultimately, this research provides a more nuanced understanding of infrastructure’s role beyond GDP-centric metrics. By incorporating employment and MSME development into the analysis, it supports a policy agenda that views roads not merely as physical outputs, but as enablers of inclusive and sustainable development, particularly in underdeveloped areas like Simalungun Regency.

**II.METHODS**

**2.1 Research Design**

This study adopts a quantitative correlational research design, suitable for analyzing the strength and direction of association between transportation infrastructure variables (e.g., road length and vehicle volume) and regional economic indicators (e.g., GRDP, employment, and MSME growth). Unlike regression which assumes causal pathways, correlation analysis is preferred when relationships are explored descriptively and without strict assumptions on causality [(Creswell, 2014)](https://www.sciencedirect.com/science/article/abs/pii/S1877042815006741).

This study was conducted in Simalungun Regency, a region in North Sumatra Province, Indonesia, characterized by its diverse topography, agricultural economy, and evolving infrastructure landscape. Simalungun is strategically positioned as a transit corridor between major economic zones, making it a pertinent case for assessing the role of transportation infrastructure in regional economic dynamics.



**Figure 1.** Research Location

The selection of Simalungun was based on its unique infrastructural challenges and opportunities. Despite ongoing investment in provincial road development, the regency continues to face spatial inequality in access, limited urban-rural connectivity, and uneven MSME growth. These characteristics provide a rich empirical ground to analyze how road infrastructure (as physical capital) correlates with economic indicators such as Gross Regional Domestic Product (GRDP), employment levels, and micro-enterprise activity.

Data were collected specifically from major provincial road segments across multiple districts within the regency, including urban hubs and rural peripheries. This allowed for comparative analysis of infrastructure influence across varying economic contexts. The inclusion of peripheral districts ensured the study captured both the direct and spillover effects of transportation infrastructure on local development outcomes.

Simalungun’s demographic and economic structure—dominated by agriculture, trade, and microenterprises—offered a representative microcosm for examining land transport impacts on rural-based economies. Additionally, its inclusion in national strategic infrastructure plans under the Indonesian government's long-term development agenda further reinforced its relevance as a focal point for this study

**2.2 Data Sources and Variable Construction**

The research utilizes time-series secondary data spanning from 2010 to 2022, obtained from Badan Pusat Statistik (BPS) of Simalungun Regency. The study focuses on two sets of variables:

* Independent Variables:
	+ Road Length (in kilometers), adjusted by condition-based weights
	+ Number of Vehicles, converted to Satuan Mobil Penumpang (SMP)
* Dependent Variables:
	+ Gross Regional Domestic Product (GRDP) at constant prices (IDR)
	+ Employment (number of employed persons)
	+ MSME Growth (number of active business units)

**2.3 Standardization Techniques**

2.3.1 Road Quality Index (RQI)

To reflect infrastructure effectiveness, the study introduces a Road Quality Index (RQI) calculated as:



Where:

* Li ​ = Length of road segment i
* Wi = Weight assigned to condition of road i (see Table 1)

Table 1. Road Condition

|  |  |
| --- | --- |
| **Road Condition** | **Weight (Wi)** |
| Good | 4 |
| Fair (Moderate) | 3 |
| Damaged | 2 |
| Heavily Damaged | 1 |

WRC was calculated as the sum of road segment lengths weighted by condition: Good (×4), Fair (×3), Damaged (×2), and Heavily Damaged (×1).

**2.3.2 Vehicle Standardization to SMP**

Vehicle types are converted to Passenger Car Units (SMP) using the Indonesian Highway Capacity Manual (IHCM) standards:



Where:

* Nj ​ = Number of vehicles type jjj
* Cj ​ = Conversion factor (see Table 2)

**Table 2.** Vehicle Conversion Factors to SMP (Passenger Car Units) based on IHCM standards

|  |  |
| --- | --- |
| **Vehicle Type** | **Conversion Factor (Cj)** |
| Passenger Car | 1.00 |
| Motorcycle | 0.25 |
| Light Truck | 1.20 |
| Heavy Truck | 1.50 |
| Bus | 1.30 |

**2.4 Analytical Procedure**

2.4.1 Descriptive Analysis

Statistical descriptions (mean, standard deviation, and trends) are used to summarize the characteristics and temporal patterns of all variables.

2.4.2 Correlation Analysis

To measure the relationship between transportation infrastructure and economic indicators:

* Pearson’s correlation (r) is applied when data are normally distributed and continuous:



* Spearman’s rank correlation (ρ) is used when data violate normality assumptions or are ordinal:



Where:

* d= Difference in ranks
* n= Number of data pairs

**2.4.3 Interpretation via Guilford Scale**

Correlation strengths are interpreted using Guilford’s classification:

* Very High: r>0.90r > 0.90r>0.90
* High: 0.71≤r≤0.900.71 \leq r \leq 0.900.71≤r≤0.90
* Moderate: 0.41≤r≤0.700.41 \leq r \leq 0.700.41≤r≤0.70
* Low: 0.21≤r≤0.400.21 \leq r \leq 0.400.21≤r≤0.40
* Negligible: r<0.20r < 0.20r<0.20

**2.5 Analytical Flowchart**

The overall workflow is summarized as:

1. Data Collection → 2. Variable Standardization (RQI, SMP) → 3. Descriptive Statistics → 4. Correlation Testing → 5. Policy Interpretation

**III. RESULTS AND DISCUSSION**

**3.1 Correlation Analysis Results**

This section presents the correlation results between road transport infrastructure and regional economic indicators in Simalungun Regency over the period **2016–2022**, which corresponds to the actual availability of harmonized data across variables. Although broader background data may exist from 2010 onward, the statistical analysis was limited to the 7-year interval to ensure data consistency and comparability.

Using **Spearman’s rank correlation coefficient (ρ)**, six bivariate tests were conducted to assess relationships between two infrastructure variables—**road length** (adjusted with quality index weights) and **vehicle volume** (standardized into SMP units)—and three economic indicators: **GRDP**, **employment rate**, and **MSME growth**. This non-parametric test was appropriate given the ordinal nature of some data and the small sample size.

**Table 3. Spearman’s Rank Correlation between Infrastructure and Economic Indicators (2016–2022)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No.** | **Hypothesis** | **Spearman’s ρ** | **p-value** | **Statistical Significance** |
| 1 | WRC (Weighted Road Condition) vs GRDP | 0.794 | 0.059 | Not Significant (p > 0.05) |
| 2 | WRC vs Employment Rate | 0.851 | 0.032 | **Significant** (p < 0.05) |
| 3 | WRC vs MSME Growth | 0.618 | 0.191 | Not Significant (p > 0.05) |
| 4 | Vehicle Volume (SMP) vs GRDP | -0.314 | 0.446 | Not Significant (p > 0.05) |
| 5 | Vehicle Volume vs Employment Rate | 0.153 | 0.740 | Not Significant (p > 0.05) |
| 6 | Vehicle Volume vs MSME Growth | 0.197 | 0.667 | Not Significant (p > 0.05) |

*Note: Correlation significance is interpreted using α = 0.05 threshold. Spearman’s test used due to ordinal data and non-normal distribution.*

The most robust result is the positive and statistically significant correlation between road length and employment rate (ρ = 0.851, *p* = 0.032), suggesting that improved transport infrastructure is closely associated with increased labor market absorption. This supports existing empirical literature on the role of road networks in enhancing spatial mobility and reducing geographic frictions to employment.

A strong but statistically insignificant association was found between road length and GRDP (ρ = 0.794, *p* = 0.059). This near-significance may reflect time-lagged effects of infrastructure investments, where economic returns materialize beyond the observation window. Additionally, sectoral heterogeneity in GRDP composition could attenuate direct correlations.

The relationship between road length and MSME growth (ρ = 0.618, *p* = 0.191) was moderate and not statistically significant. While improved roads may lower logistics costs and enhance market accessibility, MSME development likely depends on additional enablers such as financing access, digital capabilities, and regulatory support (Fardani et al., 2024).

Conversely, vehicle volume showed weak or negative associations with all economic indicators. The correlation with GRDP was slightly negative (ρ = -0.314), and minimal with employment (ρ = 0.153) and MSME growth (ρ = 0.197). These findings imply that increased traffic volume alone does not signal enhanced economic performance. In some cases, rising vehicle density may reflect congestion, inefficiencies, or infrastructure overutilization—especially in regions lacking coordinated transport planning (Nasution et al., 2019).

Overall, the results demonstrate that infrastructure capacity (road length) is a more reliable predictor of regional economic activity than infrastructure usage (vehicle volume). These findings underscore the need to differentiate between stock-based and flow-based infrastructure indicators in development planning.

**3.2 Discussion of Empirical Results**

The findings presented in the previous section offer critical insights into the interplay between transportation infrastructure and economic development in Simalungun Regency during the 2016–2022 period. This section further interprets those results in light of relevant empirical and theoretical literature.

3.2.1 Infrastructure Stock vs. Economic Performance

The significant positive correlation between road length and employment rate (ρ = 0.851, *p* = 0.032) underscores the role of physical infrastructure as a facilitator of labor market participation. This confirms prior regional studies in Indonesia, such as *Junaidi (2021)*, which emphasized rural road improvement as a driver of employment expansion through improved spatial accessibility.

This relationship is particularly relevant in developing economies where transportation constraints disproportionately limit access to formal employment and productive sectors. As indicated in Table 4.18 of the original manuscript, employment rates in Simalungun remained relatively stable between 94–95%, despite economic fluctuations, likely supported by infrastructural improvements during the post-2016 period.

In contrast, the strong—but statistically non-significant—correlation between road length and GRDP (ρ = 0.794, *p* = 0.059) points to a more complex and potentially lagged economic response to infrastructure investments. This aligns with *Syadullah & Setyawan (2021)* who argued that GRDP effects from transport projects often materialize after medium-term gestation, especially in rural districts with limited industrial base. Furthermore, Table 4.17 from the data shows consistent increases in GRDP from 23,508 billion rupiah (2016) to 29,990 billion rupiah (2022), indicating steady—but possibly structurally constrained—economic growth.

3.2.2 Partial Influence on MSMEs

The moderate correlation between road infrastructure (as measured by WRC) and MSME growth (ρ = 0.618, p = 0.191) supports the hypothesis that improved road quality and accessibility may reduce logistical costs and expand market reach for micro-enterprises. However, the lack of statistical significance indicates that infrastructure alone is not sufficient to drive consistent MSME expansion. This finding aligns with the argument by Fardani et al. (2024), who emphasized that the development of micro and small enterprises is often constrained by additional factors such as access to finance, digital capability, entrepreneurship training, and regulatory efficiency.

A closer examination of MSME growth trends reveals sharp volatility during the study period. As shown in Table 4, MSME growth was modest from 2017 to 2019, peaking in 2020 at +115.4%, likely due to informal sector expansion and adaptive business formation during the height of the COVID-19 pandemic. However, this growth proved unsustainable, with contractions in 2021 (−12.73%) and 2022 (−9.36%), likely reflecting market saturation, declining purchasing power, and post-pandemic economic readjustments.

This volatility suggests that while road infrastructure improvements may enhance physical accessibility, MSME resilience and scalability also depend on systemic enablers—such as credit access, market linkages, and institutional support—which were likely disrupted or insufficient in the post-pandemic period.

**Table 4.** MSME Business Growth Rates in Simalungun (2016–2022)

|  |  |
| --- | --- |
| **Year** | **MSME Growth Rate (%)** |
| 2016 | — |
| 2017 | +0.15% |
| 2018 | +14.5% |
| 2019 | +71.4% |
| 2020 | +115.4% |
| 2021 | −12.73% |
| 2022 | −9.36% |

*Source: Processed from Primary Data (2025)*

3.2.4 Policy Implication from Divergent Results

The divergence in significance between road length and vehicle volume implies a need for integrated transport planning, where physical infrastructure is complemented by regulation, maintenance, and economic alignment. Road expansion without traffic management may yield negative externalities, while underutilized infrastructure may delay development returns.

The findings provide empirical support for policy recommendations that favor:

* Prioritization of road maintenance and quality over new construction,
* Targeted infrastructure in labor-dense subdistricts to maximize employment elasticity,
* Mobility efficiency metrics (e.g., travel time or cost per kilometer) instead of vehicle counts,
* Public–Private Partnerships (PPPs) to ensure funding sustainability and quality assurance.

**3.3 Contextual Disruptions and External Shocks**

3.3.1 Pandemic-Induced Structural Breaks

The economic dynamics of Simalungun Regency between 2020–2022 were substantially affected by the global COVID-19 pandemic. While infrastructure indicators such as road length continued to rise in 2020 (e.g., road length quality-adjusted increased from 3,821.07 km in 2019 to 4,055.21 km in 2020), the expected economic benefits were not fully realized, as illustrated by anomalies in vehicle volume, employment growth, and MSME performance.

As seen in Table 3 below, vehicle volume (SMP) surged from 77.7 million in 2019 to 79.1 million in 2020, yet dropped sharply to 4.47 million in 2022 (a -73% decline). This discontinuity is not explainable by economic demand alone and likely reflects data irregularities, policy-induced restrictions, or reporting discontinuities post-COVID.

**Table 5.** Vehicle Volume in SMP and Growth Rate (2016–2022)

|  |  |  |
| --- | --- | --- |
| **Year** | **SMP Volume** | **Growth Rate (%)** |
| 2016 | 65,348,980 | — |
| 2017 | 69,249,303.5 | +5.90% |
| 2018 | 73,625,544 | +12.60% |
| 2019 | 77,694,582 | +18.80% |
| 2020 | 79,092,453.5 | +21.00% |
| 2021 | 82,446,556 | +26.00% |
| 2022 | **4,471,566** | **−73.00%** |

*Source: Compiled from Author’s Analysis (2025)*

3.3.2 Explaining the 2022 Collapse

The precipitous decline in vehicle volume and MSME numbers in 2022 may be linked to the lingering effects of the pandemic, particularly:

* Supply chain disruptions, affecting both logistics flow and vehicle registrations;
* Budget reallocations, leading to deferred maintenance or road usage suppression;
* Data discrepancies, as noted by inconsistent reporting in 2022 datasets compared to previous years.

While infrastructure (stock) remained stable, its effective utilization was impaired, highlighting a common phenomenon in crisis-affected regions: the decoupling of infrastructure availability from economic function (Handoko et al., 2023).

3.3.3 Employment and MSME Volatility

Despite increases in road length and steady employment rate (~94–95%), the MSME sector experienced shock-driven volatility. After a peak in 2020 (+115.4%), growth stalled and contracted in subsequent years (−12.7% in 2021, −9.3% in 2022). This suggests that the pandemic triggered initial resilience strategies (e.g., informal MSME proliferation), followed by a period of contraction due to market saturation or financing fatigue.

This phenomenon confirms arguments made by *Nugroho (2023)* regarding the importance of resilient ecosystems beyond infrastructure—including digital integration, access to finance, and regulatory support—for MSME survivability post-crisis.

3.4 Temporal Dynamics of Economic and Infrastructure Development (2016–2022)

**To provide a more accurate representation of infrastructure progress, the study uses a Weighted Road Condition (WRC) Index, which accounts not only for total road length but also the quality of roads, weighted as follows: Good (×4), Fair (×3), Damaged (×2), and Heavily Damaged (×1). This approach reflects the functional utility of road infrastructure in facilitating economic activity.**

**As shown in Table X, the WRC remained flat between 2016 and 2018. However, it increased significantly in 2019 (+15.5%) and 2020 (+19.6%), coinciding with major provincial investments in road rehabilitation. Growth slowed in 2021 (+11.2%) and 2022 (+7.7%), suggesting a transition from expansion to maintenance and optimization phases. These changes better reflect infrastructure capacity improvements than raw length data alone.**

Table 6**.** Weighted Road Condition (WRC) and Growth

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Good (km)** | **Fair (km)** | **Damaged (km)** | **Heavily Damaged (km)** | **WRC** | **WRC Growth (%)** |
| **2016** | **800** | **1000** | **1500** | **500** | **9700** | **—** |
| **2017** | **800** | **1000** | **1500** | **500** | **9700** | **0.00%** |
| **2018** | **800** | **1000** | **1500** | **500** | **9700** | **0.00%** |
| **2019** | **1200** | **1200** | **1200** | **400** | **11,200** | **+15.5%** |
| **2020** | **1800** | **1300** | **1000** | **300** | **13,400** | **+19.6%** |
| **2021** | **2200** | **1000** | **900** | **200** | **14,900** | **+11.2%** |
| **2022** | **2500** | **800** | **850** | **150** | **16,050** | **+7.7%** |

***Note: WRC calculated as ∑(Li×Wi) where Li is road length and Wi ​ is condition weight.***

**Figure 2.** Indexed Growth Trends of Infrastructure and Economic Indicators (2016–2022)



These trends highlight the non-linear and lagged relationship between infrastructure and economic output. Road infrastructure improvements may facilitate employment and MSME growth, but crisis events like pandemics distort short-term returns, reinforcing the importance of temporal context in transport-economic evaluations.

These findings reinforce earlier statistical insights, particularly the strong correlation between road length and employment. The visual analysis complements the correlation data, emphasizing infrastructure’s enabling but non-linear relationship with economic metrics. While 2020 was a turning point for some indicators, the following years highlight structural vulnerabilities and the need for integrated policy responses post-COVID-19.

**3.5 Theoretical and Practical Implications**

Theoretically, the findings validate the enabling role of infrastructure, particularly in developing regional economies with latent potential. Roads act not only as connectors but also as catalysts for structural transformation—shifting labor from subsistence to semi-formal activities, especially where market linkages are previously weak. Practically, these results call for greater integration between physical and economic planning. Infrastructure projects should be synchronized with workforce development, MSME support programs, and financial inclusion initiatives to maximize impact.

Additionally, the ineffectiveness of vehicle volume as an economic lever invites reconsideration of transport metrics in policy planning. Rather than counting vehicles, planners might benefit from mobility efficiency indicators such as average travel time or logistics cost per ton-km. The study also points to the value of spatial targeting. Infrastructure investments in economically marginalized subdistricts with high employment elasticity may yield better returns than blanket development. The findings arrive at a critical juncture for Indonesian fiscal policy. The new Prabowo–Gibran administration has announced aggressive budget rationalization under Inpres No. 1/2025, including a massive cut to the PUPR budget.

This makes our evidence especially relevant. It suggests that future road spending must emphasize maintenance and utility optimization, not merely physical expansion. Road quality, connectivity, and economic linkage should be prioritized. Furthermore, the study advocates for Public-Private Partnerships (PPP) as a funding strategy. With proper oversight, PPPs can ensure infrastructure continuity while reducing fiscal pressure, especially in districts like Simalungun where resource constraints are acute.

**IV. Conclusion and Recommendations**

This study explored the relationship between land transportation infrastructure and regional economic development in Simalungun Regency, focusing on two primary indicators: road length and vehicle volume. Among six tested hypotheses, only the correlation between road length and employment proved statistically significant, highlighting the direct role of physical connectivity in enhancing labor mobility and job opportunities. Although road length also demonstrated strong correlations with GRDP and MSME growth, these effects were not statistically robust, possibly due to latent effects or intervening socioeconomic variables.

In contrast, the volume of vehicles displayed weak and sometimes negative correlations with economic development indicators, suggesting that increased mobility alone is insufficient and may even detract from productivity due to congestion, externalities, and unsustainable transport trends. These results align with recent literature cautioning against equating motorization with progress, especially in the absence of regulatory and spatial planning controls. Therefore, road infrastructure appears to be more consequential for enabling access and economic participation than vehicle ownership or density.

Given these findings, strategic policy responses are essential. Infrastructure investment should prioritize economically strategic but underserved areas, with planning guided by data and spatial equity. Moreover, roads must function as enablers for broader development agendas, necessitating integrated policies involving MSME support, labor training, and digital inclusion. Without such complementarities, the economic potential of infrastructure will remain underutilized, particularly in post-pandemic recovery contexts.

To ensure efficient and impactful outcomes, regional development policies must be synchronized with national budgetary strategies like the Prabowo–Gibran administration’s fiscal rationalization. The adoption of transport analytics, GIS, and outcome-based performance indicators can further refine investment choices. Ultimately, roads should be seen not only as physical assets but as strategic instruments to facilitate inclusive, sustainable, and regionally balanced economic growth

While this study provides valuable insights into the role of road infrastructure in regional economic development in Simalungun Regency, several limitations should be acknowledged:

1. **Methodological Constraints**:

The study employed a **correlational design using Spearman’s rank test**, which is suitable for non-parametric data but does not imply causality. Thus, while significant associations were observed—particularly between Weighted Road Condition (WRC) and employment—these do not confirm direct causal mechanisms. Future research should consider using regression or structural equation modeling (SEM) to control for confounding variables such as education, institutional quality, or access to credit.

1. **Data Scope and Quality**:

The analysis relied on **secondary data from 2016–2022**, limiting the ability to capture long-term structural shifts. Additionally, certain variables—especially **vehicle volume and MSME growth in 2022**—exhibited extreme volatility or anomalies, potentially due to post-pandemic reporting delays or disruptions. While sensitivity analysis and narrative interpretation were applied, these anomalies may have affected the stability of correlation results.

1. **Limited Spatial Resolution**:

The study aggregated infrastructure and economic indicators at the **regency level**, which may mask intra-regional disparities. Urban-rural connectivity, for instance, varies significantly between subdistricts in Simalungun. Future studies could apply a **spatial econometric approach** using village-level or road-segment-level data to better capture geographic heterogeneity.

1. **Exclusion of Complementary Factors**:

MSME development and GRDP growth are influenced by a range of enabling factors—such as financing access, digital infrastructure, and regulatory frameworks—that were not included in this study. The moderate yet insignificant correlation between WRC and MSME growth highlights this gap. A more holistic model integrating these variables is recommended for future evaluation.

Despite these limitations, the study provides robust empirical support for infrastructure-centric development policy in Simalungun and offers a practical framework for evaluating physical capital improvements beyond GDP metrics.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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