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Road Infrastructure and Local Economic Activity: Insight from Mobility Data

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ABSTRACT

Research Originality: This research measures local economic activity through a mobility approach, using Google Mobility Report (GMR) data across all provinces in Indonesia. Measuring economic activity using conventional macro indicators, such as GDP, has limitations due to lengthy collection processes.

Research Objectives: This study aims to determine the impact of road infrastructure on local economic activity using data from the GMR in categories such as Retail and recreation, Grocery and pharmacy, Parks, and Workplaces.

Research Methods: This study uses panel data on the GMR, Ministry of Public Works and Public Housing, Ministry of Finance, and Central Bureau of Statistics from 2019–2022, which is analyzed using fixed-effect methods.

Empirical Results: The results show a positive effect of road infrastructure on Retail and recreation and Grocery and pharmacy but a negative impact on Workplaces, likely due to the shift to remote work during COVID-19.

Implications: These findings suggest that the government should prioritize road construction in areas that enhance economic activity. However, road construction in the Workplaces area still needs to be considered in line with the recovery of activities after the pandemic ends.

Keywords:

road infrastructure; mobility; economic activity; google mobility report

How to Cite:

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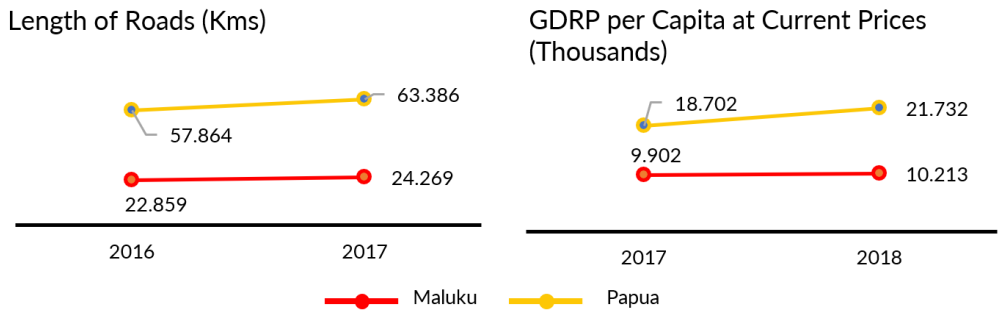
INTRODUCTION

Indonesia ranked 52nd in the World Competitiveness Center's infrastructure ranking in 2022, an improvement from 57th in 2021 (Institute for Management Development [IMD], 2023). This ranking is an improvement above 2021's 57th place. Despite this progress, Indonesia continues to lag behind other Asian nations, highlighting the persistent challenge of infrastructure development. Economic performance is intricately linked to the quality of infrastructure, which has led the government to enhance its investment in this sector, amounting to Rp 213.8 trillion from 2014 to 2023. A considerable share of this funding has been directed towards the construction of non-toll roads, establishing 17,653 kilometers of new roadways from 2015 to 2022. These developments significantly enhance connectivity, facilitating the transportation of goods and services and fostering economic growth. As demonstrated in Figure 1, the relationship between the length of roads and the Gross Regional Domestic Product (GRDP) per Capita in Maluku and Papua indicates a connection between infrastructure advancement and economic activity.

Figure 1. Length of Roads and GDRP per Capita at Current Prices



Source: Ministry of PUPR (2024c, 2024a, 2024b) and BPS (2024)

Gross Domestic Product (GDP) and its regional counterpart, GRDP, serve as a metric for assessing a nation's economic performance by depicting total economic activities. However, However, economists argue that these indicators fail to capture economic variations and real-time activity (Stiglitz et al., 2018; Todaro & Smith, 2015). Furthermore, GDP and GDRP are published quarterly or annually, making them less responsive to short-term economic fluctuations. Given these limitations, alternative indicators, such as mobility data, have emerged as proxies for economic activity (Güell et al., 2018; Monika, 2021) because they reflect job mobilization (Brynjolfsson & McAfee, 2014), consumer activity (Landais et al., 2020), and the movement of goods and services (Rodrigue, 2020). Studies have shown that mobility data can effectively indicate economic dynamics, particularly during periods of economic disruption such as the COVID-19 pandemic (Khoirunurrofik et al., 2022; Spelta & Pagnottoni, 2021). Researchers have tested the use of economic activity indicators using various proxies, including Damuri et al. (2021), Gamtkitsulashvili & Plekhanov (2023), Putra & Arini (2020), and Sampi

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Bravo & Jooste (2020). These studies examined the relationships between mobility data and GDP and other macroeconomic indicators. The results indicated a strong correlation among them.

The Google Mobility Report (GMR) provides valuable mobility data that can serve as a real-time indicator of economic activity (Caselli et al., 2020; Sampi Bravo & Jooste, 2020). In line with this statement, Campos-Vazquez and Esquivel (2021) used GMR data linked to consumption, finding that a decrease in mobility is associated with a decrease in consumption. According to Google LLC documentation, GMR data is anonymously retrieved from users' location captures shared via smartphones. The aggregated location captures data, which can be either the number of visitors or the duration of a visit, and then compares it to a baseline number at that location. The baseline is the median value of a location's activity level from corresponding days between January 3 and February 6, 2020. The activity levels of the locations were divided into several groups, namely: (a) Retail and Recreation, describing activity levels at museums, libraries, cafes, shopping malls, playgrounds, movie theaters, and other indoor recreation; (b) Grocery and Pharmacy, describing activity levels at markets, food stalls, food warehouses, and pharmacies; (c) Parks, describing activity levels at public parks, national parks, beaches, and outdoor recreation areas; (d) Workplaces, describing the level of activity in offices; (e) Residential, describing the level of activity in residential areas or villages; and (f) Transit Stations, describing the level of activity in public transportation centers, such as terminals, stations, and bus stops. With the availability of GMR data, it is possible to see the level of activity based on these locations.

The GMR indexes used in this study consist of Retail and Recreation, Grocery and Pharmacy, Parks, and Workplaces. We select the indexes based on the consideration that they reflect various aspects of economic activity. Cepparulo (2023) used the Retail and Recreation index to represent mobility linked to community consumption. Almgren & Holmberg (2021) excluded the Parks and Residential index when measuring GMR as economic activity. In this research, we still analyze the Parks index, considering the economic potential arising from activities conducted in these public places—such as trade and tourism—as Nagy et al. (2023) stated.

New approaches to measuring economic activity allow for a better understanding of the economic impacts of policies, such as road infrastructure development. If economic activity increases in locations where road infrastructure is constructed, it may indicate a positive impact of infrastructure development on economic activity.

The role of local governments in road management has increased due to decentralization following the issuance of Law No. 32/2004 on Regional Government. In Indonesia, based on their status and authority at various levels of government, roads are categorized as follows: (a) national roads, which connect provincial capitals, national strategic roads, and toll roads; (b) provincial roads, which connect district/city capitals to provincial capitals; and (c) district/city roads, which connect residential centers, activity centers, and public service centers within the district/city.

In multi-level government, where governments share tasks in implementing infrastructure policies, failed coordination will fail to maximize resource management (Gamper & Charbit, 2014). Marra (2014) states that decentralization will not be effective without an increase in regional government capacity. Higher-level government guidance is often needed to ensure the effectiveness of a program. Road construction in Indonesia requires government-level coordination to ensure integrated regional development. The Provincial Government, overseeing district/city authorities, coordinates local road projects. The provincial government's commitment to road development is measured by the share of Public Works Expenditure in total Provincial Government Expenditure. Previous studies, including those by Giammanco & Gitto (2019) and W. Zhao & Xu (2022), have used this kind of proxy, which clearly indicates government priorities.

Ji and Huang (2023) analyzed panel data from 800 Chinese counties between 2000-2019 to study the impact of road infrastructure on mobility, which is proxied by the non-permanent population ratio. Their findings reveal that increased road density significantly attracts residents. Economically developed areas further enhance this mobility. The study also explored how education interacts with road density, indicating that a higher average education level strengthens the influence of road infrastructure on mobility. Khoirunurrofik et al. (2022) identified education as a key socio-economic factor affecting mobility. Similarly, Yulianita et al. (2023) emphasize that for inclusive economic growth, the government should enhance human resource capacity and inclusive infrastructure.

Researchers have examined the impact of road infrastructure on economic activity in Indonesia, especially on a regional scale limited to a certain regency/municipality or province (Ambarita et al., 2024; Maqin, 2011; Runtunuwu, 2024; Suswita et al., 2020; Tarigan et al., 2021). Only a few studies have examined its impact on a national scale, including Khurriah & Istifadah (2019), Owusu-Manu et al. (2019), Nugraha et al. (2020), Khoirunurrofik et al. (2022), Gertler et al. (2022) and Timilsina et al. (2024). Despite these advancements, gaps remain in the literature. First, previous studies have not fully integrated mobility data to assess the local economic impact of road infrastructure. Traditional economic indicators such as GDP and GRDP fail to capture localized economic changes from infrastructure development. Second, earlier research on Indonesia's road infrastructure has primarily focused on national and provincial roads, neglecting district/city roads that directly impact local economies. Third, studies such as Gertler et al. (2022) were constrained by data limitations, as they lacked district/city-level road data.

This study addresses these gaps by introducing a novel perspective on road infrastructure and economic activity using mobility data as a proxy. Specifically, this research examines the correlation between district/city road infrastructure and local economic activity, as measured by GMR data. Road infrastructure is a proxy for infrastructure development because, first, highways ensure access to resources, labor, and markets (Queiroz & Gautam, 1992). Second, road data is more straightforward to measure and consistently recorded across Indonesia. Third, mobility data from GMR

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needs physical infrastructure data to establish causality. This study focuses on district/city roads that link activity centers and local services. The construction or maintenance of these roads directly impacts the local economy. While national and provincial roads are important, their effects on local economies are less direct and more challenging to discern.

GMR data is available from February 15, 2020, to October 15, 2022, longer than Apple Mobility Trend (up to April 14, 2022) and Facebook Mobility Report (March 1, 2020, to May 22, 2022). However, GMR is limited to sub-national or provincial levels, whereas Facebook Mobility provides district/city levels. Additionally, GMR may introduce sample bias as it depends on Google service users and internet access, possibly excluding portions of the population, particularly in areas with low-tech infrastructure.

Controlling factors affecting the results is important when using the GMR index. Previous research used Base Transceiver Station data to control the mobility index (Ridhwan et al., 2025). Based on smartphone user location capture, the GMR index relies heavily on telecommunications infrastructure for internet availability. The roads and locations in the GMR index are predominantly in the tertiary sector, which is related to the services sector. Ji and Huang (2023) examine economic structure to assess road infrastructure's impact on mobility but use a different tertiary economic structure due to the difference in mobility data proxies. Attiah (2019) notes that the service sector in developed countries provides over two-thirds of GDP and fuels growth in developing countries.

The study offers three key contributions: First, it provides empirical evidence on the impact of road infrastructure on localized economic activity, and second, it utilizes real-time mobility data as an economic indicator. Third, it emphasizes district/city roads' role in fostering local economic development. This research enhances the understanding of infrastructure's role in economic growth and informs policy decisions regarding road development and urban planning in Indonesia.

METHODS

This study employs panel data from the Ministry of Public Works and Housing, the Ministry of Finance, the Ministry of Communication and Information Technology, and the Central Statistics Agency (BPS). The road data includes the length of district/city roads aggregated at the provincial level during 2019-2021. GMR data informs about daily community activity levels in specific location categories identifiable up to the provincial level. DKI Jakarta was excluded from the analysis because it does not have district/city roads. After data cleansing, 99 observations remain over three years.

In this study, a fixed-effects panel data model is used to assess the impact of road infrastructure on economic activity, with the GMR activity index as the dependent variable. This model is ideal for controlling unobserved, time-invariant factors at the provincial level (e.g., geographic and demographic characteristics) that may affect infrastructure development and economic performance. By isolating the effect of road infrastructure, it

accounts for potential confounders. The fixed-effects model is widely used in infrastructure studies for its ability to control for unobserved heterogeneity and analyze cross-sectional and time-series data efficiently. (Khoirunurrofik et al., 2022; Khurriah & Istifadah, 2019; Ng et al., 2019; Nugraha et al., 2020)

The daily GMR index is calculated as an annual average, using data from 7 February to 15 October each year to avoid bias from the holiday season. The analysis excludes the transit station index data because information on the train station index related to Gorontalo Province for 2022 is unavailable. Therefore, this analysis uses the GMR indexes: Retail & Recreation, Grocery & Pharmacy, Park, and Workplaces. The interest variables are the length of district/city roads and the interaction between the length of district/city roads and the provincial government's commitment to public works. The use of district/city road data is because public activities measured by the GMR index fall within the range of that road network. The length of district/city roads is proportioned to the area of the respective province, referred to as road density. The use of road density is also consistent with previous research conducted by Aschauer (1990) and Nugraha et al. (2020).

Additionally, the provincial government's commitment to public works is included as an interaction term to capture the role of governance in enhancing the impact of infrastructure on economic activity. The share of public works expenditure in the provincial government's total expenditure is a proxy for the government's dedication to infrastructure development (Giammanco & Gitto, 2019). This variable is crucial because coordination between different levels of government (national, provincial, and district/city) plays a significant role in the effectiveness of infrastructure policies.

To ensure the robustness of the results, the model controls for several additional variables. Domestic Investment in the Secondary and Tertiary Sectors represents economic development (Ji & Huang, 2023). The selection of Domestic Investment in the secondary and tertiary sectors is due to the industries in these sectors being directly related to the GMR economic activity index. The School Participation Rate (SPR) represents the education level variable. The Tertiary Economic Structure is measured using the share of gross value added in the tertiary sector to the GDP in the respective region. The variable number of BTS represents the number of BTS in each province proportionate to the population. The COVID Year and the Recovery Year are used to control the temporal effects on the model, as it is necessary to determine whether the increase in economic activity is due to the recovery of post-pandemic activities or purely from the increase in road length. Specific control variables in the model according to the GMR index as follows: (i) Online Shopping Rates in the Retail and Recreation index and the Grocery and Pharmacy index, (ii) Number of Rainy Days in the Parks index, and (iii) Labor Force Participation Rate in the Workplaces index.

Based on the description above, we develop the following regression model to measure the impact of road infrastructure on local economic activity:

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$$EconomicActivity_{it} = \beta_0 + \beta_1 \ln DistrictRoad_{it-1} + \beta_2\, PWCommitmentProv_{it-1} + \beta_3\, RoadInteraction_{it-1} + \beta_4 \ln DomesticInvestment_{it-1} + \beta_5 SPR_{it} + \beta_6 TertiaryEcoStructure_{it} + \beta_7 BTS_{it} + \beta_8\, SpecificVariable_{it} + \beta_9\, DCovid_{it} + \beta_{10} DRecoveryInteraction_{it} + c_i + \mu_{it}$$

RESULTS AND DISCUSSION

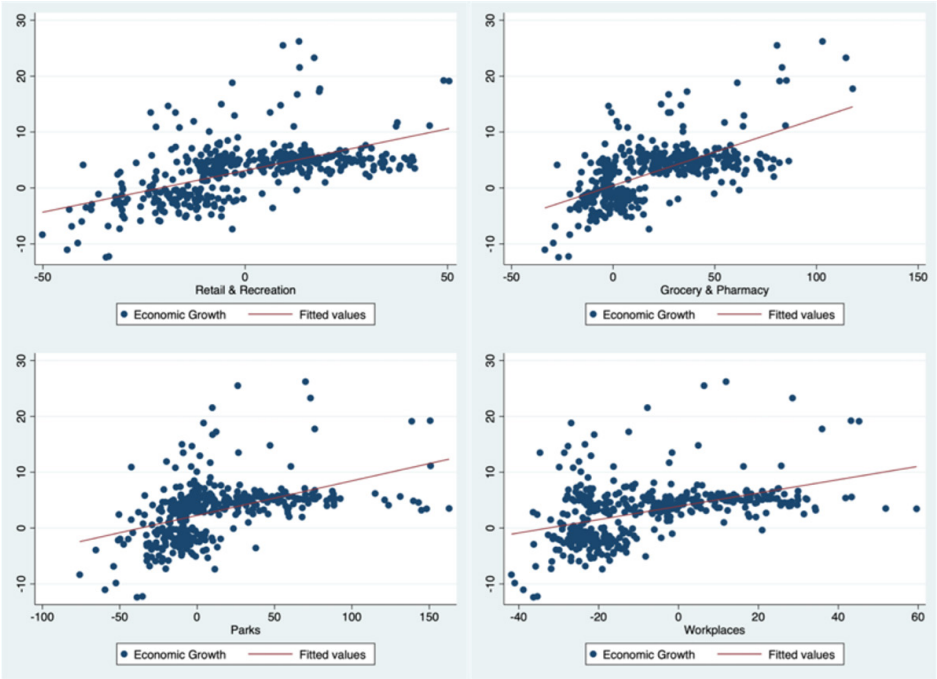
Table 1 presents the descriptive statistics of the key variables used in this study. Among the GMR Indexes, the Grocery & Pharmacy index shows the highest mean value, at 19.225%, reflecting the importance of essential services during the pandemic, when people's activities were predominantly focused on health-related locations and acquiring essential goods. Conversely, the Workplaces index has the lowest mean value at 9.42%, which can be attributed to the shift to work-from-home policies and mobility restrictions during the COVID-19 pandemic. These findings align with global mobility patterns observed during the pandemic, which saw a sharp decline in workplace-related activities compared to essential services (Caselli et al., 2020). The Parks index has the most significant standard deviation value and a wider range of values, indicating a significant variation in the various units of analysis. Meanwhile, the retail & recreation and workplace indices have lower standard deviations, indicating more consistent mobility patterns within these categories across regions.

Table 1. Descriptive Statistics

Variable	Unit	Obs	Mean	Std. Dev.	Min	Max
Retail & Recreation	%	99	-3,01	18,13	-36,16	44,35
Grocery & Pharmacy	%	99	19,22	26,03	-25,77	100,42
Parks	%	99	10,11	36,62	-45,35	126,7
Workplaces	%	99	-9,42	16,89	-37,41	36,58
DistrictRoad	km/km^2	99	0,38	0,29	0,04	1,29
PWCommitmentProv	%	99	10,535	5,19	1,94	31,87
DomesticInvestment	Billion/1.000 population	99	1183,79	1.003,14	19,84	5.514,69
School Participation Rate (SPR)	%	99	75,05	6,02	63,5	89,63
TertiaryEcoStructure	%	99	28,17	8,30	11,89	46,92
BTS	Unit/1.000 population	99	2,363	0,71	0,95	3,94
SpecificVariable–Household Online Shopping Rate	%	99	8,48	2,57	4,01	16,56
SpecificVariable–Rainy Days	Days	99	216,40	33,37	113	286
SpecificVariable–Labor Force Participation Rate	%	99	68,43	3,26	62,15	78,29

Figure 2 displays a scatter plot showing the relationship between each GMR index and provincial economic growth from 2020-2022 every quarter. Based on the scatter plot and trend line analysis, economic growth and GMR mobility data have a relatively strong positive correlation across all indices. The Grocery & Pharmacy index shows the strongest positive correlation, while the Workplaces index exhibits the weakest. These patterns can be evidence to add confidence in GMR mobility data as an indicator of local economic activity, which is also in line with previous studies (Caselli et al., 2020; Putra & Arini, 2020; Sampi Bravo & Jooste, 2020; Spelta & Pagnottoni, 2021).

Figure 2. Scatter Plot GMR index and Economic Growth 2020-2022



Source: Google LLC and BPS (2024)

Table 2 shows the estimation results for the Retail & Recreation index. The models indicate a significant positive relationship between district road infrastructure and Retail and recreation activities. Specifically, a 1% increase in district road density (measured as road length per km²) leads to a 3.60 percent increase in Retail and recreation activity in the basic model (RR-1). This effect decreases in magnitude in the controlled models (RR-2 and RR-3), which control for other variables, including the temporal effect of COVID-19. However, the reduction in effect size does not diminish the overall significance of road infrastructure in driving economic activity in Retail and recreation. This finding aligns with previous studies emphasizing the importance of transportation accessibility in promoting economic activities (Queiroz & Gautam, 1992; Rodrigue, 2016).

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Table 2. Estimation Result of the Effect of Road Infrastructure on Economic Activity in Retail & Recreation

Variables	Retail & Recreation		
	Model RR-1	Model RR-2	Model RR-3
LnDistrictRoad	360.6***	126.8**	94.52**
PWCommitmentProv	-0.520	-0.917**	-0.374**
RoadInteraction	0.280	-0.575*	0.0222
SPR		19.60***	3.186
LnDomesticInvestment		3.687	0.450
TertiaryEcoStructure		4.942**	-1.111
BTS		79.13***	35.16***
SpecificVariable–Household Online Shopping Rate		0.906	2.884***
DCovid			-30.89***
DRecoveryInteraction			4.052***
Constant	457.5***	-1,550***	-122.2
Observations	99	99	99
R-squared	0.157	0.669	0.930
Number of prov	33	33	33
Robust Standard Error	Yes	Yes	Yes

*** p<0.01, ** p<0.05, * p<0.1

RoadInteraction variable—the interaction between LnDistrictRoad and PWCommitmentProv, proxy of Coordination Function—shows a significant negative relationship (10%) in the RR-2 model. In addition, the PWCommitmentProv variable also has a significant negative effect (5%). This result suggests that increased public works expenditure at the provincial level may not enhance the relationship between road infrastructure and mobility in Retail and recreation. The direction of the negative coefficient on the interaction variable means that the higher the increase in the Provincial Government's commitment to public works weakens the relationship between road infrastructure and mobility in Retail and recreation, which is consistent with findings from previous studies that suggest coordination challenges in multi-level governance systems (Gamper & Charbit, 2014).

The School Participation Rate (SPR) in the RR-2 model has a positive effect with a significance level of 1%, which means that more people accessing education services will increase economic activity in Retail and recreation. However, adding the COVID recovery temporal effect control renders the SPR variable insignificant. The TertiaryEcoStructure variable also shows similar findings. This result supports findings from Ng et al. (2019), suggesting that education levels are a key factor in driving consumption and economic activities. Areas with higher education likely benefit from better access to retail centers and increased disposable income for leisure.

The Household Online Shopping Rate variable has a positive and significant relationship of 5% in the RR-3 model with a coefficient of 2.884. This positive relationship

may result from increased delivery courier activities, such as online motorcycle taxis or package delivery services, which continue to visit Retail and recreation locations despite declining physical shopping activities. The BTS variable also supports this statement by showing a positive and significant effect. The GMR index measures activity based on the locations of smartphone users. Meanwhile, goods or food delivery services must activate the location on the cellphone, so the increase in activity also depends on the internet availability in the area. According to Mouratidis and Papagiannakis (2021), digital activities such as online shopping have increased significantly since the pandemic.

Table 3. Estimation Result of the Effect of Road Infrastructure on Economic Activity in Grocery & Pharmacy

Variables	Grocery & Pharmacy		
	Model GP-1	Model GP-2	Model GP-3
LnDistrictRoad	566.8***	290.1***	255.5***
PWCommitmentProv	-0.424	-1.149**	-0.565*
RoadInteraction	0.668	-0.595	0.0467
SPR		27.14***	9.501***
LnDomesticInvestment		6.959**	3.482
TertiaryEcoStructure		1.859	-4.646**
BTS		126.6***	79.33***
SpecificVariable–Household Online Shopping Rate		0.637	2.762*
DCovid			-33.20***
DRecoveryInteraction			4.362
Constant	742.2***	-1,859***	-324.4
Observations	99	99	99
R-squared	0.191	0.761	0.910
Number of prov	33	33	33
Robust Standard Error	Yes	Yes	Yes

Note: *** p<0.01, ** p<0.05, * p<0.1

The analysis of the Grocery & Pharmacy (Table 3) shows a positive and significant relationship at the 1% level. The interpretation of the DistrictRoad variable in the GP-3 model is that every 1% increase in district roads per km2 will increase activity in Grocery & Pharmacy by 2.55 percentage points. Although the coefficient of the DistrictRoad variable in the GP-3 model is lower than in the GP-1 and GP-2 models, the coefficient figure is still quite prominent, where the R-squared value also increases significantly. The positive relationship reinforces the idea that better access to grocery stores and pharmacies is linked to better road networks, particularly in rural and underserved areas. The coordination function represented by the RoadInteraction variable does not show a significant relationship. The analysis indicates that the coordination function does not strengthen the relationship between district roads and activities in Grocery & Pharmacy.

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The SPR variable shows a significant positive effect at the 1% level in all Grocery & Pharmacy estimation models, which indicates that more people attending school at the appropriate age will increase activity in Grocery & Pharmacy. The DomesticInvestment variable has a positive and significant effect (5%) in the GP-1 and GP-2 models. However, in the GP-3 model, the coefficient becomes insignificant. This finding suggests that the previous significant effect is more due to the variation in the temporal effect of COVID-19. The TertiaryEcoStructure has a negative relationship with activity in Grocery & Pharmacy in the GP-3 model. It means that the higher the tertiary economic structure, the lower the activity in Grocery and pharmacy. This finding is different from previous research by Attiah (2019). It is due to the shift in production factors and capital in other service sectors. The Household Online Shopping Rate shows a significant positive relationship (10%) in the GP-3 model. This result means that online shopping increases grocery and pharmacy activity. It is due to the online delivery courier activity that keeps the location enabled on the cellphone so that it is detected as a visit to the Grocery and pharmacy location.

Table 4. Estimation Result of the Effect of Road Infrastructure on Economic Activity in Parks

Variables	Parks		
	Model P-1	Model P-2	Model P-3
LnDistrictRoad	640.4***	201.0	78.83
PWCommitmentProv	-1.026	-1.905**	-0.349
RoadInteraction	-0.0256	-1.876**	-0.248
SPR		37.64***	5.191
LnDomesticInvestment		6.883	-0.123
TertiaryEcoStructure		6.065	-2.123
BTS		96.60**	19.36
SpecificVariable–Rainy Days		-0.480**	0.0918
DCovid			-57.72***
DRecoveryInteraction			-3.658
Constant	821.8***	-2,762***	-218.7
Observations	99	99	99
R-squared	0.109	0.577	0.877
Number of prov	33	33	33
Robust Standard Error	Yes	Yes	Yes

Note: *** p<0.01, ** p<0.05, * p<0.1

The results in Table 4 show that DistrictRoad variable has a significant positive relationship (1%), but only in the P-1 model. However, the model does not show a significant relationship after adding control variables and the temporal effect of COVID-19. The level of community activity in Parks is not necessarily dependent on road construction. Other factors, such as weather, have a more significant influence. The number of rainy days had a negative and significant impact of 1% in the P-2 model. This

negative relationship between weather and activity in Parks is consistent with previous studies by Hewer et al. (2016) and Paudyal et al. (2019).

The RoadInteraction variable showed no significant relationship in all the Parks estimation models. The SPR has a positive and significant effect on mobility in Parks in the P-2 model, which means that more people attending school at school age will increase visits to Parks. This finding aligns with the study of Gu et al. (2020), which states that higher education levels will increase park visits, but it contradicts the study of Gong et al. (2023). However, after adjusting for COVID-19 temporal effects, no control variables show a significant relationship with park mobility. This further supports the idea that the pandemic's disruption of normal activities outweighs the impact on road infrastructure.

Table 5. Estimation Result of the Effect of Road Infrastructure on Economic Activity in Workplaces

Variables	Workplaces		
	Model W-1	Model W-2	Model W-3
LnDistrictRoad	254.6***	43.25	-61.48**
PWCommitmentProv	-0.559	-1.039**	-0.000310
RoadInteraction	-0.240	-1.031**	-0.218
SPR		12.93***	0.257
LnDomesticInvestment		1.930	-1.767
TertiaryEcoStructure		7.516**	-0.276
BTS		67.14***	-10.44*
SpecificVariable–Labor Force Participation Rate		2.322	-0.786
DCovid			-31.65***
DRecoveryInteraction			-2.902*
Constant	311.6***	-1,367***	-6.834
Observations	99	99	99
R-squared	0.070	0.468	0.937
Number of prov	33	33	33
Robust Standard Error	Yes	Yes	Yes

Note: *** p<0.01, ** p<0.05, * p<0.1

The results of the effect of road infrastructure in workplaces are presented in Table 5. The DistrictRoad variable in model W-1 has a positive effect with a significance level of 1% for model W-1. The interpretation is that every 1% increase in district road length per km2 will increase activity in Workplaces by 2.54 percentage points. Meanwhile, adding control variables to the W-2 model makes the DistrictRoad variable insignificant. The coordination function, proxied by the RoadInteraction variable, shows a negative and significant result in model W-2. This finding means that an increase in the coordination function of the provincial government will

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weaken the relationship between district roads and workplace activities. The SPR, TertiaryEcoStructure, and BTS variables in model W-2 show a positive and significant relationship, indicating that these three variables increase activity in Workplaces. The DomesticInvestment and Labor Force Participation Rate variables do not show a significant effect.

When the model uses the temporal effect of COVID in Model W-3, the DistrictRoad variable shows a negative relationship. Changes in people's behavior regarding how to work affect the relationship. Many offices implemented Work From Home (WFH) and Work From Anywhere (WFA) policies during the COVID pandemic. The construction of district roads shifted activities from workplaces to other locations, such as housing, cafes, or coworking spaces, which are more easily accessible through new roads. It can also be seen that the BTS variable has a negative relationship (significant at 10%), which means that an increase in BTS will decrease workplace activity. Improved telecommunications infrastructure supports and facilitates remote working, replacing the physical functions of the office with virtual solutions, allowing workers to work without the need to be physically present in the office.

The results of this study show that road infrastructure has a significant and positive impact on activities in the Retail and recreation and Grocery and pharmacy indices, with coefficient values of 94.52 (0.94%) for Retail and recreation and 255.5 (2.55%) for Grocery & Pharmacy, respectively. The coefficient values obtained for these two indices are large compared to previous studies measuring the impact of roads on mobility, such as those reported by Yu and Zhao (2021) at 0.83% and Ji and Huang (2023) at 0.828%. When compared to studies analyzing the impact of road infrastructure on economic activities, these coefficient values are still more significant, such as by Aschauer (1990) at 0.22%–0.30%, Prasetyo and Firdaus (2009) at 0.13%, Kalan (2017) at -1.33%, and Ng et al. (2019) at 0.2%.

The more significant coefficients shown in the study above suggest that the road infrastructure in Indonesia impacts the economy of the Retail & Recreation and Grocery & Pharmacy sectors more than what has been found in previous studies in other parts of the world. The conditions may be due to several reasons specific to Indonesia, such as (1) the increased demand for basic health services that came with the COVID-19 pandemic, especially in the Grocery and pharmacy. New and better roads enabled people to procure these essential services. Such development would result in greater economic activity and mobility within these sectors. (2) the geographical constraints that Indonesia faces will, for example, benefit significantly from road improvements for rural and underdeveloped areas as they have a lack of accessibility. On the other hand, more developed countries tend to have lower coefficient values. This is because the value added from extra road construction is less in infrastructure-rich countries. (3) the active response of mobility in these sectors to new roads is significant. Mobility increases as people living in places with poor road infrastructure and are economically inactive become economically active, which causes improved road access.

If the GMR indices are compared using the district road coefficient values after controlling for the temporal effects of COVID, the lowest district road coefficient value is found in the Workplaces index at -61.48 (-0.6148 percentage points), and the highest coefficient value is found in the Grocery & Pharmacy index at 255.5 (2.55 percentage points). This finding is consistent with the descriptive analysis, in which the Workplaces index has the lowest mean, while the Grocery & Pharmacy index has the highest value. Related to the research data that uses the period of the COVID pandemic, population activities were more concentrated in areas selling food and health supplies. In addition, implementing social restrictions and new work patterns also affected the negative coefficient value of road infrastructure at Workplaces. The statement is also in line with what was conveyed by Gauvin et al. (2021), that there was a significant decrease in mobility in the industrial sector during the lockdown, as well as in the service sector during the late lockdown period and the reopening. The significant coefficient value for Grocery & Pharmacy indicates that activities at those locations are sensitive to the development of district roads. People tend to need better accessibility to reach Grocery and pharmacy areas.

When the model controls for the temporal effects of COVID, the Coordination Function—proxied by the interaction variable between the Provincial Government's Public Works Commitment variable and the district road infrastructure variable—does not have a significant relationship with all GMR indices. A significant negative relationship between the Provincial Government's Public Works Commitment variable and the Retail and Recreation and Grocery and Pharmacy indices was found, with coefficients of -0.374 and -0.565, respectively. The findings indicate that the Provincial Government is not optimally carrying out the road development coordination function. According to Freeman and Rossi (2012), the challenge of coordination is the presence of overlapping policies, where each government has different agendas, which can lead to a decrease in the effectiveness of coordination. Furthermore, Rodrigue (2016) states that developing countries often exhibit low managerial capacity and a lack of coordination in managing transportation infrastructure. Ideally, with the coordination role held by the Provincial Government, it can align and integrate various district/city road developments in its region, thereby strengthening connectivity and accessibility.

The School Participation Rate shows a positive and significant relationship in all GMR index models when the model does not control for the temporal effects of COVID-19. These findings prove that residents who receive education—regardless of a specific level of education—can enhance mobility. When the model included the temporal effects of COVID-19, a significant relationship of the SPR variable was found only in the Grocery & Pharmacy index. The results are consistent with the research by Yu and Zhao (2021) and Zhao and Yu (2021) but differ from the findings of Gauvin et al. (2021) and Khoirunurrofik et al. (2022). The difference is likely due to using different mobility data proxies and the periods used.

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CONCLUSION

The estimation results using fixed effects show that road infrastructure positively and significantly impacts mobility in Retail and recreation, Grocery and pharmacy, Parks, and Workplaces when not using temporal COVID effect controls. After applying temporal COVID effect controls, the estimation results for the road infrastructure variable vary. The road infrastructure variable consistently has a positive and significant impact for the Retail and recreation and Grocery and pharmacy models. The Parks model shows different results, which indicates insignificant results. It indicates that factors other than road infrastructure, such as weather, largely influence the increase in economic activity in Parks.

Meanwhile, in the Workplaces model, the road infrastructure variable has a significant negative impact. Due to the changing work patterns, such as the implementation of Work From Home (WFH) and Work From Anywhere (WFA) policies, employees are not required to be physically present in the office. Among all the models implemented, Grocery & Pharmacy shows the highest coefficient for the effect of road construction. During the COVID pandemic, people concentrated more on fulfilling basic needs and healthcare services, specifically in markets, supermarkets, and pharmacies. In addition, this may also indicate that the effects of road construction are more sensitive in the Grocery and pharmacy area compared to other locations, where the community tends to require better accessibility to reach these areas. The coordination function, represented by the interaction between road construction and Provincial Government Public Works Expenditure, mostly does not show significant results. These findings may indicate that the coordination carried out by the Provincial Government in road development has yet to be optimal. Coordination issues are a common occurrence in developing countries that implement multi-level governance.

Based on the analysis and findings above, the government needs to prioritize the development of better road networks, especially in areas that support local economic activities, such as Retail & Recreation and Grocery & Pharmacy. Improving accessibility will have a significantly positive impact on the local economy. Although the research results show a negative impact of road construction on mobility in workplace areas, building roads to workplace regions remains important to support long-term work mobility. Changes in work patterns during the pandemic most likely caused this negative effect. Furthermore, we need to address the suboptimal coordination function. The provincial government can enhance its coordination role by ensuring that the road development plans of the regency/municipality in the Regency/Municipality Spatial Planning and Zoning align with the Provincial Spatial Planning and Zoning. Additionally, the provincial government can initiate a joint discussion forum with the regency/municipality government to share best practices in road development.

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