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Evaluating Socio-Economic and Safety Impacts of Grade-Separated Railway Crossings in Indonesia

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ABSTRACT: This study analyzes grade-separated rail infrastructure development's socio-economic and safety impacts at railway crossings in Indonesia through Structural Equation Modeling—Partial Least Squares (SEM-PLS). The research examines relationships between safety enhancement, congestion reduction, property values, local business effects, and community support. Data collection involved 450 respondents across six major crossing sites through stratified random sampling using a validated questionnaire (Cronbach's $\alpha = 0.89$). Results demonstrate significant correlations between safety enhancement and community support ($\beta = 0.678$, $p < 0.001$), traffic congestion reduction ($\beta = 0.623$, $p < 0.001$), and property values ($\beta = 0.589$, $p < 0.001$). The measurement model confirms robust construct reliability (CR > 0.84) and validity (AVE > 0.65), with community support showing strong predictive power ($R^2 = 0.762$). Findings indicate that grade-separated crossings reduce accidents while positively impacting property values and business activities. The study contributes to transportation infrastructure theory and provides evidence-based policy recommendations for sustainable development in Indonesia, emphasizing integrated safety measures with socio-economic considerations in infrastructure planning.

Keywords: Grade-Separated Crossings, Socio-Economic Impact, Safety Enhancement, Community Engagement, Transportation Infrastructure.

INTRODUCTION

Railway safety infrastructure has become a critical concern in Indonesia's transportation development. Statistical data from the Ministry of Transportation reveals a significant increase in railway-related incidents from 738 cases in 2022 to 774 cases in 2023, representing a 4.9% growth, with 35% of these incidents occurring at rail crossings (Restuputri et al., 2022). This trend highlights a critical vulnerability in infrastructure systems, particularly at rail-road intersection points (V. Gitelman & Hakkert, 1997).

The paper discusses the factors contributing to accidents at railroad crossings and the socioeconomic and safety impacts of grade-separated rail infrastructure (Kallberg et al., 2002)(Mathew et al., 2021). One proposed solution is the construction of grade-separated crossings, which can eliminate the direct interaction between trains and road traffic (De Gruyter & Currie, 2016). However, the implementation of grade-separated infrastructure also has complex socio-economic implications, including changes in accessibility, mobility, and the impact on surrounding community activities (Keramati et al., 2020) (Mathew et al., 2021)(Sharma et al., 2023).

Inadequate warning signs and insufficient road user training are also significant contributors to accidents at railroad crossings (Mathew et al., 2021). There is an urgent need to transform infrastructure towards more excellent safety and enhance road user awareness (Khoudour et al., 2009)(Schartung et al., 2011)(Metaxatos & Sriraj, 2015). Improving warning signs and implementing training programs can help reduce accident risks at these locations (Schartung et al., 2011). This underscores the pressing need to transform infrastructure towards safer designs and increase road user consciousness (Montoya-Alcaraz et al., 2020). Furthermore, the construction of grade-separated infrastructure, such as flyovers or underpasses, offers potential solutions to address safety and efficiency issues at railroad crossings (Mitcheltree & Sunikka-Blank, 2023). However, implementing large-scale infrastructure projects requires substantial investment and can have significant socioeconomic impacts on the surrounding community (Rezvani et al., 2015) (Mathew et al., 2021). Evaluating the effectiveness of grade-separated intersections in improving traffic safety can demonstrate that grade-separated crossings significantly reduce accident rates (De Gruyter & Currie, 2016). This emphasises the importance of designing infrastructure that prioritises the safety of road users, particularly in high-traffic urban areas (V. Gitelman & Hakkert, 1997)(Kallberg et al., 2002)(Victoria Gitelman et al., 2006).

The primary challenge in evaluating grade-separated infrastructure projects lies in the complexity of quantifying the long-term socioeconomic and safety benefits and their impacts on local communities (Rezvani et al., 2015). Developing a framework to assess transportation investments and their effects on economic performance has demonstrated that investments in transportation infrastructure have a significant positive impact on economic performance (Sinha & Labi, 2007)(Rafferty, 2009)(Deng, 2013)(Chèze & Nègre, 2017). By designing projects that enhance accessibility, local economic growth can be more effectively stimulated. This underscores the importance of a holistic approach in evaluating the impact of infrastructure projects in developing countries (Ngacho & Das, 2014)(Hussain et al., 2017)(Timilsina et al., 2021).

This highlights the potential to provide empirical evidence to support decision-making in the allocation of resources for transportation infrastructure projects in Indonesia (Alamgir et al., 2017)(Yii et al., 2018)(Monyane & Awuzie, 2019). The strategic actions of external stakeholders involved in the project can significantly influence the outcomes (Cantarelli et al., 2012)(Alamgir et al., 2017)(Yii et al., 2018). The strategic actions taken by stakeholders often become a determining factor in the success or failure of a project, emphasizing the importance of an integrated approach in evaluating transportation infrastructure projects to optimize resource allocation, enhance public safety, and promote sustainable economic growth (Dimitriou & Sartzetaki, 2016)(Larsson & Larsson, 2020)(Ametepey et al., 2022).

Quantitative and qualitative analysis focuses on developing a comprehensive and contextual cost-benefit model (Gharehbaghi et al., 2019). Multicriteria analysis methods in transportation infrastructure decision-making are effective in helping decision-makers consider the various complex factors involved in transportation infrastructure development (Rafferty, 2009). This approach allows for more informed and inclusive decisions, aligning with a multidimensional approach to infrastructure project evaluation recommendations to ensure sustainability and social acceptance (Gharehbaghi et al., 2019)(Yang et al., 2020).

Despite extensive research on grade-separated rail crossings, significant knowledge gaps persist in current literature, particularly regarding implementation in developing nations. Current research predominantly focuses on developed countries, leaving critical uncertainties about socio-economic impacts in emerging economies. The absence of integrated evaluation models that combine safety metrics with socioeconomic factors limits comprehensive project assessment. Furthermore, while stakeholder engagement is widely acknowledged as crucial, documentation of its effectiveness remains insufficient, especially in the Indonesian context. The unique challenges of implementing grade-separated infrastructure in Indonesia, including regulatory frameworks, local community dynamics, and resource constraints, remain inadequately explored in existing scholarly work.

This investigation examines grade-separated railway crossings in Indonesia through a comprehensive quantitative analysis utilizing Structural Equation Modeling to evaluate socioeconomic impacts. The research analyzes correlations between safety enhancements and community acceptance while quantifying effects on local business activities and property values by systematically measuring economic indicators during pre- and post-implementation phases. The study culminates in developing an evidence-based decision-making framework for infrastructure development in emerging economies, integrating safety, social, and economic parameters. This methodologically robust approach ensures systematic investigation of infrastructure development impacts on community well-being and economic vitality.

Literature Review

Infrastructure is fundamental to a region's economic performance (Restuputri et al., 2022). The quality of infrastructure at the regional level affects its economic development and the surrounding areas. Spatial impact analysis of infrastructure on economic growth shows spillover effects across regions, where economic development in one area also influences the economic growth of other areas (Pokharel et al., 2023). Furthermore, studies have shown that infrastructure development impacts improving public access and mobility and the potential to increase economic income (Fedorets et al., 2019). Other studies have also underscored the importance of infrastructure in supporting long-term economic growth in Southeast Asia (Singh & Kathuria, 2016)(Yii et al., 2018). However, the implementation of large-scale infrastructure projects, such as the construction of grade-separated rail crossings, also has the potential to cause socio-economic changes in the surrounding areas (Ramlawati & Hilmi, 2020).

The impact of grade-separated infrastructure development on traffic safety is also critical. Research indicates that grade-separated crossings significantly reduce accident rates compared to at-grade crossings. Therefore, a comprehensive evaluation is necessary to quantify grade-separated rail infrastructure projects' long-term socioeconomic and safety benefits and their impacts on local communities (De Gruyter & Currie, 2016). Cost-benefit analysis of grade-separated infrastructure at railroad crossings has been a significant research focus in recent years, particularly given the increasing need for safe and efficient transportation in various countries (Rezvani et al., 2015).

Advances in Cost-Benefit Analysis Methodologies for Transportation Infrastructure Projects

Researchers have developed a framework to assess the impact of transportation investments on economic performance (Lane & Sherman, 2013)(de Jong & Bliemer, 2015). This framework demonstrates that investments in transportation infrastructure have a significant positive impact on economic performance. By designing projects that enhance accessibility, local economic growth can be more effectively stimulated (Deng, 2013)(Banerjee et al., 2020)(Pokharel et al., 2023). Furthermore, studies have shown that multicriteria analysis methods are effective in helping decision-makers consider the various complex factors involved in the development of transportation infrastructure.

Multicriteria analysis methods have been widely recognized as effective tools in helping decision-makers navigate the complex landscape of transportation infrastructure development (Zhu et al., 2019)(Bellsolà Olba et al., 2019)(Yang et al., 2020). This approach allows for a more comprehensive and inclusive evaluation process, considering a wide range of factors that influence the success and impact of such projects. By adopting a holistic perspective, decision-makers can make more informed and well-rounded decisions, which is particularly crucial in the context of developing countries where infrastructure projects can have significant socioeconomic implications (Yanwen, 2012)(Monyane & Awuzie, 2019). This underscores the importance of a multidimensional approach to assessing the impacts of infrastructure projects, ensuring that the needs and concerns of various stakeholders are taken into account to foster sustainable and equitable development (Mottee et al., 2020)(Juffe-Bignoli et al., 2021).

Evaluation of the Socioeconomic Impacts of Grade-Separated Infrastructure

The strategic actions of external stakeholders in the project state that "the involvement of external stakeholders in the project can significantly influence the outcomes". The strategic actions taken by stakeholders often become a determining factor in the success or failure of a project (Oppong et al., 2017)(Srinivasan & Dhivya, 2020)(Zakaria et al., 2023). This underscores the importance of an integrated approach in evaluating transportation infrastructure projects to optimize resource allocation, enhance public safety, and promote sustainable economic growth (Rangarajan et al., 2013)(Gharehbaghi et al., 2019)(Larsson & Larsson, 2020). Additionally, public participation in infrastructure project evaluation increases transparency and creates more relevant and beneficial outcomes for the community. Projects that engage the community tend to be more successful in meeting local expectations and needs (Hussain et al., 2017)(Badasyan & Alfen, 2017)(Hasan et al., 2018)(Shrestha et al., 2019).

Analysis of Safety Enhancement Through Grade-Separated Infrastructure

The evaluation results indicate that grade-separated intersections significantly reduce accident rates compared to at-grade crossings. This underscores the critical importance of infrastructure design that prioritizes road user safety, particularly in urban areas with high traffic volume and complex transportation networks (Kallberg et al., 2002)(Stamatiadis et al., 2012)(Keramati et al., 2020). The lack of adequate warning signs, poor driver behaviour, and insufficient driver training has contributed significantly to accidents at railway crossings (MACIOSZEK et al., 2020). Enhancing warning signage, implementing comprehensive driver training programs, and improving overall safety infrastructure can help mitigate the risk of accidents at these high-risk locations (Barić et al., 2020). A holistic approach that addresses both engineering design and human factors is essential to maximize the safety benefits of grade-separated rail infrastructure projects.

Implementation Challenges in Developing Countries

Factors such as poor road conditions and risky driver behavior significantly influence motorcycle accident rates at unsignalized intersections (Teoh, 2018)(Halbersberg & Lerner, 2019)(Champahom et al., 2020)(Wallius et al., 2022). Enhancing road infrastructure through improved design, maintenance, and signaling, as well as providing comprehensive driver training programs, are essential to mitigate the accident risks faced by vulnerable road users like motorcyclists (Teoh, 2018)(Halbersberg & Lerner, 2019)(Huertas-Leyva et al., 2021). Additionally, the operational readiness of rail systems to address the growing impacts of climate change highlights the urgent need to strengthen and adapt the existing rail infrastructure. By proactively adapting operational systems and improving climate resilience, rail services can be ensured to continue uninterrupted despite the increasing climate-related challenges such as extreme weather events and changing weather patterns (Hayhoe et al., 2015)(Dundon et al., 2016)(Cheng et al., 2022)(Wang et al., 2023).

Through SEM-PLS modelling, this study advances transportation infrastructure theory by establishing empirical connections between safety improvements, socioeconomic benefits, and community support. The research extends existing theoretical frameworks by demonstrating how grade-separated infrastructure simultaneously affects multiple stakeholder groups. The validated measurement model provides a theoretical foundation for understanding infrastructure impacts in developing economies, while the high R^2 values for community support (0.762) enhance understanding of how infrastructure benefits translate into stakeholder acceptance.

The research provides robust empirical evidence of grade-separated rail crossing benefits in Indonesia, quantifying relationships between safety enhancement, property values, and community support. The SEM-PLS results, with significant path coefficients and strong construct reliability, offer practical metrics for evaluating infrastructure project outcomes. The comprehensive analysis of 450 respondents across six major sites establishes a valuable dataset for understanding stakeholder perspectives in developing economies.

The findings significantly influence transportation infrastructure policy in Indonesia. The strong correlation between safety enhancement and community support ($\beta = 0.678$) suggests prioritizing safety improvements in infrastructure planning. The research recommends:

- Implementing comprehensive safety measures alongside infrastructure development
- Developing integrated approaches considering technical and social factors
- Establishing clear stakeholder engagement frameworks
- Creating policies maximizing socioeconomic benefits through strategic infrastructure placement
- Enhancing warning systems and driver education programs These recommendations align with national development goals while addressing local community needs and safety concerns.

METHOD

This study implemented a comprehensive data collection process utilizing a structured questionnaire developed through rigorous validation procedures, including expert panel review (n=5 transportation specialists) and pilot testing (n=30 respondents), achieving high reliability (Cronbach's $\alpha = 0.89$). The research instrument comprised 25 items measuring five distinct constructs: Safety Enhancement, Traffic Congestion Reduction, Property Value Impact, Local Business Effects, and Community Support, employing a 4-point Likert scale. Field implementation occurred during January-March 2024 across six major grade-separated railway crossing sites in Indonesia, utilizing face-to-face interviews conducted in Bahasa Indonesia with validated translations. The sampling design, determined through power analysis (α=0.05, power=0.80, effect size=0.15), established a minimum requirement of 400 respondents, with 450 surveyed, incorporating stratified random sampling across four stakeholder categories: residents (40%, n=180), business owners (30%, n=135), regular commuters (20%, n=90), and transportation experts (10%, n=45), each meeting specific eligibility criteria.

The analytical methodology employed Structural Equation Modeling with Partial Least Squares (SEM-PLS), following a two-phase evaluation protocol. The measurement model assessment encompassed reliability testing (factor loadings>0.7, composite reliability>0.7), convergent validity examination (AVE>0.5), and discriminant validity verification through Fornell-Larcker criterion and HTMT ratio analysis. The structural model evaluation involved path analysis examining direct, indirect, and total effects, supported by bootstrap resampling (5000 iterations) for hypothesis testing. Model fit assessment included R^2 evaluation, f^2 effect size analysis, Q^2 predictive relevance examination, and VIF multicollinearity checking, ensuring robust statistical validation of the hypothesized relationships.

RESULT AND DISCUSSION

Table 1. Data Sosio-Demografi Responden

Characteristic	Frequency	Percentage
Gender		
Male	271	60.2%
Female	179	39.8%
Age		
18-30 years	128	28.4%
31-45 years	197	43.8%
46-60 years	103	22.9%
> 60 years	22	4.9%
Education Level		
High School/Equivalent	124	27.6%
Diploma	87	19.3%
Bachelor's Degree	189	42.0%
Master's/Doctoral Degree	50	11.1%
Occupation		
Student	36	8.0%
Private Sector Employee	165	36.7%
Government Employee	89	19.8%
Entrepreneur	112	24.9%
Other	48	10.7%
Monthly Income		
< 5 million IDR	159	35.3%
5-10 million IDR	183	40.7%
> 10 million IDR	108	24.0%

Source: Research Data Analysis, 2024

Analyzing respondents' sociodemographic characteristics provides important insights into the stakeholder profile involved in grade-separated infrastructure projects in Indonesia. The majority of respondents were male and within the productive age range of 31-45 years old, indicating the dominance of this demographic group in the sample. Respondents were predominantly college graduates, suggesting a relatively high stakeholder literacy level. Regarding occupation, private sector employees were the largest group, followed by entrepreneurs, reflecting significant representation from the private sector in this study. The income distribution shows that 40.7% of respondents have a monthly income between Rp 5-10 million, providing a snapshot of the middle-income economic status of most respondents. This demographic profile is crucial for understanding the socioeconomic context of perceptions and attitudes toward grade-separated infrastructure projects. It can help design more effective communication and engagement strategies with various stakeholder groups.

Table 2. Path Coefficients and Model Fit

Path Relationship	β Value	t-value	p-value	Effect Size (f^2)
Safety Enhancement → Community Support	0.678	15.234	<0.001	0.459
Traffic Congestion → Community Support	0.623	13.567	<0.001	0.388
Property Value → Community Support	0.589	12.345	<0.001	0.347
Business Effects → Community Support	0.612	13.892	<0.001	0.374
Community Support → Community Support	0.678	15.234	<0.001	0.459

Source: Research Data Analysis, 2024

The analysis shows a strong relationship between safety enhancement, traffic congestion reduction, property value improvement, and their influence on community support. With high β values (e.g., Safety Enhancement → Community Support: β = 0.678) and significant t-values (>13.5), the findings affirm that grade-separated crossings significantly improve public perception and community backing. The effect sizes (f^2) ranging from 0.347 to 0.459 demonstrate a moderate to high impact, emphasizing the structural importance of these variables in explaining community support.

Table 3. Measurement Model Validation

Construct	CR	AVE	R^2	√AVE
Safety Enhancement	0.87	0.68	0.712	0.824
Traffic Congestion	0.91	0.72	0.642	0.849
Property Value	0.84	0.65	0.584	0.806
Business Effects	0.88	0.69	0.622	0.831
Community Support	0.92	0.74	0.762	0.860

Source: Research Data Analysis, 2024

The measurement model is robust, with composite reliability (CR) values above 0.7 and AVE exceeding the 0.5 threshold. Constructs like Community Support (CR = 0.92, AVE = 0.74) indicate high reliability and validity. The R^2 value of 0.762 for community support shows that the exogenous variables account for 76.2% of its variance, highlighting the model's explanatory power. This suggests that infrastructure benefits like safety and congestion reduction significantly drive stakeholders' support.

Table 4. Discriminant Validity (Fornell-Larcker Criterion)

Construct	Safety Enhancement	Traffic Congestion	Property Value	Business Effects	Community Support
Safety Enhancement	0.824				
Traffic Congestion	0.612	0.849			
Property Value	0.584	0.543	0.806		
Business Effects	0.601	0.578	0.562	0.831	
Community Support	0.678	0.623	0.589	0.612	0.860

Source: Research Data Analysis, 2024

Notes : CR = Composite Reliability (threshold > 0.7), AVE = Average Variance Extracted (threshold > 0.5), R^2 = Coefficient of Determination, √AVE = Square root of AVE, Diagonal elements (bold) are √AVE, Off-diagonal elements are correlations.

The Fornell-Larcker criterion confirms discriminant validity, with diagonal elements (√AVE) surpassing inter-construct correlations. Safety Enhancement correlates most strongly with Community Support (r = 0.678), showing that safety improvements are pivotal in fostering community acceptance. The distinctiveness of the constructs supports the robustness of the SEM-PLS model.

The research findings demonstrate significant impacts of grade-separated rail infrastructure development in Indonesia, aligning with recent studies by Restuputri et al. (2022) that revealed increasing railway-related incidents. The SEM-PLS analysis shows strong relationships between safety enhancement and community support ($\beta = 0.678$, $p < 0.001$), validating De Gruyter & Currie (2016) findings on the effectiveness of grade-separated crossings in reducing accidents. The high composite reliability values (CR > 0.84) across constructs indicate robust relationships between infrastructure development and community outcomes.

Cost-benefit analysis methodologies, as highlighted by Deng (2013) and Banerjee et al. (2020), support our findings that infrastructure investments positively influence economic performance. The study's measurement model validation demonstrates strong construct reliability and validity (AVE > 0.65), confirming the multifaceted benefits of grade-separated crossings. Property value impacts show a significant correlation with community support ($\beta = 0.589$, $p < 0.001$), supporting Rezvani et al. (2015) research on the socioeconomic benefits of transportation infrastructure.

Stakeholder engagement emerges as crucial, with community support showing strong predictive power ($R^2 = 0.762$). This aligns with Monyane & Awuzie (2019) emphasis on stakeholder involvement in infrastructure projects. The demographic analysis reveals diverse representation, with private sector employees (36.7%) and entrepreneurs (24.9%) forming the majority, indicating broad community interest in infrastructure improvements. This supports Hussain et al. (2017) findings on the importance of community participation in project success.

Safety enhancement through grade-separated infrastructure significantly correlates with reduced accident rates, supporting Kallberg et al. (2002) and Keramati et al. (2020) research. Implementing comprehensive safety measures, including enhanced warning systems and driver education programs, aligns with MACIOSZEK et al. (2020) recommendations for accident prevention at railway crossings. The high correlation between safety enhancement and community support (r = 0.678) emphasizes the importance of safety considerations in project planning.

Implementation challenges in developing countries, as identified by Yanwen (2012) and Timilsina et al. (2021), are reflected in our findings. The study reveals that successful implementation requires careful consideration of local context and stakeholder needs, with 43.8% of respondents aged 31-45 years and 42% holding bachelor's degrees. This demographic insight supports Ngacho & Das (2014) emphasis on contextual factors in infrastructure project success.

The socioeconomic impacts extend beyond immediate safety benefits, as evidenced by significant relationships between infrastructure development and local business effects ($\beta = 0.612$, $p < 0.001$).

This supports Singh & Kathuria (2016) research on infrastructure's role in supporting economic growth in Southeast Asia. The study results indicate that grade-separated crossings can catalyse broader urban development, aligning with Fedorets et al. (2019) findings on infrastructure's impact on economic mobility.

The analysis reveals the importance of integrated approaches combining infrastructure development with enhanced safety measures and community engagement. This supports Larsson & Larsson (2020) research on sustainable project management and Gharehbaghi et al. (2019) findings on the complexity of transportation infrastructure projects. The high R^2 values across constructs indicate strong model fit and validate the theoretical framework connecting safety, economic benefits, and community support.

CONCLUSION

This research demonstrates the substantial positive impact of grade-separated rail infrastructure on safety enhancement and socioeconomic development in Indonesia. Through rigorous SEM-PLS analysis, the study establishes strong correlations between infrastructure improvements and multiple beneficial outcomes, including enhanced safety ($\beta = 0.678$), reduced congestion ($\beta = 0.623$), and increased property values ($\beta = 0.589$). These findings provide empirical support for continued investment in grade-separated crossings as a strategic approach to addressing transportation safety challenges while promoting economic development.

The research highlights the critical role of stakeholder engagement in infrastructure project success, with community support showing strong predictive power ($R^2 = 0.762$). The demographic analysis reveals broad stakeholder representation, suggesting successful implementation requires addressing diverse community needs and expectations. The validated measurement model, with high composite reliability values (CR > 0.84) and significant path coefficients, provides a robust framework for evaluating infrastructure project impacts and guiding future development decisions.

Several limitations and opportunities for future research emerge from this study. First, the cross-sectional nature of the data limits understanding of long-term impacts; longitudinal studies could better capture temporal changes in socioeconomic outcomes. Second, while the sample size was adequate (n=450), expanding geographic coverage could enhance generalizability. Future research should explore cultural factors in infrastructure acceptance, examine environmental impacts, and investigate interactions between different types of transportation infrastructure improvements. Additionally, studies could focus on cost-benefit analyses across various implementation contexts and explore innovative financing mechanisms for infrastructure development in developing economies.

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