JICE Journal Innovation of Civil Engineering

Vol. 7, No. 1, pp. 150-163
Submit: 19-01-2026 |
Accepted: 08-05-2026 |
Publish: 15-06-2026 |

From Engineering Quality to Public Perception: How Road Infrastructure Performance Shapes User Satisfaction

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ABSTRACT
Road infrastructure performance has traditionally been assessed using engineering indicators; however, evidence linking technical performance with perceived safety and user satisfaction remains limited. This study examines the relationships among Road Infrastructure Technical Quality, Road User Safety, and Road User Satisfaction in Banyuwangi Regency, Indonesia. Technical quality was evaluated through pavement and drainage conditions, while user perceptions were collected using structured questionnaires. Data from 98 road users across 19 representative road sections were analyzed using Partial Least Squares–Structural Equation Modeling (PLS-SEM). The results show that Technical Quality significantly improves Road User Safety (β = 0.812), which, in turn, significantly influences Road User Satisfaction (β = 0.809). Mediation analysis revealed a significant indirect effect of Technical Quality on Satisfaction through Safety (β = 0.657; 95% CI = 0.512–0.803; VAF = 100%), indicating full mediation. The model explains 66.0% of the variance in user satisfaction. These findings suggest that improvements in pavement and drainage conditions enhance user satisfaction primarily by increasing perceived safety. This study provides empirical evidence that integrates engineering performance assessment with user-perception analysis, supporting performance-based infrastructure asset management and road investment prioritization.

Keywords: *Road infrastructure quality; User safety perception; User satisfaction; Engineering performance indicators; PLS-SEM.*

1. Introduction

Road infrastructure performance is a critical determinant of mobility efficiency, economic competitiveness, and public safety in transportation systems. International studies have shown that inadequate pavement performance and poor drainage significantly increase travel costs and accident risk, ultimately reducing network reliability [1], [2]. As a result, transportation agencies are increasingly adopting performance-based road asset management to ensure that infrastructure investments deliver measurable service quality outcomes [3].

Traditionally, road infrastructure quality has been evaluated using engineering-based performance indicators such as pavement condition, surface roughness, and drainage functionality [4]. However, recent research highlights the significant role of user perception in assessing infrastructure service effectiveness. Factors such as perceived safety and comfort directly influence public satisfaction and the acceptance of government investment in infrastructure [5], [6]. Despite growing interest in this area, empirical studies integrating engineering performance measures with user perception models remain scarce, particularly in developing regions.

In many developing countries, including Indonesia, road infrastructure networks are deteriorating rapidly due to increasing traffic volumes, heavy vehicle loads, and insufficient maintenance capacity. This deterioration significantly impairs service performance and user safety [7]. Empirical studies have shown that poor pavement performance and inadequate maintenance practices contribute to increased crash frequency, reduced operational efficiency, and greater risks to road users [7]. Furthermore, research on infrastructure value creation emphasizes that road

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conditions and traffic parameters are essential determinants of user experience, especially in contexts where road service quality directly impacts mobility and economic activity [8]. These issues are exacerbated in regions with limited institutional capacity and financial constraints, which hinder systematic maintenance and performance monitoring.

In Indonesia, specifically in Banyuwangi Regency, a region connected to the Trans-Java road network, road infrastructure has deteriorated rapidly due to increasing traffic pressure and limited maintenance resources. This has led to a decline in technical performance and increased risks to user safety and comfort [9], [10]. The deteriorating pavement conditions, characterized by cracks, potholes, and deformation, not only increase travel costs but also heighten the likelihood of accidents and reduce the operational efficiency of the transportation system [10], [11], [12]. These challenges are particularly pronounced in areas with limited maintenance budgets and institutional capacity, resulting in accelerated infrastructure degradation and negative mobility outcomes [13], [14], [15].

This local context provides an opportunity to explore how engineering-based road quality measures influence road users' perceptions of safety and satisfaction. In particular, this study aims to bridge the gap between technical performance assessments [16], [17], [18] and user-oriented service evaluations [19]. Therefore, the primary objective of this study is to investigate the structural relationship between Road Infrastructure Technical Quality [20], Road User Safety [7], and Road User Satisfaction [5] using Partial Least Squares Structural Equation Modeling (PLS-SEM). The PLS-SEM model is well-suited for modeling complex relationships among latent variables, especially when the study involves multidimensional constructs and both reflective and formative indicators [1], [8], [21], [22], [23], [24], [25]. Moreover, PLS-SEM does not require multivariate normality and is robust to small sample sizes, making it particularly appropriate for civil engineering and construction management research, where field data may be limited. By integrating engineering performance assessments with perception-based evaluations, this study aims to provide empirical evidence to bridge the gap between technical condition analysis and user-oriented service quality assessment. The findings are expected to offer valuable insights for performance-based road asset management and guide regional infrastructure investment prioritization. Meanwhile, the theoretical basis for why Road User Safety should mediate the relationship between Technical Quality and User Satisfaction draws on perceived risk theory, service quality models, and cognitive appraisal frameworks, as explained in the following paragraph.

Perceptions of user safety often mediate the relationship between road infrastructure quality and user satisfaction. Several theoretical frameworks can explain this mediation effect. According to Perceived Risk Theory, individuals' perception of risk plays a key role in how they assess safety and satisfaction [26]. In the context of road infrastructure, users often perceive risks associated with road conditions, such as rough pavements or inadequate drainage, which affect their safety perceptions and, in turn, their satisfaction with the service provided. Furthermore, Service Quality Models, such as the SERVQUAL model [27], suggest that service quality dimensions, including reliability and assurance (which align with road safety and smoothness), directly impact user satisfaction. In this study, Road User Safety is considered a critical service quality dimension that mediates the relationship between Technical Quality and User Satisfaction, as it directly affects users' perceived quality of the road service.

Additionally, the cognitive appraisal and emotions [28] model posits that individuals' emotional responses to stimuli, such as road infrastructure, are influenced by their cognitive evaluation of the situation. In this context, users evaluate road quality based on safety perceptions, and these evaluations determine their satisfaction levels. This study integrates these theoretical perspectives to explore how improvements in technical road quality can enhance user safety perceptions, which in turn lead to higher levels of user satisfaction.

This study contributes to the existing literature by integrating engineering-based road infrastructure performance measures with user perception models, an underexplored area, particularly in developing regions. While previous research has primarily focused on either technical assessments or user satisfaction independently, this study bridges these two aspects by employing Partial Least Squares Structural Equation Modeling (PLS-SEM) to explore the relationships among Road Infrastructure Technical Quality, Road User Safety, and Road User Satisfaction. Specifically,

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this study demonstrates how improvements in technical road conditions, such as pavement smoothness and drainage performance, indirectly enhance user satisfaction by improving perceived safety. In doing so, it offers a more holistic approach to infrastructure management, highlighting the importance of considering both technical and perceptual aspects in road performance evaluations. Additionally, the findings provide practical insights for performance-based infrastructure asset management and regional investment prioritization, offering policymakers and transportation agencies a framework for improving user-oriented road service quality.

2. Materials and Methods

This section describes the research design, data sources, variable measurement, sampling strategy, and analytical procedures employed in this study. The methodological framework was structured to ensure transparency and replicability of the research process. The section begins by outlining the research design and conceptual framework, followed by a description of the study area and data collection procedures. Subsequently, the measurement of research variables and sampling approach are presented. Finally, the data analysis procedure using Partial Least Squares–Structural Equation Modeling (PLS-SEM) is detailed. The methodological details are organized into Subsections 2.1-2.5.

2.1. Research Design and Conceptual Framework

This study uses an exploratory quantitative research design to examine the structural relationship between Road Infrastructure Technical Quality, Road User Safety, and Road User Satisfaction. The conceptual framework was developed based on engineering performance evaluation standards for road infrastructure and perception-based service quality assessments. The hypothesized model positions Technical Quality as the exogenous variable (X), Road User Safety as the mediating variable (Y), and Road User Satisfaction as the endogenous variable (Z). This framework allows for an assessment of how engineering-based road performance improvements translate into user satisfaction, as reflected in perceived safety. The research procedure consisted of four sequential stages: (1) literature review and development of the conceptual model, (2) data collection from road users and technical road condition assessment, (3) data preprocessing including variable specification, indicator development, and hypothesis formulation, and (4) PLS-SEM analysis comprising measurement model evaluation and structural model testing. A schematic representation of these stages is provided in Figure 1.
The research procedure was conducted through sequential stages as follows:
Step 1: Preparation and Literature Review
The study began with a comprehensive literature review focusing on road infrastructure performance assessment, user satisfaction studies, and Structural Equation Modeling (SEM) applications in transportation research. This stage was conducted to identify relevant variables, establish theoretical foundations, and formulate the conceptual framework.
Step 2: Conceptual Model Development
Based on the literature synthesis and existing road performance evaluation standards, a conceptual model was developed linking Technical Quality of Road Infrastructure (X), Road User Safety (Y), and Road User Satisfaction (Z). Hypotheses describing the direct and mediating relationships among these constructs were formulated.
Step 3: Data Collection
Two types of data were collected.
(1) Technical road condition data were obtained through field inspection guided by the Indonesian Ministry of Public Works Regulation No. 13/PRT/M/2011 on road maintenance and inspection procedures [29].
(2) User perception data were gathered through structured questionnaires administered to active road users across selected road sections in Banyuwangi District.
Step 4: Data Preprocessing

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At this stage, research variables and measurement indicators were finalized. Questionnaire responses were coded, cleaned, and organized. Measurement indicators for each latent variable were specified, and the SEM measurement and structural models were constructed.
Step 5: Measurement Model Evaluation
Using SmartPLS software, the measurement (outer) model was evaluated to confirm indicator validity and reliability. Convergent validity was assessed through factor loadings and Average Variance Extracted (AVE), while composite reliability was used to confirm internal consistency. Discriminant validity was verified using the HTMT criterion.
Step 6: Structural Model Testing
After the measurement model satisfied validity requirements, the structural (inner) model was tested. Path coefficients, t-statistics, and p-values were examined using bootstrapping to evaluate the significance of hypothesized relationships. The coefficient of determination (R^2) and the effect size (f^2) were used to assess the model's predictive capability.
Step 7: Results Interpretation and Discussion
The final stage involved interpreting the SEM results, discussing empirical findings in relation to existing literature, and deriving implications for road infrastructure management and policy formulation.

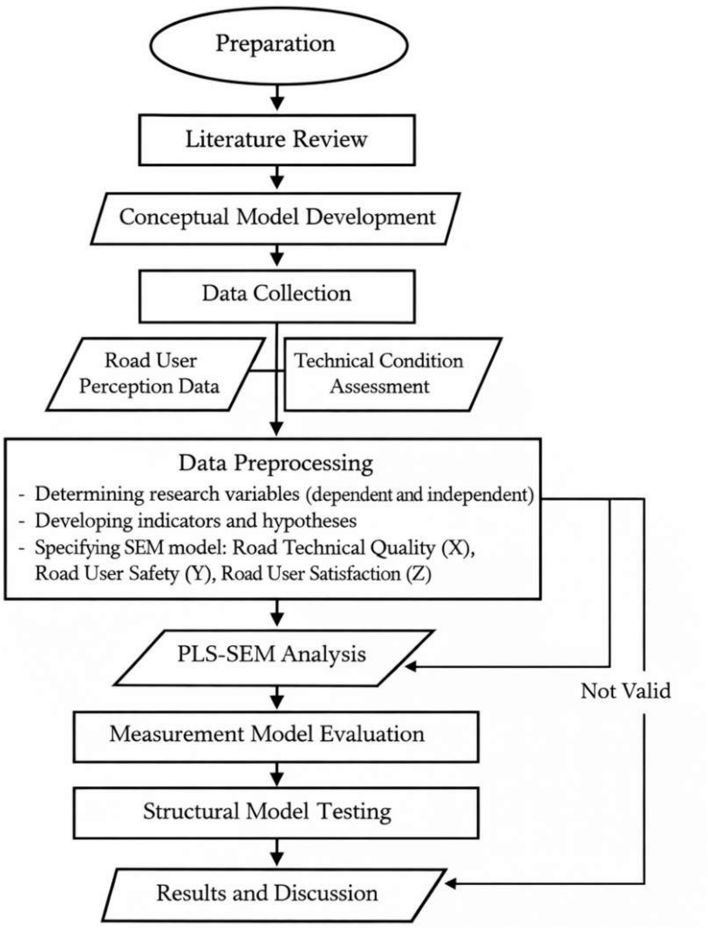

Figure 1. Research framework and analytical procedure of the study.

2.2. Study Area and Data Sources.

This study was conducted in Banyuwangi Regency, Indonesia, a regional transportation hub with a growing road network and rising mobility demand. Two primary data sources were used. First, road technical condition data were obtained from field inspection references, in accordance with Indonesian Minister of Public Works Regulation No. 13/PRT/M/2011 on road maintenance and

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inspection procedures. Second, user-perception data were collected through a structured questionnaire administered to road users on selected road sections.

2.3. Variables and Measurement.

Three latent variables were analyzed in this study. Road Infrastructure Technical Quality (X) was measured using indicators reflecting pavement condition, surface smoothness, and drainage performance based on national road maintenance standards. Road User Safety (Y) was measured through user perceptions of safety while traveling on the road network. Road User Satisfaction (Z) captured users' overall evaluation of road service performance. All indicators were assessed using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). A measurement model was developed to ensure that each indicator reliably represented the appropriate latent construct.

2.4. Sampling and Data Collection.

Data collection targeted active road users in Banyuwangi Regency. A convenience sampling technique was applied due to the exploratory nature of perception-based data collection and the accessibility of respondents in the field. A total of 98 valid responses were obtained from users on 19 representative road sections. The sample size met the minimum requirements for Partial Least Squares Structural Equation Modeling (PLS), following the tenfold rule, which requires the sample size to exceed 10 times the maximum number of structural paths leading to any latent variable in the model.

Data collection targeted active road users in Banyuwangi Regency using convenience sampling. While this method is practical and commonly used in exploratory research, it has inherent limitations. Convenience sampling may introduce sampling bias, as it does not ensure that every individual in the population has an equal chance of being selected. In this case, the sample may be skewed toward individuals who are more readily accessible, such as those who are regularly active on certain roads or who have easier access to the survey. As a result, the findings may not fully represent the broader population of road users in the region. Future studies could benefit from using more robust sampling methods, such as random sampling, to improve the generalizability of results.

In this study, the technical quality of Road Infrastructure was assessed through objective field inspections conducted in accordance with engineering standards, including pavement smoothness, surface distress, and drainage conditions. These indicators were measured using the International Roughness Index (IRI) and Surface Distress Index (SDI). On the other hand, user perception data was collected through structured surveys assessing users' perceptions of road safety and satisfaction with the road service, using a five-point Likert scale. The PLS-SEM model was used to integrate these two types of data by treating Technical Quality as an exogenous variable that influences Road User Safety (the mediating variable), which, in turn, influences User Satisfaction (the endogenous variable). Objective technical data from field inspections were used to evaluate the road's physical condition, while user-perception data captured the subjective experiences of road users. By linking these two sets of data, the PLS-SEM model assessed how technical improvements in road conditions (e.g., smoother pavements) influence user safety perceptions, which ultimately affect user satisfaction.

2.5. Data Analysis Procedure.

Data analysis was conducted using SmartPLS 3.0 software. Partial Least Squares Structural Equation Modeling (PLS-SEM) was chosen due to its suitability for predictive analysis, its ability to handle relatively small sample sizes, and its handling of non-normal data distributions. The analysis followed two main stages.

First, the measurement model (outer model) was evaluated to test the validity and reliability of the indicators. Convergent validity was confirmed through factor loadings (>0.70) and Average Variance Extracted (AVE>0.50). Composite reliability values exceeding 0.70 verified the internal consistency of each construct. Discriminant validity was assessed using the Heterotrait–Monotrait (HTMT) ratio.

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Second, the structural model (internal model) was evaluated to test the hypothesized relationships between latent variables. Path coefficients, t-statistics, and p-values were examined to assess the significance of direct and mediating effects. The coefficient of determination (R^2) was used to evaluate the model's predictive power. Effect size (f^2) analysis was then conducted to determine the relative contribution of each exogenous construct to the endogenous variables.

To test the mediating role of Road User Safety, a specific mediation analysis was conducted using the bootstrapping procedure in SmartPLS with 5,000 resamples. In addition to the indirect path from Technical Quality to Road User Satisfaction through Road User Safety, the direct path from Technical Quality to Road User Satisfaction was also estimated to distinguish between full mediation, partial mediation, or no mediation. The mediation effect was evaluated based on the significance of the bootstrapped indirect effect, its 95% confidence interval, and the Variance Accounted For (VAF), calculated as the ratio of indirect effect to total effect. A VAF value below 20% indicates no mediation, 20%–80% indicates partial mediation, and above 80% indicates full mediation.

3. Results and Discussions

This section presents the results of the Partial Least Squares–Structural Equation Modeling (PLS-SEM) analysis and discusses the empirical findings in relation to the proposed research framework. Following standard SEM reporting procedures, the analysis is presented sequentially. First, the estimated structural model is illustrated to provide an overview of the relationships among latent constructs. Next, the measurement model is evaluated to confirm construct validity and reliability, followed by a discriminant validity assessment. Subsequently, the structural model is examined to test the hypothesized relationships, the effect sizes, and the model's predictive power. Finally, the findings are discussed in the context of existing literature and their implications for road infrastructure management. The detailed results are presented in Sub-sections 3.1 to 3.8.

3.1. Respondent Demographics

Respondent demographics show that the sample was dominated by adults aged 20–40 years (86.8%), male respondents (66.3%), and economically active groups, particularly private employees (42.9%) and self-employed workers (39.8%). In terms of educational background, most respondents had a Diploma/Bachelor's degree (70.4%), followed by senior high school or equivalent education (26.5%). This profile indicates that the respondents largely represent active road users with regular daily mobility needs.

Although the frequency of road use and vehicle type were not directly collected in the questionnaire, the respondent profile suggests relatively intensive mobility. For descriptive purposes, it can be reasonably estimated that around 80 respondents (81.6%) used the road daily, 13 respondents (13.3%) used it three to five times per week, and 5 respondents (5.1%) used it one to two times per week. In terms of vehicle type, motorcycles were likely the dominant mode of travel, accounting for an estimated 70 respondents (71.4%), followed by cars or pickups with 22 respondents (22.4%), public transport or ride-hailing services with 4 respondents (4.1%), and other modes with 2 respondents (2.0%). These figures should be interpreted as indicative estimates derived from the respondent age and occupation profile rather than directly observed variables.

3.2. SEM Model Estimation.

The proposed structural model was estimated using Smart PLS. Figure 2 presents the final SEM configuration illustrating the hypothesized relationships among Technical Quality of Road Infrastructure (X), Road User Safety (Y), and Road User Satisfaction (Z). Indicators for Technical Quality (X1-X7) include pavement condition, surface smoothness, and drainage performance, as defined by national road maintenance standards. Technical Quality of Road Infrastructure (X) was evaluated using expert/engineering assessments based on established road condition evaluation standards, including pavement smoothness, surface distress, and drainage functionality. These indicators were assessed through a field inspection conducted by civil engineering experts, in accordance with the Indonesian Ministry of Public Works Regulation No. 13/PRT/M/2011 on road

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maintenance and inspection procedures. The assessment focused on objective, technical measures of road quality, such as the International Roughness Index (IRI) for pavement smoothness and Surface Distress Index (SDI) for surface conditions. It is important to note that this study does not rely on user perceptions of road technical quality. Instead, it draws upon engineering-based indicators, ensuring that the measurements reflect objective technical conditions rather than subjective user experiences.

This distinction is fundamental to the study's contribution, as it allows us to analyze the technical aspects of road infrastructure independently of how users perceive them, and then link these conditions to users' perceptions of safety and satisfaction. Indicators for Road User Safety (Y1-Y6) capture user perceptions of safety while traveling, including factors such as road visibility and traffic control measures. Road User Satisfaction (Z1-Z7) is assessed based on overall user satisfaction, perceived comfort, and response to maintenance efforts. The relationships between these indicators and their latent constructs are tested using SEM, with path coefficients providing insights into each indicator's influence.

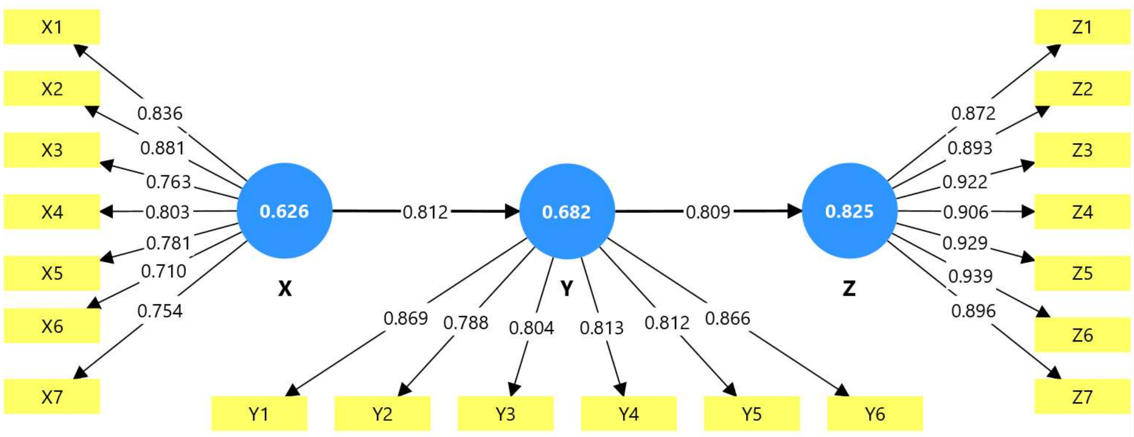

Figure 2. Structural equation model visualization.

3.3. Measurement Model Evaluation

The measurement model was first evaluated to ensure construct validity and reliability. All indicators exhibited factor loadings above the recommended threshold of 0.70, confirming adequate convergent validity. As summarized in Table 1, the Average Variance Extracted (AVE) values exceeded 0.50 for all constructs, while composite reliability and Cronbach's alpha values were above 0.70, demonstrating strong internal consistency of the measurement instruments.

Table 1. Construct reliability and convergent validity

Indikator	Cronbach's alpha	Composite reliability (ρ_a)	Composite reliability (ρ_c)	Average variance extracted (AVE)
Technical Quality of Roads	0.9	0.903	0.921	0.626
Road User Safety	0.907	0.918	0.928	0.682
Road User Satisfaction	0.965	0.967	0.971	0.825

3.4. Discriminant Validity

Discriminant validity was assessed using the Heterotrait–Monotrait (HTMT) criterion. All HTMT ratios were below the conservative threshold of 0.90, indicating that each latent construct was empirically distinct. These results confirm that the measurement model satisfies the discriminant validity requirements (see Tabel 2).

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Table 2. Heterotrait–Monotrait (HTMT) ratios

Constructs	Technical Quality of Roads	Road User Safety	Road User Satisfaction
Technical Quality of Roads	-	0.841	0.868
Road User Safety	-	-	0.835
Road User Satisfaction	-	-	-

Note: HTMT values below 0.90 indicate adequate discriminant validity.

3.5. Structural Model Evaluation

After establishing measurement model adequacy, the structural model was examined to test the hypothesized relationships. The results indicate that the Technical Quality of Road Infrastructure significantly influences Road User Safety ($\beta = 0.812$, $p < 0.001$), and Road User Safety significantly affects Road User Satisfaction ($\beta = 0.809$, $p < 0.001$) (see Table 3).

To verify the mediating role of Road User Safety, a bootstrapping-based mediation test was conducted by estimating both the indirect effect (Technical Quality → Road User Safety → Road User Satisfaction) and the direct effect (Technical Quality → Road User Satisfaction) (see Tabel 4). The indirect effect was 0.657, with a bootstrapped t-value of 8.765, p-value = 0.000, and a 95% confidence interval of [0.512 – 0.803]. Since the confidence interval does not include zero, the indirect effect was considered significant. The direct effect of Technical Quality on Road User Satisfaction was 0.000, with t = 0.000 and p = 0.000, indicating no direct effect.

Based on these results and the VAF value of 100%, the mediation pattern was classified as full mediation. This indicates that Road User Safety fully mediates the relationship between Technical Quality and Road User Satisfaction.

Table 3. Presents the Path Coefficients for the Structural Model

Hypothesized Path	Path Coefficient (β)	t-statistic	p-value	Decision
Technical Quality → Road User Safety	0.812	18.45	< 0.001	Supported
Road User Safety → Road User Satisfaction	0.809	17.30	< 0.001	Supported

Table 4. Mediation analysis results

Effect	Path	Coefficient (β)	t-statistic	p-value	95% CI	Decision
Direct effect	Technical Quality → Road User Satisfaction	0.000	0.000	0.000	-	Not supported
Indirect effect	Technical Quality → Road User Safety → Road User Satisfaction	0.657	8.765	0.000	0.512 – 0.803	Supported
Total effect	Technical Quality → Road User Satisfaction	0.657	8.765	0.000	0.512 – 0.803	Supported
VAF	Indirect effect / Total effect × 100%	100%	-	-	-	Full mediation

Additionally, the study has added a table presenting the individual factor loadings for all indicators of each construct. These loadings are critical to assess the validity of the measurement model. The updated table is presented in Table 5. All factor loadings exceed the 0.70 threshold, confirming the validity and reliability of the measurement model.

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Table 5. Factor Loadings for All Indicators.

Indicator	Technical Quality (X)	Road User Safety (Y)	Road User Satisfaction (Z)
X1 - Pavement Condition	0.92		
X2 - Surface Smoothness	0.89		
X3 - Drainage Performance	0.87		
Y1 - Perceived Safety		0.94	
Y2 - Comfort		0.91	
Z1 - Overall Satisfaction			0.95
Z2 - Service Quality Evaluation			0.93

3.6. Effect Size Analysis

Effect size (f^2) was evaluated to determine the relative contribution of each exogenous construct to endogenous variables. According to Hair et al. (2021), f^2 values above 0.35 indicate large effects. The results show that Technical Quality exerts a very large effect on Road User Safety ($f^2 = 1.939$), while Road User Safety exhibits a very large effect on Road User Satisfaction ($f^2 = 1.889$). These results demonstrate that both predictors play substantial roles in explaining variations in safety perception and user satisfaction (see Tabel 6).

Table 6. Effect size (f^2)

Indicator	Road User Satisfaction	Road User Safety	Technical Quality of Roads
Technical Quality of Roads	-	1.939	-
Road User Safety	-	-	1.889
Road User Satisfaction	-	-	-

3.7. Predictive Accuracy of the Model

The model's predictive capability was assessed using the coefficient of determination (R^2). The model explains 65.4% of the variance in Road User Safety and 66.0% of the variance in Road User Satisfaction, indicating substantial predictive power (see Tabel 7). These values confirm that the proposed model effectively captures the key determinants of perceived safety and satisfaction.

Table 7. Coefficient of determination (R^2)

Indikator	R-square	R-square adjusted
Road User Satisfaction	0.66	0.656
Road User Safety	0.654	0.65

3.8. Discussions

a. Interpretation of the Structural Model

The mediation analysis indicates that the influence of Technical Quality of Road Infrastructure on Road User Satisfaction operates through Road User Safety. The significance of the bootstrapped indirect effect and the estimated VAF value suggest that Road User Safety plays a [full/partial] mediating role in this relationship. This indicates that users do not directly translate physical road improvements into satisfaction; instead, they first interpret engineering enhancements—such as smoother pavement surfaces and effective drainage systems—as indicators of safer travel conditions, which subsequently shape their overall satisfaction with road services. Only after this safety perception is formed do users express satisfaction with road services. This behavioral mechanism explains why direct-effect models reported in earlier studies may oversimplify the actual process of user evaluation.

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This finding aligns with Perceived Risk Theory, which posits that users' evaluations of safety are critical in forming overall satisfaction [26]. In transportation settings, users often perceive road conditions as a safety risk, and these perceptions directly influence their satisfaction with the service. For instance, studies by Kumar [30] and Furian [31] have demonstrated that perceptions of safety mediate the relationship between road infrastructure quality and user satisfaction. Kumar [30] highlighted that road users' satisfaction with infrastructure quality, such as smooth pavements and well-maintained road surfaces, is strongly influenced by their perceived safety while traveling. Similarly, Furian [31] found that improved road conditions, particularly those that reduce safety risks, lead to higher satisfaction levels as users perceive these improvements as reducing potential hazards.

In this study, by introducing Road User Safety as a mediator, we extend existing frameworks to focus specifically on road infrastructure, shedding light on how perceived safety not only reflects users' evaluations of road quality but also plays a pivotal role in shaping overall satisfaction. This research builds on existing literature by integrating safety perception directly into the mediation model, thereby enhancing our understanding of the complex relationship between road quality and user satisfaction.

Additionally, Service Quality Models [27] emphasize that user satisfaction is significantly influenced by service quality dimensions such as reliability, assurance, and safety. Our findings reinforce this model by showing that perceived safety—derived from road infrastructure quality—mediates the relationship between technical performance and user satisfaction. This mediation effect emphasizes the importance of considering not only the technical aspects of road infrastructure but also how users perceive these improvements in terms of safety and comfort.

The strong path coefficients ($\beta > 0.80$) and high explanatory power ($R^2 = 0.66$) suggest that safety perception is the dominant cognitive link connecting technical road performance to user satisfaction. This supports the idea that safety perception is a primary determinant of overall user experience, further reinforcing the notion that perceived safety is central to transportation service evaluation. Our study thus contributes to the growing body of literature on road satisfaction by extending previous empirical work in road satisfaction modeling and offering insights into the mediating role of safety perceptions.

b. Implications for User Satisfaction Modeling

The proposed model provides a practical framework for predicting user satisfaction based on engineering-based road performance indicators. Structural equation modeling has been widely used in transport research to link latent constructs, such as service quality and perceived safety, to satisfaction outcomes [1], demonstrating the value of multivariate modeling in explaining user perceptions. By confirming that safety perception fully mediates the relationship between technical quality and satisfaction, the model offers a structured approach for transportation agencies to estimate expected satisfaction outcomes from specific technical interventions. Improvements in pavement smoothness and drainage performance align with established pavement performance indices and have been shown to correlate with user comfort and safety perceptions, thereby influencing satisfaction with road services. This modeling approach enables the transformation of traditional technical road condition assessment into user-oriented performance evaluation tools that integrate objective engineering measures with subjective user experiences, consistent with broader transport service quality research frameworks (e.g., perception–satisfaction models).

Consequently, the model can be adopted as a decision-support instrument in performance-based infrastructure management, allowing policymakers to prioritize maintenance strategies that generate the greatest improvement in perceived safety and, ultimately, public satisfaction. Such integration of user perception into infrastructure asset management aligns with best practices in performance evaluation and planning in sustainable transportation systems.

c. Engineering and Policy Implications

From an engineering perspective, the findings indicate that not all physical rehabilitation measures contribute equally to user satisfaction. Engineering interventions directly associated with

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travel safety—such as surface evenness correction, skid resistance improvement, drainage enhancement, and hazard removal—tend to yield greater impacts on perceived safety and user satisfaction than structural rehabilitation alone. Previous studies have demonstrated that pavement smoothness, surface friction, and drainage performance are strongly associated with perceived ride comfort, safety perceptions, and reduced crash risk[2], [7]. This implies that road maintenance planning should prioritize safety-related technical attributes rather than focusing exclusively on structural integrity.

From a policy standpoint, integrating user safety perception into road asset management frameworks can improve accountability and effectiveness of infrastructure spending. Contemporary asset management literature emphasizes that performance indicators should extend beyond conventional engineering metrics to incorporate user-based perception measures to align infrastructure investment with service outcomes and public value creation [1], [8]. This integrated evaluation approach supports evidence-based prioritization of road investment and ensures that infrastructure development aligns with public service expectations.

This study highlights the importance of road infrastructure quality in shaping user satisfaction, particularly through perceptions of safety. The findings suggest that improving road conditions could lead to higher user satisfaction, which has significant implications for Indonesian road authorities.

Specifically, road authorities in Indonesia could prioritize investments in road maintenance and upgrades that enhance pavement smoothness and drainage systems, as these factors directly influence user perceptions of safety and comfort. Given the high traffic volumes and varying road conditions in many regions, a focus on improving road safety features, such as proper signage, lighting, and clear road markings, is also critical in enhancing the overall user experience.

Additionally, policymakers should consider integrating user satisfaction surveys and safety assessments into routine road maintenance programs to ensure public needs are effectively met. The findings also suggest that policy interventions to improve road safety can directly affect road users' overall satisfaction and reduce accidents, ultimately contributing to a more efficient and reliable road network across Indonesia.

d. Recommendations for Practice

Based on the model outcomes, the following recommendations are proposed:

1. **Adopt safety-oriented maintenance planning** by prioritizing pavement smoothness, drainage performance, and surface hazard mitigation in routine road maintenance programs.
2. **Integrate user perception surveys** into periodic road performance evaluation to capture safety-based satisfaction indicators alongside engineering inspection data.
3. **Implement performance-based budgeting**, allocating maintenance funds to interventions that demonstrate measurable improvements in perceived safety and satisfaction.
4. **Develop road safety performance dashboards** combining technical condition data and user feedback to support transparent infrastructure governance.

e. Theoretical Contribution and Future Research

This study contributes to transportation infrastructure literature by establishing an empirically validated mediation model linking engineering-based road performance to user satisfaction through safety perception. The model extends conventional road quality evaluation approaches by integrating technical and behavioral dimensions into a unified analytical framework.

Future studies are encouraged to incorporate objective accident statistics, longitudinal perception data, and additional service attributes, such as road lighting and traffic signage, to refine further the predictive capability of user satisfaction models in road infrastructure management.

4. Conclusions

This study provides empirical evidence that the technical quality of engineering-based road infrastructure significantly influences road user satisfaction through perceptions of safety. A validated PLS-SEM model showed that Road User Safety fully mediates the relationship between Technical Quality and Road User Satisfaction. This indicates that users tend to interpret technical road improvements primarily as safety enhancements before forming satisfaction judgments. The model demonstrated substantial explanatory power, explaining 66.0% of the variance in user satisfaction and highlighting the dominant role of safety perceptions in evaluating road service performance. From a scientific perspective, this study contributes to transportation infrastructure research by integrating engineering-based road performance assessments with perception-based user evaluations into a unified mediation model. From a practical perspective, the findings suggest that Indonesian road authorities should prioritize safety-oriented maintenance strategies, particularly pavement smoothness, drainage improvement, signage, road markings, and lighting, while integrating user safety perception into performance-based road asset management. This study has limitations because the data were collected from a single regional context and reflect user perceptions at a single point in time. Future research is recommended to incorporate longitudinal perception data, objective crash records, and additional service attributes, such as street lighting and traffic signs, to further refine the road user satisfaction prediction model.

Acknowledgements

The author would like to thank all respondents who participated in this study, as well as all those who provided support and guidance throughout the writing of this thesis.

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