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UPDATING THE TOLL ROAD SERVICE QUALITY (TRSQ) MODEL THROUGH THE INTEGRATION OF AI-BASED TECHNOLOGICAL INNOVATIONS

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ARTICLEINFORMATION

Keywords:

artificial intelligence, smartpls, technological innovation, toll road service, TRSQ model, user satisfaction

ABSTRACT

Toll roads can play a vital role in supporting mobility, logistics, and regional economic growth. However, issues such as congestion, declining road quality, and limited real-time information systems often hinder service performance. This study aims to update the Toll Road Service Quality (TRSQ) model by integrating artificial intelligence (AI)-based technological innovations as a mediating variable to enhance excellent toll road services. Using a quantitative explanatory approach, data were collected from 480 users of the Pemalang–Batang Toll Road via a questionnaire survey. Data analysis employed SmartPLS to test causal relationships among TRSQ variables, which include information, accessibility, reliability, mobility, safety and security, rest areas, and responsiveness. Results show that all TRSQ variables significantly influence service excellence, both directly and through technology as a mediator. Priority indicators identified include toll gate queue length, availability of road markings and information boards, traffic flow, real-time traffic updates, and service comfort. The study highlights the urgency of applying AI-based intelligent transportation systems—such as innovative CCTV, remote sensors, and automated information management—to optimise toll road performance, improve user satisfaction, and strengthen sustainable transport services.

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INTRODUCTION

Toll roads serve as strategic transport infrastructure that supports mobility and accelerates economic growth. Despite their critical role, Indonesian toll roads continue to face several challenges, including long queues at toll gates, substandard road maintenance, incomplete safety equipment, poor lighting, and limited access to real-time traffic information. These issues reduce service efficiency, comfort, and user satisfaction (Hendarto et al. 2021). The need for service modernisation is therefore urgent, primarily through the application of advanced digital technology (Rangkuty and Tarigan 2022).

The Toll Road Service Quality (TRSQ) model, developed by Zuna, Hadiwardoyo, and Rahadian (2016), has been widely used to evaluate toll road services based on seven variables: information, accessibility, reliability, mobility, safety and security, rest areas, and responsiveness. However, this model does not yet account for the rapidly evolving technological dimension in the era of intelligent transportation systems (Santosa et al. 2023). The increasing adoption of AI-based technologies—such as automated traffic management, real-time monitoring, and predictive maintenance—has changed how toll roads operate and serve users (BPJT 2021).

Accordingly, this study aims to update the TRSQ model by incorporating technology as a mediating variable that links service attributes to user perceptions of excellent service. This innovation not only enhances the theoretical robustness of the TRSQ framework but also provides practical guidance for toll road operators, such as Jasa Marga and BPJT, in implementing AI-driven service management. The research also emphasises that the updated model can be replicated across other toll roads in Indonesia and, potentially, adopted internationally to support global sustainable transport initiatives.

HYPOTHESIS

The hypotheses that have been formulated are provisional answers or assumptions established in this study as follows:

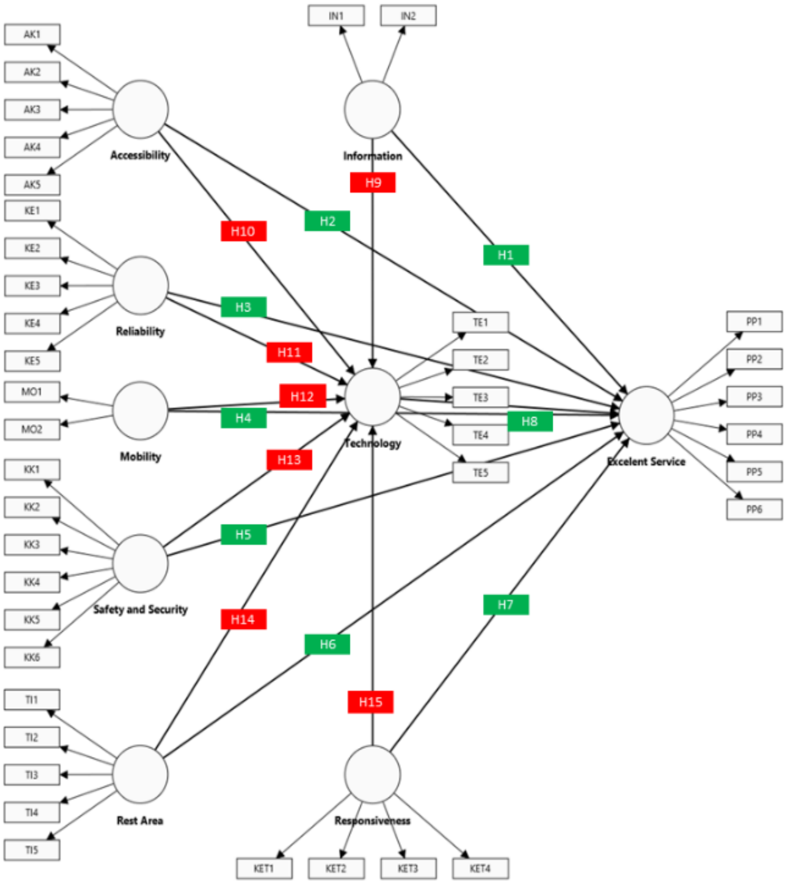

Figure 1. Conceptual Framework

Based on the conceptual framework illustrated in Figure 1, this study proposes a set of hypotheses to examine both the direct and mediated effects of key service quality dimensions and technological innovation on toll road service excellence. The direct effect hypotheses posit that H1 information has a significant effect on toll road service excellence, H2 accessibility significantly affects the quality of toll road service, H3 reliability has a significant effect on toll road service excellence, H4 mobility has a significant effect on the quality of toll road service, H5 safety and security have a significant effect on toll road service excellence, H6 rest area has a significant effect on toll road service excellence, H7 responsiveness has a significant effect on toll road service excellence, and H8 technology has a significant effect on the excellence of toll road service. Furthermore, the mediating effect hypotheses state that H9 technology mediates the effect of information on toll road service excellence, H10 technology mediates the effect of accessibility on toll road service excellence, H11 technology mediates the effect of reliability on toll road service excellence, H12 technology mediates the effect of mobility on toll road service excellence, H13 technology mediates the effect of safety and security on toll road service excellence, H14 technology mediates the effect of rest area on toll road service excellence, and H15 technology mediates the effect of responsiveness on toll road service excellence.

METHODOLOGY

The research location is on the Pemalang-Batang toll road section, which is part of the Trans Java toll road located in Central Java.

Source: PT. PBTR (2023)

Figure 2. Map of Pemalang Batang Toll Road

This study employs an explanatory research approach to examine the causal relationships among research variables through hypothesis testing (Mahbara 2024). Data collection techniques include distributing questionnaires related to users' perceptions of toll road services. The questionnaire uses a Likert scale, a psychometric scale commonly used in questionnaires and frequently employed in survey-based research (Tahrir et al. 2023). Before the questionnaire is widely distributed, the instrument is calibrated. Once declared valid and reliable, the questionnaire is distributed offline by approaching toll road users at rest areas and online via social media platforms such as WhatsApp and Instagram.

The sampling technique used is purposive sampling, which selects samples based on specific criteria (Putra, Wicaksono, and Prayitno 2022). Only users who have used the toll road within the last year will be considered as research data. Respondents who do not meet the criteria will be dropped via judgment sampling. The sample size follows the approach of Hair et al. (2017), with a minimum sample size of 10 times the total number of indicators (Ngantung 2021). This study has 40 indicators, so the minimum required sample size is 40 × 10 = 400.

The data analysis technique used in this study is quantitative. The data collected from the research objects are numerical and will be analysed using statistical calculations. The results of this statistical analysis will describe the research object, often presented in tables or graphs (Sutisna 2020). The method used for data analysis involves the assistance of SPSS (Statistical Product and Service Solutions) software to test the questionnaire and analyse the respondent distribution, as well as SmartPLS (Partial Least Squares) software to test the relationships between research variables.

Variables

In this study, there are three main types of variables. The exogenous variables are represented by the Toll Road Service Quality (TRSQ) model, which consists of seven key dimensions: information, accessibility, reliability, mobility, safety and security, rest areas, and responsiveness. These components were adopted from the TRSQ framework as they comprehensively represent the service attributes that influence users' perceptions of toll road performance and satisfaction.

The endogenous variable is service excellence, which reflects the overall performance and quality outcomes of toll road operations as perceived by users. The technology variable serves as a mediating variable, linking the effects of TRSQ dimensions to service excellence. Specifically, it is hypothesised that technology, particularly AI-based innovations, enhances the influence of service quality dimensions on service excellence by improving operational efficiency, user experience, and safety performance.

The following diagram presents the research design illustrating the relationships among these variables.

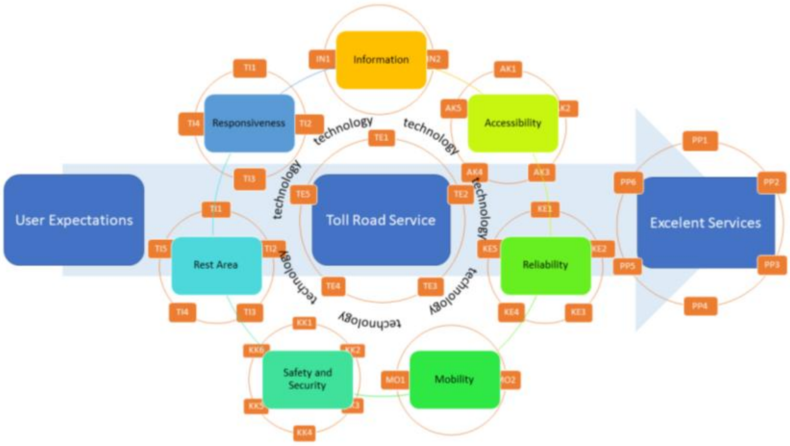

Figure 3. Research Variables

TRSQ Model

The TRSQ model is a toll-road service quality development model developed by Dr Herry Trisaputra Zuna (Humas FT UI 2016). The TRSQ model is an adaptation of the SERVQUAL (Service Quality) model, which consists of five service dimensions. This SERVQUAL model was then developed using the toll road SPM (Minimum Service Standards) indicators as measurement dimensions. This model, the modified SERVQUAL, can be used to assess toll road service quality. The model not only considers the physical aspects found in the SPM but also incorporates indicators sourced from the user's perspective (Hendarto et al. 2021). Research on the development of the TRSQ model shows that it has the highest accuracy among the three models (SERVQUAL and SPM). Therefore, the TRSQ model was chosen to measure toll road service levels (Zuna, Hadiwardoyo, and Rahadian 2016).

Technology

The technology variable is derived from identification through bibliometric mapping using VOSviewer.

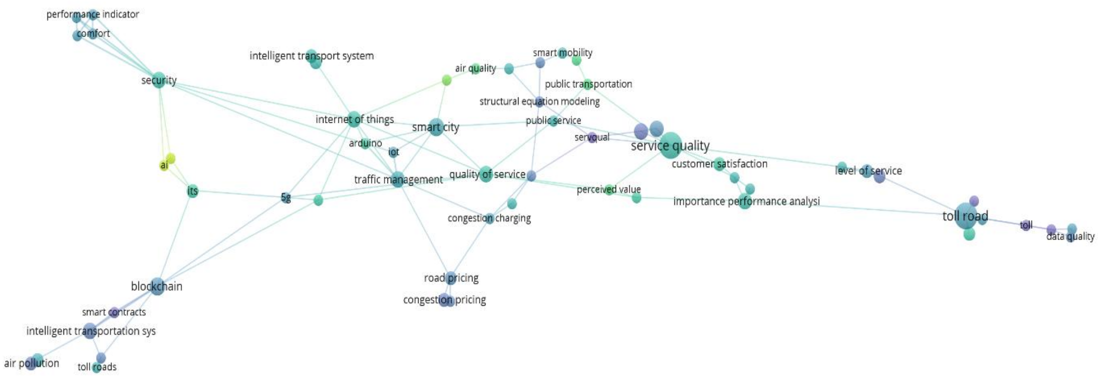

Figure 4. Bibliometric Identification

The technology variable is derived from identification through bibliometric mapping using VOSviewer, as shown in Figure 4. The bibliometric mapping was conducted to explore emerging research trends related to technological innovation in toll road and transportation service studies.

As shown in the figure above, overlay visualisation is used to map toll road service research trends based on historical traces or publication years. Information obtained from the overlay visualisation can serve as a reference for identifying and assessing the state of the art of research conducted between 2020 and 2024. In this visualisation, the nodes' colours indicate the publication year. The brighter the colour (yellow), the more recent or current the research topic is.

The results of the bibliometric mapping revealed that "Artificial Intelligence (AI)" is among the most frequent and strongly connected keywords within the cluster of recent studies, as indicated by the red arrow in Figure 4. This finding shows that AI represents a current and emerging trend in toll road and transportation research. Therefore, AI was adopted as the core element of the technology variable in this study. This adoption reflects the growing role of AI-based innovations, such as intelligent transportation systems (ITS), automated traffic monitoring, predictive maintenance, and data-driven decision support, in enhancing the efficiency, comfort, and safety of toll road operations.

Instrument Calibration

In this study, validity and reliability tests were conducted through a pilot test involving 36 respondents. Referring to a significance level of 5% (r table = 0.329; n = 36), the validity test results of the questionnaire are shown in the table below.

Table 1. Validity Test

Variable	Code	r Stat	Result
Information	IN1	0,577	Valid
	IN2	0,557	Valid
Accessibility	AK1	0,364	Valid
	AK2	0,617	Valid
	AK3	0,400	Valid
	AK4	0,557	Valid
	AK5	0,686	Valid
Reliability	KE1	0,630	Valid
	KE2	0,477	Valid
	KE3	0,697	Valid
	KE4	0,545	Valid
	KE5	0,668	Valid
Mobility	MO1	0,470	Valid
	MO2	0,628	Valid
Safety and Security	KK1	0,673	Valid
	KK2	0,587	Valid
	KK3	0,676	Valid
	KK4	0,710	Valid
	KK5	0,670	Valid
	KK6	0,702	Valid
Rest Area	TI1	0,608	Valid
	TI2	0,740	Valid
	TI3	0,617	Valid
	TI4	0,789	Valid
	TI5	0,726	Valid
Responsiveness	KET1	0,755	Valid
	KET2	0,817	Valid
	KET3	0,775	Valid
	KET4	0,766	Valid
Excellent Service	PP1	0,808	Valid
	PP2	0,837	Valid
	PP3	0,756	Valid
	PP4	0,763	Valid
	PP5	0,773	Valid
	PP6	0,765	Valid
Technology	TE1	0,409	Valid
	TE2	0,434	Valid
	TE3	0,486	Valid
	TE4	0,449	Valid
	TE5	0,509	Valid

Note: If r-statistic > r-table, it is considered valid.

Based on the table above, each indicator's value exceeds the calculated R value, indicating it is valid.

A research instrument is considered reliable if Cronbach's Alpha is greater than 0.60 (Ghozali, 2016), as cited in Slamet and Wahyuningsih (2022). The test results show that Cronbach's Alpha is 0.96, exceeding the 0.60 threshold, indicating reliability.

Respondent Characteristic

The respondents in this study are users of the Pemalang-Batang toll road, totalling 480 people. Respondents are grouped by gender, age, occupation, education, frequency of toll road use, type of vehicle used, and purpose of toll road use as specified in the distributed questionnaire. The overall depiction, according to the most dominant proportion of each category, is as follows:

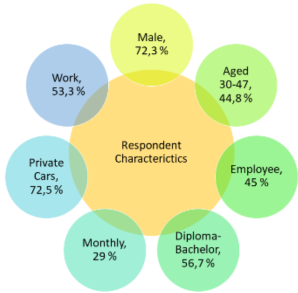

Figure 5. Respondent Characteristic

The figure above shows that the most dominant characteristics of respondents participating in this study are male (72.3%), aged 30-47 years (44.8%), employed (45%), and with an education level of Diploma-Bachelor/DI-IV/S1 (56.7%). The frequency of using the Pemalang-Batang toll road is monthly (29%), using private cars (72.5%), and for work purposes (53.3%).

Structural Equation Modelling (SEM) Test

In testing the relationship between toll road service variables, the SEMPLS method is used. At this stage, several assessments are conducted as prerequisites to proceed to the next testing stage. The first test is the measurement model/outer model, which has several criteria, including convergent validity, discriminant validity, and reliability. Once this test meets the requirements, the structural model/inner model is tested, which also has several criteria, such as collinearity, coefficient of determination, model predictive relevance, and hypothesis testing.

RESULTS AND ANALYSIS

Below are the general test results using SEMPLS:

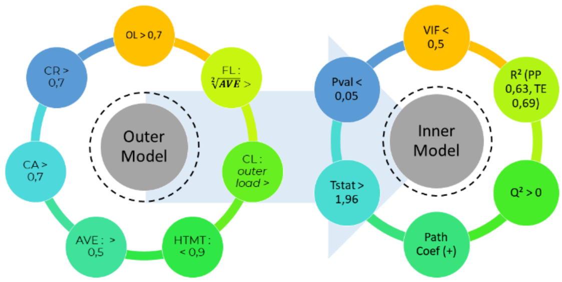

Figure 6. SEMPLS Results

For further clarity, the details of each criterion in the SEMPLS test are explained below.

Outer Model

The outer model image in SmartPLS is as follows:

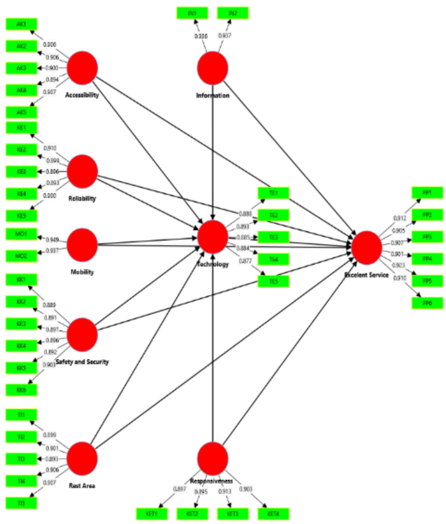

Figure 7. Outer Model

The measurement model represents the relationships between constructs and their indicator variables, commonly referred to as the outer model in SEMPLS. The measurement model explains how constructs are measured and assesses their reliability and validity by examining convergent validity, discriminant validity, and construct reliability.

Table 2. Outer Loading (OL)

	Accessibility	**Iformation**	**Reliability**	**Safety and Security**	**Responsiveness**	**Mobility**	**Excellen Service**	**Technology**	**Rest Area**
AK1	0.9								
AK2	0.9								
AK3	0.9								
AK4	0.8								
AK5	0.9								
IN1		0.9							
IN2		0.9							
KE1			0.9						
KE2			0.8						
KE3			0.8						
KE4			0.8						
KE5			0.9						
KET1					0.8				
KET2					0.8				
KET3					0.9				
KET4					0.9				
KK1				0.8					
KK2				0.8					
KK3				0.8					
KK4				0.8					
KK5				0.8					
KK6				0.9					
MO1						0.9			
MO2						0.9			
PP1							0.9		
PP2							0.9		
PP3							0.9		
PP4							0.9		
PP5							0.9		
PP6							0.9		
TE1								0.8	
TE2								0.8	
TE3								0.8	
TE4								0.8	
TE5								0.8	
TI3									0.8
TI1									0.8
TI2									0.9
TI4									0.9
TI5									0.9

Based on the convergent validity test results, all indicators have an outer loading value ≥ 0.7 (Hair et al., 2022). Therefore, all indicators in this study meet the criteria.

Table 2. Fornell-Larcker Criterion (FL)

	Accessibility	Information	Reliability	Safety and Security	Responsiveness	Mobility	Excellent Service	Technology	Rest Area
Accessi bility	**0.9**								
Infor mation	0.6	**0.9**							
Relia bility	0.6	0.6	**0.9**						
Safety and Security	0.6	0.6	0.6	**0.8**					
Respon siveness	0.3	0.3	0.3	0.3	**0.9**				
Mobility	0.6	0.6	0.6	0.6	0.3	**0.9**			
Excellent Service	0.5	0.5	0.5	0.5	0.5	0.5	**0.9**		
Techno logy	0.6	0.6	0.6	0.6	0.6	0.6	0.7	**0.8**	
Rest Area	0.3	0.3	0.3	0.3	0.6	0.3	0.5	0.6	**0.9**

The square root value of the AVE for each construct is greater than the correlation with other constructs, meaning it meets the Fornell-Larcker criterion.

Table 4. Cross Loading (CL)

	Accessibility	Information	Reliability	Safety and Security	Responsiveness	Mobility	Excellent Service	Technology	Rest Area
AK1	**0.9**	0.5	0.5	0.5	0.3	0.5	0.5	0.5	0.3
AK2	**0.9**	0.6	0.5	0.5	0.3	0.5	0.5	0.5	0.3
AK3	**0.9**	0.6	0.6	0.5	0.3	0.5	0.5	0.5	0.3
AK4	**0.8**	0.5	0.6	0.6	0.3	0.5	0.5	0.5	0.3
AK5	**0.9**	0.5	0.6	0.6	0.3	0.5	0.5	0.5	0.3
IN1	0.6	**0.9**	0.6	0.6	0.3	0.5	0.5	**0.5**	0.3
IN2	0.6	**0.9**	0.5	0.5	0.3	0.5	0.5	0.5	0.3
KE1	0.6	0.5	**0.9**	0.6	0.3	0.5	0.5	0.5	0.3
KE2	0.6	0.5	**0.8**	0.6	0.3	0.5	0.5	0.5	0.3
KE3	0.6	0.6	**0.8**	0.5	0.3	0.5	0.5	0.5	0.3
KE4	0.5	0.5	**0.8**	0.5	0.3	0.5	0.5	0.5	0.3
KE5	0.6	0.5	**0.9**	0.6	0.3	0.6	0.5	0.5	0.3
KET1	0.3	0.3	0.3	0.3	**0.8**	0.3	0.5	0.5	0.5
KET2	0.3	0.3	0.3	0.3	**0.8**	0.3	0.5	0.5	0.5
KET3	0.3	0.3	0.3	0.3	**0.9**	0.3	0.5	0.6	0.5
KET4	0.3	0.3	0.3	0.3	**0.9**	0.3	0.5	0.5	0.5
KK1	0.5	0.5	0.5	**0.8**	0.3	0.5	0.5	0.5	0.3
KK2	0.5	0.5	0.5	**0.8**	0.3	0.5	0.5	0.5	0.3
KK3	0.6	0.5	0.6	**0.8**	0.3	0.5	0.5	0.5	0.3
KK4	0.6	0.5	0.5	**0.8**	0.3	0.5	0.5	0.5	0.3
KK5	0.5	0.5	0.6	**0.8**	0.3	0.5	0.5	0.5	0.3
KK6	0.5	0.5	0.6	**0.9**	0.3	0.5	0.5	0.5	0.3
MO1	0.6	0.5	0.6	0.6	0.3	**0.9**	0.5	0.5	0.3
MO2	0.5	0.5	0.6	0.5	0.3	**0.9**	0.5	0.5	0.3
PP1	0.5	0.5	0.5	0.5	0.5	0.5	**0.9**	0.6	0.5
PP2	0.5	0.5	0.5	0.5	0.5	0.5	**0.9**	0.6	0.5
PP3	0.5	0.5	0.5	0.5	0.5	0.5	**0.9**	0.6	0.4
PP4	0.5	0.4	0.5	0.5	0.5	0.5	**0.9**	0.6	0.5
PP5	0.5	0.5	0.5	0.5	0.5	0.5	**0.9**	0.6	0.5
PP6	0.5	0.5	0.5	0.5	0.5	0.5	**0.9**	0.6	0.5
TE1	0.5	0.5	0.5	0.5	0.5	0.5	0.6	**0.8**	0.5
TE2	0.5	0.5	0.5	0.5	0.5	0.5	0.6	**0.8**	0.5
TE3	0.5	0.5	0.5	0.5	0.5	0.5	0.6	**0.8**	0.5
TE4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	**0.8**	0.5
TE5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	**0.8**	0.5
TI1	0.3	0.3	0.3	0.3	0.5	0.3	0.5	0.5	**0.8**
TI2	0.3	0.3	0.3	0.3	0.5	0.3	0.5	0.5	**0.9**
TI3	0.3	0.3	0.3	0.3	0.5	0.3	0.4	0.5	**0.8**
TI4	0.3	0.3	0.3	0.3	0.6	0.3	0.5	0.5	**0.9**
TI5	0.3	0.3	0.3	0.3	0.5	0.3	0.5	0.5	**0.9**

Based on the table, the cross-loadings of each indicator for each variable are higher (i.e., greater) than those for other variables. This result shows that these indicators have met the criteria for discriminant validity.

Table 5. Heterotrait Monotrait Rasio (HTMT)

	Accessibility	**Information**	**Reliability**	**Safety and Security**	**Responsiveness**	**Mobility**	**Excellent Service**	**Technology**	**Rest Area**
Accessi bility									
Infor mation	0.7								
Relia bility	0.7	0.7							
Safety and Security	0.6	0.7	0.7						
Respon siveness	0.4	0.4	0.3	0.4					
Mobility	0.7	0.7	0.7	0.6	0.4				
Excellent Service	0.6	0.6	0.6	0.6	0.6	0.6			
Techno logy	0.6	0.6	0.6	0.6	0.6	0.6	0.7		
Rest Area	0.4	0.4	0.3	0.3	0.7	0.4	0.6	0.6	

Based on the table above, there is no HTMT correlation value greater than 0.9 (Hair et al. 2022). This value meets the HTMT criteria and has passed the discriminant validity test, indicating it is well-discriminated in measuring its variable.

Table 6. Average Variance Extracted (AVE)

	AVE
Accessibility	0.814
Information	0.878
Reliability	0.810
Safety and Security	0.800
Responsiveness	0.814
Mobility	0.889
Excellent Service	0.828
Technology	0.784
Rest Area	0.812

The table above shows that the AVEs for all constructs exceed 0.5 (Hair et al., 2022). Therefore, there is no issue with discriminant validity in the tested model.

Table 7. Cronbach Alpha (CA) and Composite Reliability (CR)

	CA	CR (rho_a)	CR (rho_c)
Accessibility	0.943	0.944	0.956
Information	0.861	0.861	0.935
Reliability	0.941	0.942	0.955
Safety and Security	0.950	0.950	0.960
Responsiveness	0.924	0.924	0.946
Mobility	0.876	0.881	0.941
Excellent Service	0.958	0.959	0.967
Technology	0.931	0.932	0.948
Rest Area	0.942	0.942	0.956

The test results in the table indicate that all latent variables meet the reliability criteria, as their Cronbach's alphas and composite reliabilities exceed 0.7 (Hair et al. 2022).

Inner Model

Below is the inner model image in SmartPLS based on the test results:

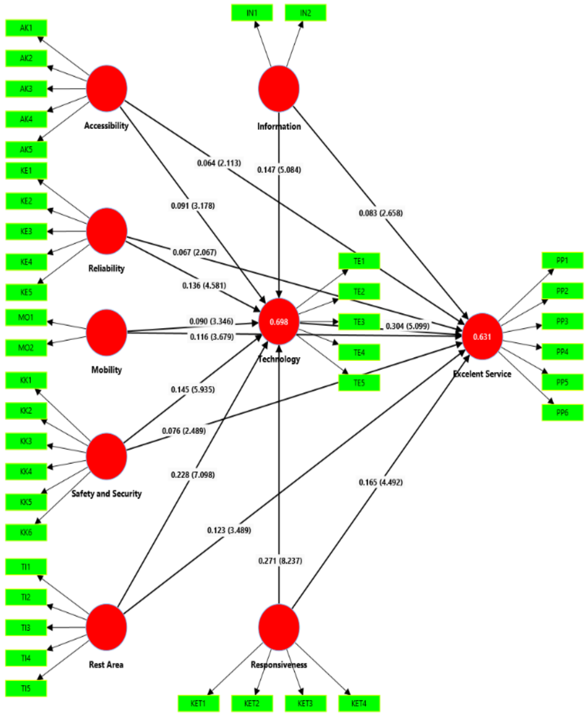

Figure 8. Inner Model

When the measurement model (outer model) shows good results, the next step in evaluating the SEMPLS results is to assess the structural model (inner model). The structural model is analysed to find evidence supporting the theoretical model (the theoretical relationship between exogenous and endogenous constructs). The inner model evaluation is conducted through several tests, including collinearity, explanatory power, predictive power, and the significance of model relationships, which are discussed below.

Collinearity

Table 8. Variance Inflation Factor (VIF)

	VIF		VIF
AK1	3.598	KK5	3.482
AK2	3.561	KK6	3.753
AK3	3.446	MO1	2.543
AK4	3.334	MO2	2.543
AK5	3.667	PP1	4.159
IN1	2.329	PP2	3.941
IN2	2.329	PP3	3.970
KE1	3.742	PP4	3.880
KE2	3.405	PP5	4.716
KE3	3.335	PP6	4.087
KE4	3.298	TE1	3.079
KE5	3.451	TE2	3.207
KET1	3.003	TE3	3.013
KET2	3.000	TE4	3.008
KET3	3.395	TE5	2.928
KET4	3.147	TI1	3.336
KK1	3.358	TI2	3.472
KK2	3.457	TI3	3.264
KK3	3.645	TI4	3.619
KK4	3.531	TI5	3.644

The table above shows that the VIF values for the research variables meet the threshold of < 5 (Hair et al., 2022). From the inner model testing, the model is generally considered adequate.

Table 9. Coefficient of Determination (R2)

	R-square	R-square adjusted
Excellent Service (PP)	0.631	0.624
Technology (TE)	0.698	0.694

The table above shows that the R-Square value for excellent service is 0.631. This value indicates that the independent variables account for 63.1% of the variance in excellent service, with the remaining 36.9% accounted for by other variables outside the model. Furthermore, the R-Square value for technology is 0.698, indicating that the independent variables explain 69.8% of the variation in technology, with the remaining 30.2% explained by other variables outside the model.

Table 10. Predictive Relavance (Q2)

	Q-Square
Excellent Service	0.518
Technologys	0,543

Based on the Q-Square results, the Q-Square values for excellent service and technology are >0, indicating that the model is predictive and quite good.

Significance

An original sample value between -1 and +1 indicates a negative-to-positive relationship. The t-statistic value must be above 1.96 or the p-value below 0.05 to be considered significant (Hair et al. 2022). Hypothesis testing aims to determine whether a significant relationship exists between the variables under study. Statistical analysis of these test results will indicate whether the hypothesis can be accepted or rejected. The following are the details of the hypotheses for both direct and mediated effects.

Table 11. Direct Effects

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Accessibility → Excellent Service	0.064	0.063	0.030	2.113	0.035
Information → Excellent Service	0.083	0.082	0.031	2.658	0.008
Reliability → Excellent Service	0.067	0.066	0.032	2.067	0.039
Safety and Security → Excellent Service	0.076	0.076	0.031	2.489	0.013
Responsiveness → Excellent Service	0.165	0.164	0.037	4.492	0.000
Mobility → Excellent Service	0.116	0.116	0.031	3.679	0.000
Technology → Excellent Service	0.304	0.305	0.060	5.099	0.000
Rest Area → Excellent Service	0.123	0.121	0.035	3.489	0.000

HI: The effect of information on excellent service. The coefficient value is 0.083 (+) with a t-statistic of 2.658 (>1.96) and a p-value of 0.008 (<0.05), indicating that information has a positive and significant effect on excellent service. Thus, H1 is accepted.

H2: The effect of accessibility on excellent service. The coefficient value is 0.064 (+) with a t-statistic of 2.113 (>1.96) and a p-value of 0.035 (<0.05), indicating that accessibility has a positive and significant effect on excellent service. Thus, H2 is accepted.

H3: The effect of reliability on excellent service. The coefficient value is 0.067 (+) with a t-statistic of 2.067 (>1.96) and a p-value of 0.039 (<0.05), indicating that reliability has a positive and significant effect on excellent service. Thus, H3 is accepted.

H4: The effect of mobility on excellent service. The coefficient value is 0.116 (+) with a t-statistic of 3.679 (>1.96) and a p-value of 0.000 (<0.05), indicating that mobility has a positive and significant effect on excellent service. Thus, H4 is accepted.

H5: The effect of safety and security on excellent service. The coefficient value is 0.076 (+) with a t-statistic of 2.489 (>1.96) and a p-value of 0.013 (<0.05), indicating that safety and security have a positive and significant effect on excellent service. Thus, H5 is accepted.

H6: The effect of rest areas on excellent service. The coefficient value is 0.123 (+) with a t-statistic of 3.489 (>1.96) and a p-value of 0.000 (<0.05), indicating that rest areas have a positive and significant effect on excellent service. Thus, H6 is accepted.

H7: The effect of responsiveness on excellent service. The coefficient value is 0.165 (+) with a t-statistic of 4.492 (>1.96) and a p-value of 0.000 (<0.05), indicating that responsiveness has a positive and significant effect on excellent service. Thus, H7 is accepted.

H8: The effect of technology on excellent service. The coefficient value is 0.304 (+) with a t-statistic of 5.099 (>1.96) and a p-value of 0.000 (<0.05), indicating that technology has a positive and significant effect on excellent service. Thus, H8 is accepted.

Table 12. Indirect Effects/Mediation

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Reliability → Technology → Excelent Service	0.041	0.042	0.013	3.129	0.002
Safety and security → Technology → Excellent Service	0.044	0.044	0.011	3.954	0.000
Responsiveness → Technology → Excelent Service	0.082	0.083	0.021	3.839	0.000
Mobility → Technology → Excelent Service	0.027	0.028	0.011	2.561	0.010
Rest Area → Technology → Excellent Service	0.069	0.070	0.019	3.683	0.000
Accesibility → Technology → Excelent Service	0.028	0.028	0.011	2.533	0.011
Information → Technology → Excelent Service	0.044	0.044	0.012	3.834	0.000

H9: The effect of information on excellent service through technology. The coefficient value is 0.044 (+), with a t-statistic of 3.834 (>1.96) and a p-value of 0.000 (<0.05), indicating that technology positively and significantly mediates the effect of information on excellent service. Thus, H9 is accepted.

H10: The effect of accessibility on excellent service through technology. The coefficient value is 0.028 (+), with a t-statistic of 2.533 (>1.96) and a p-value of 0.011 (<0.05), indicating that technology positively and significantly mediates the effect of accessibility on excellent service. Thus, H10 is accepted.

H11: The effect of reliability on excellent service through technology. The coefficient value is 0.041 (+), with a t-statistic of 3.129 (>1.96) and a p-value of 0.002 (<0.05), indicating that technology positively and significantly mediates the effect of reliability on excellent service. Thus, H11 is accepted.

H12: The effect of mobility on excellent service through technology. The coefficient value is 0.027 (+), with a t-statistic of 2.561 (>1.96) and a p-value of 0.010 (<0.05), indicating that technology positively and significantly mediates the effect of mobility on excellent service. Thus, H12 is accepted.

H13: The effect of safety and security on excellent service through technology. The coefficient value is 0.044 (+), with a t-statistic of 3.954 (>1.96) and a p-value of 0.000 (<0.05), indicating that technology positively and significantly mediates the effect of safety and security on excellent service. Thus, H13 is accepted.

H14: The effect of rest areas on excellent service through technology. The coefficient value is 0.069 (+) with a t-statistic of 3.683 (>1.96) and a p-value of 0.000 (<0.05), indicating that technology mediates the effect of rest areas on excellent service positively and significantly. Thus, H14 is accepted

H15: The effect of responsiveness on excellent service through technology. The coefficient value is 0.082 (+), with a t-statistic of 3.839 (>1.96) and a p-value of 0.000 (<0.05), indicating that technology positively and significantly mediates the effect of responsiveness on excellent service. Thus, H15 is accepted.

Priority Management

Priority management is based on indicators for each variable that influences toll road services. Each variable consists of two to six indicators, with a total of 40 indicators. Priority management is based on the values obtained from the outer loading results, as shown in the table below.

Table 13. Priority Management Indicators

Code	Indicator	Value
MO1	Queue length	0,949
IN2	Markings, signs, information boards	0,937
MO2	Traffic flow	0,937
IN1	Traffic and road maintenance information	0,936
PP5	Service quality	0,923
KET3	Towing service	0,913
PP1	Service speed	0,912
KE1	Road width	0,910
PP6	Information and guidance	0,910
AK5	Toll gate officers	0,907
PP3	Officer politeness	0,907
TI5	Fuel Station	0,907
AK1	Toll road rates	0,906
AK2	Travel time	0,906
TI4	Repair shop	0,906
PP2	Service accuracy	0,905
KET4	Emergency staff	0,903
KK6	Road patrol	0,903
PP4	Responsibility	0,901
TI2	Parking	0,901
AK3	Number of toll gates	0,900
KE5	Road maintenance and repair	0,900
KE2	Road surface	0,899
TI1	Food and beverage facilities	0,899
KET1	Call center	0,897
KK3	Crime security	0,897
KE3	Road geometry	0,896
KK4	Environmental safety	0,896
KET2	Accident handling	0,895
AK4	Distance between toll gates	0,894
KE4	Environment	0,893
TE2	Road maintenance	0,893
TI3	Toilet facilities	0,893
KK5	Ambulance, rescue	0,892
KK2	Traffic accidents	0,891
KK1	Road lighting	0,889
TE1	Traffic management	0,888
TE3	User information	0,885
TE4	Safety management	0,884
TE5	Toll payment	0,877

Based on the table above, the outer loading values are arranged from the highest to the lowest, which also serves as the priority order for improving toll road services. The top five indicators that toll road managers should focus on are queue length at toll gates; availability of markings, signs, and information boards; traffic conditions (congestion level); availability of up-to-date traffic and road maintenance information; and quality of services provided (comfort, facilities, technology).

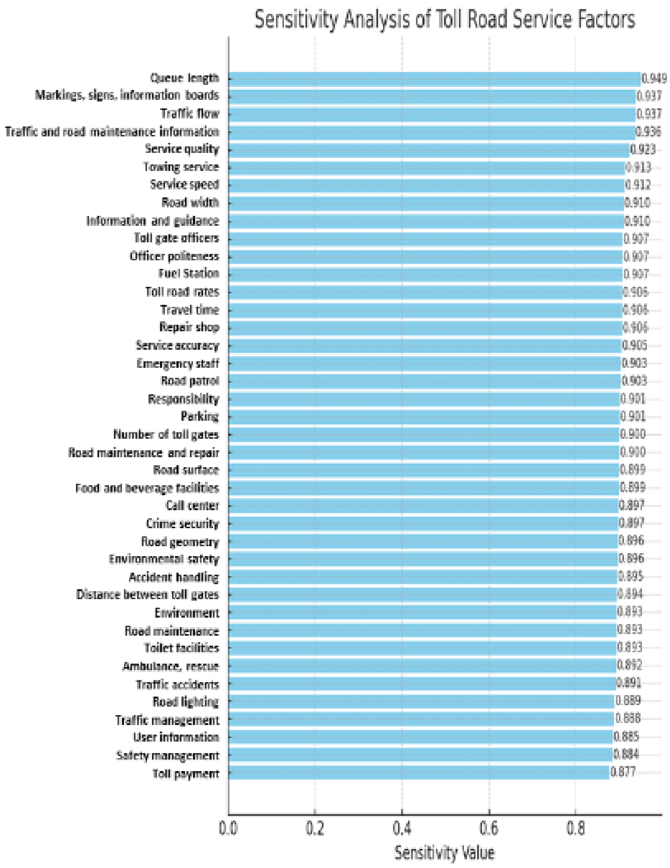

Figure 9. Sensitivity Diagram

The sensitivity graph above displays the sensitivity values for each toll road service factor. These values indicate the extent to which each factor influences the overall service quality.

DISCUSSION

The variables in this study are based on the TRSQ (Toll Road Service Quality) model, which is a service quality development model. The service quality comprises seven variables: accessibility, information, reliability, safety and security, responsiveness, mobility, and rest areas. Based on the hypothesis testing, these service quality variables positively influence the primary service of the Pemalang-Batang toll road. This result indicates that high-quality toll road services can deliver excellent service to users, thereby increasing user satisfaction. This study is supported by several relevant studies, such as the one by Rezky, Hajji, and Siswanto 2023), which found that 74.11% of Balikpapan-Samarinda toll road users are satisfied with the services, including accessibility, travel speed, mobility, assistance units, service units, road conditions, safety, environment, and rest areas. (Kurnia, Pataras, and Permata 2020) reported that Palindra toll road users are reasonably satisfied with the toll road services. (Imron, Suwaji, and W. 2023) showed that the quality of Cipali toll road services significantly affects consumer satisfaction by 85.6%. (Putra et al. 2023). Moreover, it reveals that the satisfaction level of Pekanbaru-Dumai toll road users is 63%, placing them in the fairly satisfied category. Furthermore, Dewi, Usadha, and Kamala 2022) stated that service quality positively and significantly affects consumer satisfaction. (Dina and Amin 2023) Indicated that toll road customer satisfaction in the Jabodetabek area is significantly influenced by service substance, accessibility, mobility, safety, assistance and rescue services, and the environment. Purnama (2020) also showed that service quality positively affects toll road user satisfaction.

Besides direct hypothesis testing between TRSQ variables and prime service, this study also tested hypotheses through an intermediary variable: the influence of TRSQ variables on prime service, mediated by technology. The hypothesis-testing results showed that TRSQ variables affect prime service through technology as an intermediary variable. Including technology in this study model is a novelty in research on toll road services, especially in its role as an intermediary variable. The author has not found similar studies with findings similar to those presented here, making this a novel contribution. However, in other fields, studies involving technology have shown positive impacts. For example, Putria 2018) stated that service quality and technology significantly influence consumer satisfaction. In line with this, technology implementation can significantly improve consumer satisfaction. (Wiranti and Frinaldi 2023) argued that using technology significantly enhances the effectiveness of public services in the modern digital era.

The influence of TRSQ variables on toll road prime service through technology stems from the benefits of technology in optimising toll road performance and services. This result highlights the urgency of toll road development to consider the increasing demands and expectations of road users for high-quality toll road services (Syukur 2020). Therefore, modernising toll road operations systems is one way to improve services through technology updates. As technology advances and road users' needs become more dynamic, toll road service improvement can leverage AI (Artificial Intelligence) technology innovations. AI technology enables toll operators to optimise intelligent transportation systems, providing safer, congestion-free, and environmentally friendly roads. The implementation of this technology aims to enhance user comfort by reducing traffic congestion, improving safety and security, increasing operational efficiency, and upgrading network infrastructure (Santosa et al. 2023). The types of technology that can be applied refer to the ITS (Intelligent Transportation System) on toll roads, including the Advanced Traffic Management System (ATMS), Intelligent Management System (IMS), Advanced Traveler Information System (ATIS), road safety management (RSM), and Electronic Toll Collection (ETC), developed with AI-based technology such as innovative CCTV, remote traffic microwave sensors, and GeoAI. Research on AI use in public services has shown that it increases efficiency, responsiveness, and service quality (Triyono, Tobirin, and Rokhman 2024).

Additionally, Zsazsa and Sitepu (2023) found that AI implementation in public services significantly improves service efficiency, quality, and accessibility, demonstrating AI's substantial potential to enhance public service effectiveness. Therefore, innovation in toll road services through AI-based technology is essential. Applying AI can achieve excellent toll road services by optimising service quality. This result is supported by Suprianto (2023), who stated that the application of technology is crucial in enhancing the quality of public services.

CONCLUSION AND RECOMMENDATIONS

Conclusion

This study demonstrates that all TRSQ variables—information, accessibility, reliability, mobility, safety and security, rest areas, and responsiveness—significantly influence the provision of excellent toll road services. Moreover, technology functions as a strong mediating variable, reinforcing the effect of each TRSQ component on service excellence. These findings confirm that integrating AI-based innovations effectively enhances toll road performance and user satisfaction.

Priority improvements should focus on the following indicators: (1) reducing toll gate queue length, (2) ensuring adequate road markings, signs, and information boards, (3) maintaining smooth traffic flow, (4) providing real-time traffic and maintenance information, and (5) improving overall comfort, facilities, and service technology.

Recommendations

There is a need to identify other variables beyond this research model that may influence toll road services, given the positive and significant results of the variable relationship tests.

Special attention is needed to maintain service stability for the five priority indicators: queue length at toll gates; the availability of markings, signs, and information boards; traffic flow conditions; the availability of real-time traffic and road maintenance information; and the quality of service provided.

There is a need to improve toll road services by implementing AI-based innovations to optimise user experience.

Synergy among operators, regulators, and road users is necessary to support the adoption of AI-based technological innovations.

Further research is needed to test the effectiveness of AI-based technologies in improving toll road services and determine the most effective types of technology to implement.

Policy and Practical Implications

Toll road operators should adopt AI-based Intelligent Transportation Systems (ITS) such as innovative CCTV, GeoAI-based traffic analytics, and automated maintenance sensors to improve operational efficiency, user comfort, and road safety. Regulators, including the BPJT and the Ministry of Public Works and Housing, should integrate technology-based service indicators into future revisions of toll road Minimum Service Standards (SPM). Collaborative implementation among operators, regulators, and road users is crucial to ensuring continuous, sustainable improvement in toll road service quality. Furthermore, future research is recommended to evaluate the effectiveness of specific AI technologies in real operational environments and to extend the applicability of the proposed model across other toll road networks.

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