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Toll Exit Length Determination Toward Arterial Road via Regression, SEM PLS4, and VISSIM

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ABSTRACT
The Jakarta-Cikampek (Japek) and Jakarta Outer Ring Road (JORR) toll road exits, which are connected to secondary arterial roads, consistently experience traffic congestion during peak hours. The purpose of this research on road performance at these intersections to develop a model that determines the optimal length of exit ramps on toll roads connected to secondary arterial roads. This research includes traffic data analysis, vehicle speed measurements, and road geometry evaluation at various exit locations. Statistical methods, such as Multiple Regression, SEM, PLS4, and VISSIM PTV Simulation, are applied to examine and construct models linking exit toll ramp configurations to the Performance of adjacent arterial roads. The research is: Higher toll exit volumes (X1.1) are hampered by shorter exit queues (Y1). Longer exits (X3.2) result in shorter queues at exits (Y1). Conversely, longer toll exits (X3.2) result in longer queues on secondary arterial roads (Y2). Longer queues at exits (Y1) are associated with shorter queues on secondary arterial roads (Y2). Conclusion and Future Research Based on these findings, a mathematical model is developed to guide the Design of efficient and safe exits. This approach is designed to enhance service quality on toll road networks and improve travel safety. The key findings of this study, acknowledging its limitations, lay the groundwork for future investigations and for advancing more effective traffic management approaches at toll exits and adjacent arterial road intersections.

Keywords: *Exit Ramp; Performance Road; Multiple Regression; Secondary Arterial Road; SEM PLS4; Queue Length; VISSIM.*

1. Introduction

Developed to improve access, the Jakarta-Cikampek (JAPEK) and Jakarta Outer Ring Road (JORR) toll roads, built in the late 1980s and early 1990s, serve as strategic routes connecting Jakarta with its surrounding regions. With the increasing volume of traffic on secondary arterial roads around toll roads, the Performance of these roads greatly influences traffic smoothness. The toll road system is vital to transportation, enabling fast and efficient mobility between urban areas. Toll road exit ramps are essential, allowing users to exit the toll road and rejoin the non-toll road network. His research examines the performance characteristics of toll exit ramps that interface with secondary arterials. Transportation is essential for facilitating the movement of individuals and goods in support of other economic activities [1].

To promote sustainable urban development, transport policy needs to shift from a car-oriented mobility planning paradigm to an accessibility-based paradigm that integrates land-use and transport policies. This paper uses planning paradigms to describe the current status of urban transport planning and problem formulation. The dominant transport planning paradigms in 172 Dutch municipalities are

Vol. 6, No. 2, pp. 194-207
Submit: 11-08-2025 |
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Publish: 01-01-2026 |

determined using a conceptual framework comprising 24 mobility and accessibility planning criteria [2]. A Jakarta–Bandung toll exit case study highlighted a pronounced decline in local road performance during peak periods (e.g., morning and evening rush hours), attributed to overflow traffic from toll ramps onto under-designed urban arterials [3]. A road system's ability to handle traffic is constrained; once this capacity is exceeded, its Performance deteriorates significantly [4]. The ramp is a vital element that connects city traffic with highways. The path settings above it influence its Performance. This paper evaluates travel time and vehicle emissions for two on-ramp configurations [5]. Urban traffic congestion is worsening globally, including in Kuala Lumpur. As cities' population, infrastructure, and economic activity grow over the next decade, mobility needs are expected to increase rapidly [6]. Accurate estimation of dynamic origin-destination demand (DODE) and understanding of driver rerouting behaviour (DRDB) are essential components in formulating practical group route guidance (GRG) strategies aimed at traffic load balancing and enhancing network performance [7].

Regression analysis can be used as a preliminary or complementary method to support theoretical relationships before structural Equation modeling. Given its emphasis on prediction and theory development, PLS-SEM has become a widely accepted analytical technique in applied research across engineering and management disciplines [8]. Increasing vehicle ownership and urban traffic growth have made congestion at expressway off-ramps a significant issue for efficiency and safety. Four collaborative strategies are proposed to manage lane changes at off-ramps. Using a VISSIM simulation for a three-lane toll road, the study evaluates an optimisation scheme: when main traffic is low, off-ramp vehicles can reduce their speed and enter the deceleration lane. When traffic is heavy, off-ramp vehicles queue in the deceleration lane, slowing down following vehicles and forcing merges at the end of the lane [9].

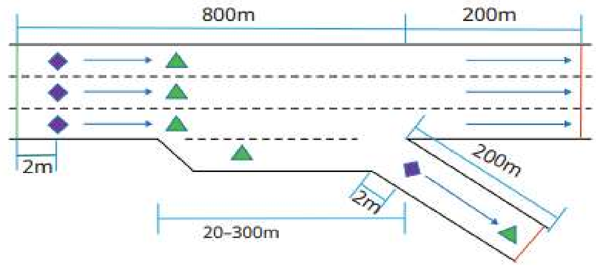

Figure 1. Sketch of VISSIM simulation model parameter settings for off-ramp areas.
Ramp parameter settings from the main road to ramp-off
Source**:** T. Mo, K. et al, 2020 [9]

The space reconstruction phase technology exhibits chaotic behaviour on toll road ramps. Accurate traffic flow forecasting helps reduce the consequences of unexpected disruptions or delayed interventions. Short-term traffic predictions are crucial for the functioning of intelligent transport systems (ITS). Wavelet transform neural networks can be utilised for short-term traffic flow forecasts on highways [10]. By linking interdependent regions, toll roads not only enhance accessibility but also foster the development of new activity zones.

Nevertheless, toll exits and adjacent roads commonly experience congestion during rush hour [11]. Inappropriate lane-changing behaviour can disrupt traffic flow and lead to various types of collisions. This study examines the lane-changing behaviour of multiple vehicles and the effects of stimulation on subsequent drivers in consecutive lane-changing scenarios [12].

To improve the accuracy of lane-change simulation, the proposed model reformulates the lane-change protocol by integrating empirical observations of aggressive driving in real-world scenarios [13]. Lane-changing behaviour is one of the complex driving behaviours. Drivers' lane-changing behaviour can exacerbate congestion; however, the characteristics of driver behaviour are challenging to obtain and measure accurately, so they are often simplified or overlooked in existing lane-changing models [14]. From a managerial perspective, this study offers strategic insights for addressing traffic congestion

JICE Journal Innovation of Civil Engineering

Vol. 6, No. 2, pp. 194-207
Submit: 11-08-2025 |
Accepted: 15-12-2025 |
Publish: 01-01-2026 |

and improving modal split efficiency in the Kuala Lumpur transportation system [6]. Previous research on RHCO has identified reasons for variations in findings across geographical regions. From the previous articles, the authors focused on (a) understanding the available funding mechanisms, (b) benefits/challenges in funding mechanisms, and (c) recommendations for improving current funding mechanisms [15].

Accurate travel time estimation is crucial for drivers and traffic managers, yet it becomes particularly challenging during periods of high traffic volume. On motorways, this usually occurs upstream of a divergent bottleneck [16]. However, it is also worth noting that traffic accidents on the route are caused by several factors, including insufficient traffic signs, poor road surface conditions, and unclear road markings, as shown by research on Narogong Street [17]. Analysis shows the circle's entrance, exit, and centre are critical locations. The entrance and exit of the circle indicate speed instability and a high accident rate. Using circular arches with a radius of more than 70 m can overcome this problem. In the centre of the circle, vehicles tend to be closer to the inner edge of the pavement, and this location experiences a high number of loss-of-control accidents [18].

The primary objective of this research is to develop a quantitative, simulation-validated model to determine the optimal length of toll road exit ramps connected to secondary arterial roads. The main contributions include: (1) the integration of regression analysis, SEM-PLS4, and microscopic simulation within a unified framework; (2) the development of predictive models for queue lengths on toll exit ramps (Y1) and secondary arterial roads (Y2); and (3) practical Design recommendations for exit ramp configuration based on empirical and simulation-based evidence.

2. Material and Method

Traffic engineering methods based on the principle of prediction and provision have self-enforcing impacts, leading to traffic congestion and an unhealthy environment for both humans and the planet. This paper aims to demonstrate that such methods trap cities in a path-dependent relationship with transport technology and the urban environment, and to find evidence that something is changing in theory, trends, and practices. A systematic and extensive literature review has been used to identify and understand the problem, recognise the changes, and examine the solutions. The main findings reveal the causes of this problem and its persistence despite the significant adverse effects, and realize that a paradigm shift is emerging from the cumulative methods and achievements developed by the academic community, experts, practitioners, policymakers, and urban society. The findings can have practical implications and effectively inform a new transport policy paradigm that breaks the path dependency trap. The originality of this approach lies in extending and applying the concept of theoretical anomalies to the adverse effects of technology and the mismatch between humans and the modern urban environment. This new paradigm has demonstrated its effectiveness in solving real problems by adapting cities and technologies to human nature and by developing more holistic, human-centred planning methods [19].

This study aims to develop a regression-based approach to calculate the optimal length of toll road exit ramps linked to secondary arterial roads. The research process is divided into the following main stages:

1. **Data Collection**
   Collect relevant traffic, infrastructure, and environmental data
2. **Data Processing**
   Clean and process collected data for further analysis
3. **Descriptive Statistical Analysis**
   The relationship between exit ramps and adjacent arterial roads was examined using a combination of multiple regression, structural Equation modelling via PLS4, and traffic simulation through PTV VISSIM
4. **Development of Regression Models**
   Develop a regression model to determine the relationship between exit ramp length and the Performance of secondary arterial roads

JICE Journal Innovation of Civil Engineering

Vol. 6, No. 2, pp. 194-207
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Publish: 01-01-2026 |

5. **Model Validation**
   Validate the model to ensure the accuracy and precision of predictions
6. **Implementation and Evaluation**
   Implement the model and evaluate the results through simulation and case studies using the PTV Visim application
7. **Interpretation and Preparation of Recommendations**
   Develop recommendations based on analysis results for exit ramp Design and management
8. **Preparation of Research Reports**
   Prepare research reports that include all stages, results, and recommendations.

This flowchart helps visualise the steps in this research, from data collection to preparing a research report.

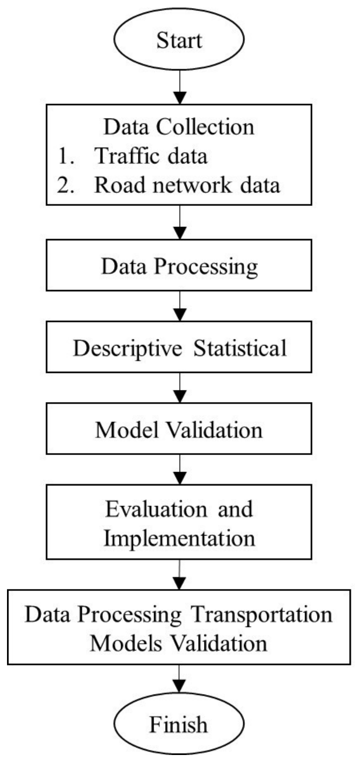

Figure 2. Flow Chart of Research Study

3. Results And Discussion

Average Daily Traffic Data (LHR)

Commonly employed AADT estimation methods for low-volume roadways include regression techniques, artificial neural networks (ANNs), travel demand modelling, traditional adjustment factors, and spatial interpolation approaches. The Performance of these AADT estimation methods is the subject of a meta-analysis. Queueing theory and AADT data must be analysed and validated with software to develop an appropriate model. The model's Performance is compared to recent freeway travel forecasting models that use backpropagation (BP) network algorithms [20]. Average Daily Traffic Data (LHR) carried out at the Jakarta Cikampek (Japek) toll road location on outbound flows from both Jakarta and Cikampek, as well as exits at the outer ring toll road (JORR) location, are summarised in hours busy in Table 1, LHR Survey Results, as in the Table 1.

Vol. 6, No. 2, pp. 194-207
Submit: 11-08-2025 |
Accepted: 15-12-2025 |
Publish: 01-01-2026 |

Table 1. LHR Survey Results

LHR Rush Hour Volume				
No	**Hour**	**Exit Ramp**	**Volume Exit Ramp /15 minutes**	**Total Hours**
1	18.00-19.00	West Bekasi	835	3339
2	19.00-20.00	East Bekasi 1	972	3728
3	19.00-20.00	East Bekasi 2	954	3816
4	19.00-20.00	Cibitung	695	2780
5	19.00-20.00	Pondok Pinang	612	2447
6	07.00-08.00	Fatmawati	755	3020

Source: Analysis Results, 2025

The relationship between travel time reliability and the variation coefficient of congestion becomes evident when comparing morning and evening rush hours, emphasising the role of congestion distribution across the transport network. Design a fairness evaluation method for expressway ramp spacing using the entropy-weighted TOPSIS approach, considering four primary indicators: traffic efficiency, safety, accessibility, and economy. Through a case study of the Beijing–Hong Kong–Macao Expressway in Henan, an optimal ramp spacing of 14 km is obtained, demonstrating that coordinated ramp spacing can enhance the overall benefits of expressways and improve their response to regional traffic demand [21].

Urban traffic congestion remains a significant challenge, leading drivers to prioritise routes that offer greater reliability and shorter travel times. However, commonly used reliability indicators—such as Standard Deviation, Buffer Time, and the Buffer Index—exhibit notable limitations. Trips (TTR) play an essential role in commuting. However, existing measurement methods are not explicitly designed for commuting. The construction of at-grade and elevated toll roads aims to reduce traffic jams. Still, traffic-jam scenarios and their direct application to assess TTR for commuting may yield results inconsistent with actual commuting conditions, as they rely too heavily on measures such as the mean and percentile. Based on the characteristics of the commuting cycle, this study has developed a TTR measurement model using information entropy and standard deviation, tailored to each commuter. By selecting trip data from a large commuting dataset and applying this model along with conventional measurement methods, the focus is on the quantitative analysis of TTR for metro and car commuters under various feature conditions, with special emphasis on commuting to work [22].

Recently, video-based and real-time vehicle counting have become popular approaches for Traffic Flow Analysis (TFA). One of the main objectives of this analysis is to solve problems that cause traffic congestion, including identifying peak hours [23]. Interest, or establishing reference points or lines for counting vehicles from traffic cameras. This work introduces a method for counting vehicles from traffic videos that automatically identifies the camera's ROI and the car's driving trajectory. This makes the technique feasible for use with Pan-Tilt-Zoom cameras, which are frequently used in developing countries [24].

Vissim Simulation Results

This study's PTV VISSIM microscopic simulation analyses traffic flow conditions at the Exit Ramp and Simpang Bekasi Barat, as well as Bekasi Timur 1 and 2, Cibitung, Pondok Pinang, and Fatmawati. The analysis includes motor vehicle traffic flow and traffic stops to obtain data on delays, queue length, and LOS. The simulation was conducted based on traffic load data collected from traffic calculations, with the results presented in Figure 4.4 and Table 4.4. From the VISSIM Exit Ramp Cibitung simulation results, the delays, queue lengths, and LOS are shown in Table 2.

Vol. 6, No. 2, pp. 194-207
Submit: 11-08-2025 |
Accepted: 15-12-2025 |
Publish: 01-01-2026 |

Table 2. Vissim Results for Delay, Queue Length, and LOS

No	Exit Ramp	Delay (sec/smp)	Queue Length (m)	LoS
1	West Bekasi Toll Road Exim Ramp	49,5	54	D
2	Exit Road Eastern Highway 1	71,35	288	E
3	Exit Road Eastern Highway 2	80	108	F
4	Exit Ramp Cibitung Toll Road	71,2	193	F
5	Exit Ramp Pondok Pinang Toll Road	64,82	122	E
6	Exit Road Fatmawati Toll Road	93,18	198	F

Source: Analysis Results, 2025

From the VISSIM results, the queue length is shown in the picture below, which still occurs at the sections connecting ramp exits to intersection roads. A traffic survey and a combined model are proposed to calculate the lengths of the connecting sections. VISSIM simulations show that section length, travel time, delays, parking time, and queue length are reduced, verifying the model [25]. As merging zones on freeways commonly initiate traffic delays during peak periods, this paper presents a new methodology for managing inter-vehicle spacing. The approach includes extending current systems with an ATM-based control strategy called “Gap Measuring,” which is considered a non-stop version of the main ramp. Signals notify vehicles in the central lane to create enough gaps for cars to merge. Highway merge sections are critical points that often trigger traffic congestion.

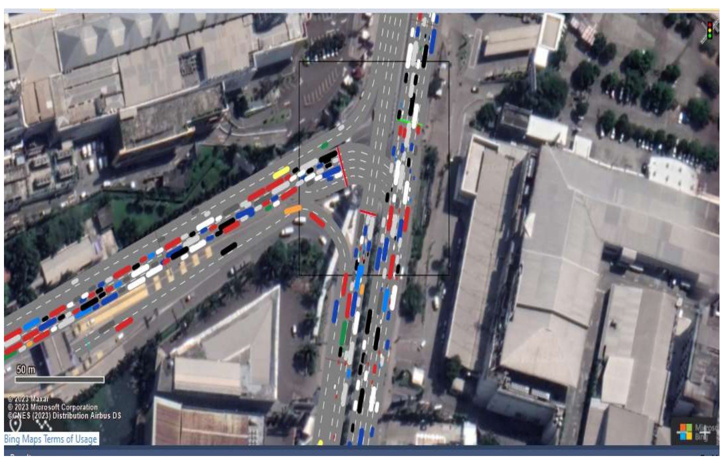

Figure 3. Simulation of the existing Exit Ramp and Simpang Wet Bekasi
Source: Vissim Analysis Results, 2025

Vol. 6, No. 2, pp. 194-207
Submit: 11-08-2025 |
Accepted: 15-12-2025 |
Publish: 01-01-2026 |

Figure 4. Simulation of the existing Exit Ramp and Simpang East Bekasi 1
Source: Vissim Analysis Results, 2025

Figure 5. Simulation of the existing Exit Ramp and Simpang East Bekasi 2
Source: Vissim Analysis Results, 2025

Figure 6. Simulation of the existing Exit Ramp and Simpang Cibitung
Source: Vissim Analysis Results, 2025

Vol. 6, No. 2, pp. 194-207
Submit: 11-08-2025 |
Accepted: 15-12-2025 |
Publish: 01-01-2026 |

Figure 7. Simulation of the existing Exit Ramp and Simpang Pondok Pinang
Source: Vissim Analysis Results, 2025

Figure 8. Vissim Congestion Simulation, Existing Exit Ramp, Fatmawati Road
Source: Vissim Analysis Results, 2025

Following the simulation, vehicle performance indicators—including speed, travel time, and delay—were collected and compared under standard and connected vehicle (CV) conditions. The results were evaluated to analyse the impact of varying CV penetration levels on traffic flow performance, as illustrated in Figure 4, which presents the simulation outcomes for the existing exit ramp configuration. On a two-lane arterial road, connected conditions increased running speed by 4 km/h and reduced total travel time and delay by 5.34% and 16.76%, respectively, compared to normal conditions. The optimal CV market penetration rate depends on running speed and delay.

Traffic counting is a fundamental data source for planning, managing, designing, and evaluating transportation systems. Recording traffic flows and counting from video footage is increasingly used due to its simplicity, high accuracy, and cost-effectiveness. Manual counting from pre-recorded video footage is prone to inconsistencies and errors, resulting in inaccurate counts. Furthermore, no standard guidelines exist for collecting video data and manually counting from video footage [26].

An Analytical Study on How Toll Exit Ramp Length Affects Queue Length

Measurement models assess discriminant validity, while structural models describe hypothesised relationships. Statistical software such as Lisrel, AMOS, and Smart PLS can simplify SEM data processing to compare two Structural Equation Modeling (SEM) approaches, namely Covariance-Based

Vol. 6, No. 2, pp. 194-207
Submit: 11-08-2025 |
Accepted: 15-12-2025 |
Publish: 01-01-2026 |

SEM (CB-SEM) and Partial Least Squares SEM (PLS-SEM), by analysing right-turning motor vehicle (RMV) data in a mixed traffic network, and evaluating the advantages of each method in terms of item loadings, model fit, and contribution to factor-based and combined models, so that the results of this comparison can enrich the literature and support the development of predictive research [27]. SEM Smart PLS 4 was applied to simulation outputs from five locations using VISSIM to analyse the relationship between toll exit ramp features and vehicle queuing. The analysis framework included queue length as the dependent variable, along with several explanatory variables. The SEM Smart PLS 4 test was conducted to determine the relationship between variables in accordance with statistical requirements.

Description of dependent variables and independent variables:

Y = Queue length
Y1 = length of the toll road of the exit ramp queue
Y2 = length of the secondary arterial queue

X1 = Toll Road exit ramp performance:
X1.1 = Toll Road exit ramp volume
X1.2 = Toll Road exit of ramp speed
X2 = Performance of secondary arterial roads:
X2.1 = Arterial Volume
X2.2 = Arterial Speed
X3 = Intersection distance and toll road
X3.1 = Distance between intersection-merger
X3.2 = length of toll road exit ramp

The results below reflect the structural model built using SEM Smart PLS 4, which captures the interaction between toll exit ramp length and secondary arterial road performance. Based on the SEM Smart PLS 4 analysis regarding the impact of the exit ramp of toll road traffic, secondary arterial road traffic, and intersection distance on queue length. Multiple regression analysis is used to establish direct, interpretable linear relationships between exit ramp characteristics and queue lengths, providing initial empirical validation of theory-driven hypotheses. SEM-PLS4 is applied to model complex interdependencies among latent variables and to capture both direct and indirect effects that cannot be adequately addressed using traditional regression alone. Finally, a PTV VISSIM simulation is employed to validate the analytical findings under realistic traffic conditions and to assess operational performance indicators, including queue length, delay, and level of service.

The mathematical models for Y1 (queue length at toll exits) and Y2 (queue length at secondary arterial roads) have been clearly defined and are presented in the revised Results and Discussion section. The regression equations explicitly measure the effects of traffic volume, speed, exit ramp length, and intersection distance on queue formation. The results indicate that increasing exit ramp length reduces queue length at toll exits (Y1) while increasing queue length at secondary arterial roads (Y2), highlighting essential considerations in exit ramp Design. These findings are further supported by SEM-PLS4 results, which confirm the structural relationships between the variables, and by VISSIM simulations, which demonstrate consistent operational results under real-world traffic conditions.

Vol. 6, No. 2, pp. 194-207
Submit: 11-08-2025 |
Accepted: 15-12-2025 |
Publish: 01-01-2026 |

Table 3. Factor Loading

Indicator	Traffic Toll Exit	Traffic Arterial	Distance Intersection	Queue Length
X1.1	0,990			
X1.2	0,991			
X2.1		0,963		
X2.2		0,972		
X3.1			1,000	
X3.2			1,000	
Y1				0,994
Y2				0,994

Source: Analysis Results, 2025

Based on Table 3 above, all factor loadings are greater than 0.7. Thus, all indicators are used in this research.

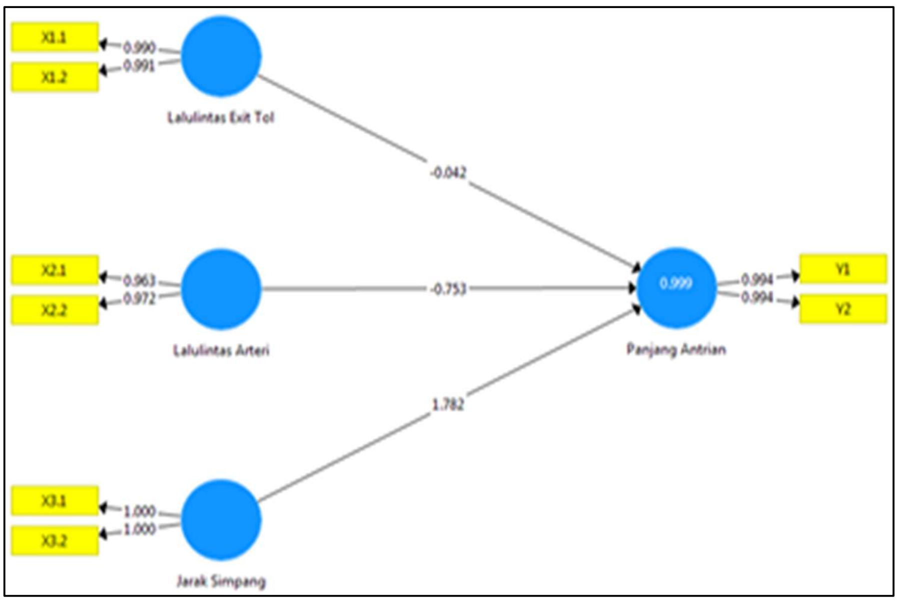

Figure 9. Relationship Line Variables
Source: Analysis Results, 2025

The results of the SEM-PLS analysis show that the Lane Width variable, measured through indicators X21 and X22, has perfect convergent validity, with outer loadings of 0.963 and 0.972, respectively. Lane width has a significant, adverse effect on queue length, with a path coefficient of -0.733, indicating that increasing lane width can significantly reduce queue length.

Mathematical Model Equations

Obtained regression results Y1:

Y1 = -0.032 X1.1 + 1.913 X1.2 + 0.044 X2.1 + 0.017

The longer the exit ramp (X3.2), the shorter the queue on the toll road (Y1).
The larger the toll exit volume (X1.1), the shorter the queue at the exit ramp (Y1).
The longer the exit ramp (X3.2), the shorter the queue at the exit ramp (Y1).

Vol. 6, No. 2, pp. 194-207
Submit: 11-08-2025 |
Accepted: 15-12-2025 |
Publish: 01-01-2026 |

Obtained regression results Y2:
Y2 = -0.028 X1.1 + 1.576 X1.2 + 0.038 X2.1 + 0.093
The longer the toll road exit ramp (X3.2), the longer the queue on the secondary arterial road (Y2)
The longer the queue at the exit ramp (Y1), the shorter the queue at the secondary arterial road (Y2).

The results show that increasing the length of toll exit ramps significantly reduces queue formation at toll exit ramps (Y1). However, beyond a certain threshold, longer toll exit ramps can increase queue lengths on secondary arterial roads (Y2), suggesting a critical Design consideration. Regression coefficients, SEM-PLS4 path relationships, and microscopic simulation results consistently support these findings. The combined regression analysis produces a graphical representation of the relationship between exit ramp length and queue lengths observed on the ramp itself and on connecting secondary arterial roads, as shown in Figure 9 below.

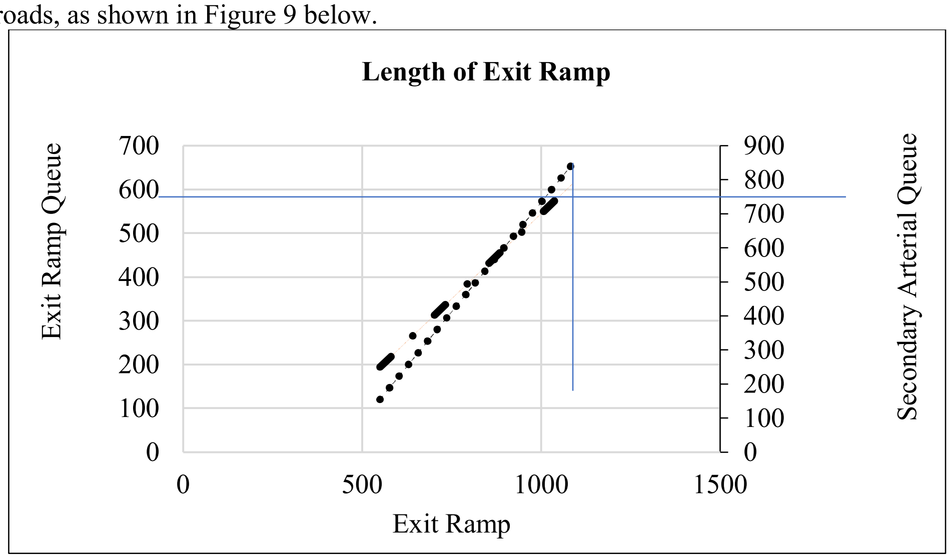

Figure 10. Relationship Between Toll Exit
Source: Analysis results

Note:
Ramp Length, Ramp Queue Length, and Secondary Arterial Queues;
Secondary queuing artery (m)
Exit toll road queue (m)

Based on the graph results in Figure 9, the optimal length of the exit ramp is 885 meters, with estimated queue lengths of 455.4 meters at the toll road exit ramp and 585.2 meters at the secondary artery.

4. Conclusion

From the analysis, discussion, and supported by various scholarly references, the study concludes the following: 1. The significant link between exit ramp dimensions and queue formation on secondary roads demonstrates how toll road infrastructure influences broader urban traffic performance. 2. Based on the VISSIM simulation results, the Performance of toll road exit ramps and connecting secondary arterial roads indicates critical operational conditions. The degree of saturation (D.S.) at the exit ramps was found to exceed 1.0, representing Level of Service (LOS) F, which corresponds to forced flow conditions characterised by low travel speeds, excessive traffic volumes beyond capacity, and long queues indicative of severe congestion. These conditions suggest that toll road exit ramps can significantly disrupt the Performance of the downstream secondary arterial roads and the mainline toll road itself. 3. Research and Vissim visual animations found that secondary arterial roads would experience congestion if the Length of the Exit Ramp is not regulated. Likewise, from the regression

JICE Journal Innovation of Civil Engineering

Vol. 6, No. 2, pp. 194-207
Submit: 11-08-2025 |
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Publish: 01-01-2026 |

analysis and SEM Smart PLS 4 validations, the following mathematical formula is obtained. The model expressing the functional relationship between toll exit ramp efficiency and the Performance of connecting local roads is formulated as follows:

Y1 = -0,032 X1.1 + 1,913 X1.2 + 0,044 X2.1 + 0,017 X2.2 -0,766 X3.1 - 0,175 X3.2 + 273,158

Y2 = -0,028 X1.1 + 1,576 X1.2 + 0,038 X2.1 + 0,093 X2.2 + 0,142 8 X3.1 + 0,043 X3.2 - 0,863 Y1 + 294,219

Based on this relationship, queue length (Y) can be used as a predictive variable to identify the optimal ramp length. The research findings regarding the relationship between toll road exit ramps and the Performance of secondary arterial roads have significant implications for road engineering, transportation systems, and infrastructure planning. Several potential applications of these findings include the following: This research provides crucial insights for road infrastructure planning and transportation policy development, with a specific focus on optimal exit ramp Design and traffic management.

Based on the findings, here are the core recommendations: Implement Advanced Traffic Control Systems: Utilise smart signals, dynamic signs, and adaptive management around exit ramps to reduce congestion. Improve Flow Management: Adjust traffic signal timings and designate alternative routes to alleviate pressure on local roads. Policies and Regulations: **Modify Design Standards,** update Exit Ramp Design criteria to account for their impact on local roads. Develop Traffic Management Policies by Create regulations for traffic management around exit ramps.

Future Research

The study also provides a foundation for advanced research: Follow-up Studies: Investigate additional factors influencing secondary arterial road performance and their interaction with exit ramps. Comprehensive Model Development: Develop more complex models that incorporate a wider range of variables. Signal Optimisation Research: Focusing on optimising signals for entry routes and upstream intersections, as well as managing delays. These suggestions aim to enhance traffic efficiency and safety around toll road exit ramps, offering a comprehensive approach to road infrastructure planning.

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Submit: 11-08-2025 |
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