Forecasting Traffic Demand Under Toll Pricing Scenarios in Vietnam: A Simulation-Based Approach

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Abstract:

This study analyzes traffic demand forecasting under different toll pricing scenarios for the Ho Chi Minh City – Trung Luong – My Thuan Expressway using a macroscopic traffic simulation model. The research aims to evaluate the impact of toll collection on traffic volume, route choice behavior, and expressway capacity requirements. A calibrated four-step travel demand model was developed in PTV VISUM, incorporating survey data, socioeconomic growth factors, and planned infrastructure developments. Traffic was assigned under multiple tolling scenarios to assess changes in vehicle distribution and congestion levels. The results indicate that toll pricing significantly influences heavy vehicle movements, with potential traffic shifts to alternative toll-free routes. Additionally, key expressway segments are nearing capacity limits, requiring future expansion planning and congestion management strategies. These findings provide insights for policy formulation on toll pricing and expressway network optimization in Vietnam.

Keywords: Toll rate, Traffic Simulation, Highway, Forecasting

1. INTRODUCTION

Efficient transportation systems are critical for supporting economic growth, social connectivity, and overall quality of life in modern cities (Vickrey, 1969). However, the increasing demand for mobility often leads to traffic congestion, which imposes significant costs on society in terms of wasted time, increased fuel consumption, air pollution, and reduced productivity (Lombardi *et al.*, 2023; Willis et al., 2024; Broster and Terzano, 2025; Kelly et al., 2011). Traditional approaches to congestion management, such as expanding road capacity, have proven to be costly, time-consuming, and often ineffective in the long run due to induced demand (Duranton and Turner, 2011). As a result, policymakers and transportation planners have increasingly turned to innovative strategies for managing traffic flow and optimizing the use of existing infrastructure. Among these strategies, toll pricing has emerged as a prominent and theoretically sound approach (Zahedian et al., 2021; Farias et al., 2024).

Toll pricing, also known as congestion pricing or value pricing, refers to the practice of charging motorists a fee for using roads, particularly during peak hours or in congested areas (Button, 1995) (Kenneth, 2022). The fundamental principle behind road pricing is to internalize the external costs of congestion by making drivers pay for the delays and environmental impacts they impose on others (Pigou, 2013). By charging a toll, road pricing aims to incentivize drivers to alter their travel behavior, such as shifting their travel times, routes, or modes, thereby reducing congestion and improving overall network efficiency (Yang, 2005). The toll collection policy is applied not only in urban areas to reduce congestion and environmental pollution but also on highways to increase revenue for investors.

In Vietnam, toll collection is usually applied to routes or highway invested by the private sector under the BOT (Build - Operate - Transfer) model. The government has strict regulations on toll rates and collection times for each project.

This study was conducted on the case of the Ho Chi Minh - Trung Luong - My Thuan highway. This is a critical component of Vietnam's North-South Highway (CT01). It serves as a vital economic corridor, enhancing connectivity between Ho Chi Minh City, the country's largest economic hub, and the agricultural and industrial provinces of Long An and Tien Giang, as well as the broader Mekong Delta region. This highway plays a crucial role in reducing transportation costs, supporting agricultural trade, attracting industrial investment, promoting real estate and tourism, and laying the groundwork for long-term economic development.

Despite its strategic importance, the highway operates under significant traffic pressure due to its limited capacity, only four lanes. Many countries have successfully implemented toll pricing strategies as a policy tool to regulate traffic demand. However, in Vietnam, toll policies are strictly controlled by the government, making it infeasible to impose excessively high toll rates. Although road pricing strategies have been widely studied and applied globally, existing research rarely focuses on the specific challenges of highway tolling in Vietnam, where: (1) Traffic characteristics differ significantly from other countries, with mixed traffic flows including motorcycles and heavy vehicles, leading to unique demand elasticity and route choice behavior; (2) Government-regulated toll policies impose strict constraints on pricing flexibility, limiting the applicability of standard dynamic toll pricing models used in Western countries (3) Few empirical studies have analyzed the impact of different tolling scenarios on traffic flow using simulation models in the context of Vietnam's highway system. While some previous studies have examined the economic and financial aspects of toll collection, there is limited research using traffic simulation models to evaluate how different toll pricing strategies affect traffic volume, travel speed, congestion levels, and overall highway performance.

This paper aims to Evaluate the impact of various toll collection scenarios on traffic performance using traffic simulation techniques; Forecast future traffic demand under different tolling strategies to understand long-term traffic trends; Identify an optimal tolling strategy that balances traffic efficiency, user affordability, and highway sustainability and propose recommendations for investment and construction management to ensure the highway's long-term effectiveness while supporting economic development in the Mekong Delta region. By conducting a simulation-based assessment of toll pricing strategies, this study provides valuable insights for policymakers and transportation planners in Vietnam and other developing countries facing similar challenges.

The remainder of the paper is structured as follows: Section 2: Literature Review discusses relevant research on toll pricing models and their impact on traffic flow. Section 3: Methodology presents the data collection process, traffic modeling techniques, and performance metrics. Section 4: Results and Discussions provides an in-depth analysis of toll pricing effects on speed and LOS, along with optimal pricing recommendations. Section 5: Conclusion and policy Implications summarizes key findings and proposes future research directions.

2. LITTERATURE REVIEW

This section provides an overview of the existing literature relevant to toll pricing, encompassing theoretical foundations, empirical evidence, and methodological approaches. The review is structured to highlight the evolution of tolling concepts, the application of toll pricing in practice, and the role of traffic simulation and optimization in designing and evaluating toll strategies.

2.1. Evolution of tolling concepts

The concept of tolling dates back centuries, with early examples primarily serving as a means to finance infrastructure development and maintenance (Walters, 1969). Traditional tolling schemes typically involved fixed charges, regardless of traffic conditions or time of day (Kenneth, 2022) (Button, 1995). However, as urban areas experienced increasing congestion, the limitations of fixed tolls became apparent, leading to the development of more sophisticated pricing mechanisms (Small and Verhoef, 2007).

Recent studies have highlighted the need for adaptive pricing strategies that respond to real-time traffic conditions. For instance, (Lombardi et al., 2021) (Farias et al., 2024) explored how fixed tolls can exacerbate congestion during peak hours and proposed variable pricing as a solution to mitigate these effects. The transition from fixed tolling to more flexible pricing models marks a significant shift in transportation economics. Several cities and countries have successfully implemented different toll pricing models to manage congestion (Ding et al., 2021) (Hu et al., 2018). Singapore's Electronic Road Pricing (ERP) (Metz, 2018) system dynamically adjusts toll rates to control urban congestion, while Stockholm's Congestion Tax has proven effective in reducing vehicle emissions and traffic volume. In the United States, managed lanes such as I-15 in San Diego and I-394 MnPASS in Minnesota have adopted high-occupancy toll (HOT) lane systems, which allow single-occupancy vehicles to pay for faster travel during peak hours (Lombardi et al., 2023) (Zahedian et al., 2021).

Unlike international tolling models, which often allow flexible, demand-based pricing adjustments, Vietnam's toll policies are strictly regulated by the government, restricting the ability to implement dynamic pricing strategies. A notable example is the Ho Chi Minh - Trung Luong Expressway, where the suspension of toll collection in 2019 resulted in a rapid 131% increase in traffic volume, underscoring the importance of a structured and sustainable pricing model. While tolling strategies have demonstrated proven benefits in managing congestion globally, research on Vietnam-specific tolling frameworks remains limited. Given the unique traffic composition, which includes motorcycles, passenger vehicles, and freight transport, an adaptive and context-specific tolling approach is essential for effective congestion management and infrastructure sustainability.

2.2. Traffic Simulation in Toll Pricing Analysis

Traffic simulation is a widely used approach to assess the effectiveness of different tolling strategies in managing congestion and optimizing road performance. Simulation models can be categorized into three types: macroscopic, mesoscopic, and microscopic models. Macroscopic models, such as the Lighthill-Whitham-Richards (LWR) model, or 4 step traffic modeling, provide aggregate-level traffic assessments, whereas microscopic models like VISSIM, Aimsun, and CORSIM simulate individual vehicle behaviors, lane-changing maneuvers, and interactions between road users. Mesoscopic models, such as DynaMIT and DynusT, balance computational efficiency with behavioral realism, making them suitable for network-wide analyses (Lombardi et al., 2021).

Traffic simulation has been extensively applied to evaluate toll pricing strategies in various contexts. Studies have used these models to estimate traffic diversion effects, analyze congestion patterns, and optimize toll rates (Lentzakis et al., 2023) (Li et al., 2017) (Nohekhan et al., 2021) (Zahedian et al., 2021) (Zapico et al., 2024) (Zheng et al., 2022). For instance, Singapore's ERP system was developed using a combination of simulation and empirical data to predict traffic responses to pricing adjustments (Xie and Olszewski, 2011). In the case of the Ho Chi Minh - Trung Luong - My Thuan Highway, a macroscopic traffic simulation model (PTV VISUM) was employed to assess different toll pricing scenarios, integrating real-world traffic survey data and demand forecasting

While toll pricing and traffic simulation have been extensively studied worldwide, several gaps remain, particularly in the context of developing countries like Vietnam. Firstly, most toll pricing models have been designed for high-income economies and fail to consider the unique demand elasticity and route-choice behaviors observed in developing nations Secondly, existing research often separates toll optimization from traffic forecasting, whereas this study integrates both to provide a more holistic evaluation. Finally, few studies have examined the effects of toll suspension on congestion, despite its real-world relevance in Vietnam, where the removal of tolls on highways has led to traffic surges and operational challenges.

3. METHODOLOGY

This section outlines the methodology used to evaluate the impact of different toll pricing strategies on the Ho Chi Minh City - Trung Luong - My Thuan Highway. The methodology consists of four key components: (1) Study Area Description, (2) Data Collection and Processing, (3) Traffic Simulation Model and Forecasting.

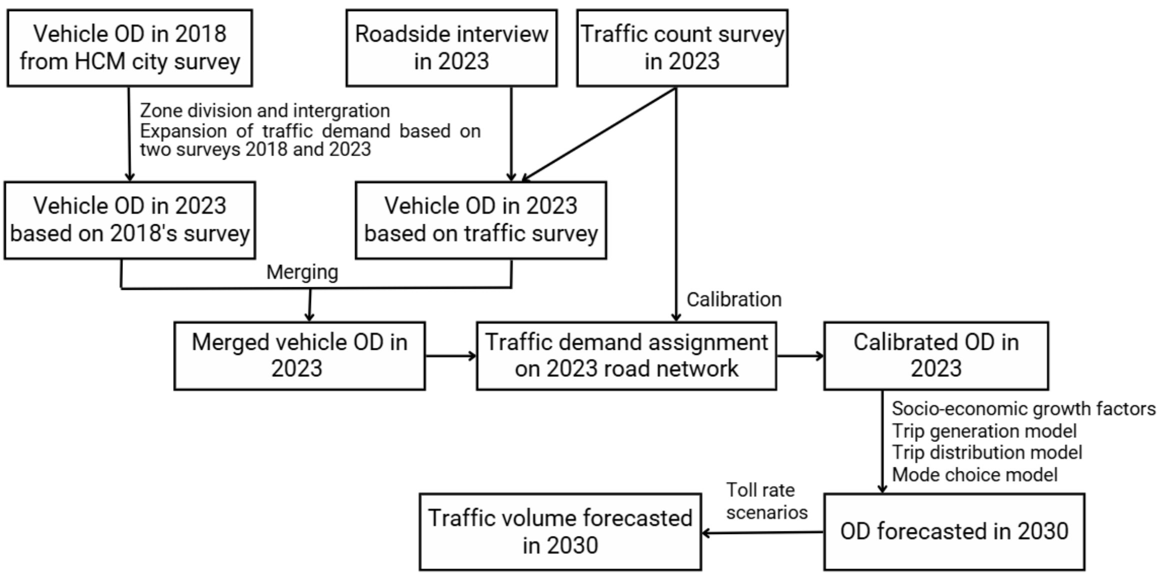

Figure 1. Methodology framework

This study applies a simulation-based approach to forecast traffic demand under different dynamic toll scenarios for the highway. The methodology follows a structured process, integrating historical data, recent surveys, and traffic modeling techniques to ensure accurate demand projections for 2025 and 2030.

First, vehicle origin-destination (OD) matrices from 2018 were obtained from the Ho

Chi Minh City traffic modeling project's survey. To update these matrices, roadside interviews and traffic count surveys were conducted in 2023, generating a new OD matrix based on observed travel patterns. These datasets were then merged to create a comprehensive 2023 vehicle OD matrix that reflects current traffic conditions.

Next, the traffic demand assignment was performed on the 2023 road network and calibrated by the real-world traffic conditions and congestion effects. The OD matrix of 2030 was then estimated using socio-economic growth factors, a trip generation model, a trip distribution model, and a mode choice model to ensure consistency with observed data.

For future demand projections, the calibrated OD matrix was used to forecast traffic volumes for 2030 under different toll rate scenarios. These scenarios were designed to assess how various pricing strategies influence traffic distribution, congestion levels, and level of service (LOS) on the highway.

By integrating survey data, traffic assignment models, and demand forecasting techniques, this study provides a data-driven analysis to evaluate the long-term effects of different toll scenarios on the Ho Chi Minh – Trung Luong – My Thuan Highway.

3.1 Study Area Description

The Ho Chi Minh City - Trung Luong - My Thuan Highway is a 96 km highway that serves as a critical transportation link connecting Ho Chi Minh City, Long An, Tien Giang, and the Mekong Delta region. The Ho Chi Minh City - Trung Luong - My Thuan is a 96 km highway, which is a vital traffic route, connecting the Mekong Delta with Ho Chi Minh City, the Southeast provinces, Long Thanh International Airport and key seaports in the South of Vietnam. This highway not only helps to reduce traffic congestion but also contributes to promoting the socio-economic development of the Southern key economic region and the Mekong Delta region. With the length of 96 km, featuring four lanes (two lanes in each direction) and two emergency lanes, and a design speed of 120 km/h, the highway is divided into two main sections:

- Section 1: Ho Chi Minh - Trung Luong (44 km), opened in 2010, initially operated under a toll collection system but was suspended in 2019, leading to a 131% increase in traffic volume and significant congestion issues.
- Section 2: Trung Luong - My Thuan (52 km), opened in 2022, currently operates under a toll system ranging from 103,000 VND (4.1 USD) to 335,000 VND (13.4 USD) depending on vehicle type and travel distance.

Parallel to the highway is the old National Highway No.1A (NH1A), with 4 lanes and no toll booths. However, due to the high demand for travel and freight transport on this corridor, the exploitation speed of National Highway No.1A is relatively slow.

Given its four-lane configuration (two lanes per direction) and heavy traffic demand, the highway has faced severe congestion, particularly during peak hours and holiday periods. To address these challenges, this study evaluates different toll pricing scenarios to determine their impact on traffic flow, congestion levels, and road efficiency.

Figure 2. Study area

3.2 Data Collection and Processing

Traffic Data: Traffic volume was counted at 14 locations including 2 locations on 2 sections of the highway (VT5 and VT11) and 12 locations on the connecting roads to the highway. The purpose of counting traffic volume is to be able to be used for reliable calibration of the traffic model. This data includes:

- Hourly traffic volumes on the highway and major alternative routes.
- Vehicle classification
- Average speeds and densities along the highway.
- The data was cleaned to remove outliers, impute missing values, and aggregated to appropriate time intervals for 1 hour for model calibration.

Socioeconomic Data: Data on population density, income levels, vehicle ownership rates, and employment patterns were obtained from the General Statistics Office of Vietnam (GSO) and relevant local government agencies. This data was used to estimate the value of time (VOT) for different traveler segments. Methods for estimating VOT include stated preference surveys and revealed preference analysis (Hensher and Stopher, 2021).

Network Data: A detailed representation of the transportation network, including the highway, alternative routes, and key intersections, was developed using GIS software. This network data includes information on road lengths, lane configurations, speed limits, and intersection characteristics.

Toll Pricing Data: Existing toll rates from the Trung Luong - My Thuan section were used as a reference. The toll rates were incorporated into a generalized cost function to analyze how they influence route choice and traffic distribution.

3.3. Traffic Simulation Model and Forecasting

A macroscopic traffic simulation model was developed using PTV VISUM, a used tool for traffic flow modeling, demand forecasting, and toll policy evaluation.

Model calibration and validation: The model was calibrated using real-world traffic data collected from 14 survey locations along the highway. 28 data points (representing different vehicle types and locations) were used for validation to ensure that simulated traffic volumes closely matched observed data. The validation process followed Wardrop's First Principle (User Equilibrium), ensuring that travel times along different routes reflect realistic driver behavior.

Traffic demand forecast: Traffic demand forecasting for the highway is conducted using the traditional Four-Step Model (FSM) with the support of PTV VISUM so. The analysis includes two forecast period 2030, under different toll pricing scenarios, evaluating traffic volumes and level of service (LOS) across the network. The FSM framework consists of trip generation, trip distribution, mode choice, and traffic assignment, ensuring a comprehensive estimation of future demand patterns (Ortúzar and Willumsen, 2011). This approach is widely applied in toll road planning and congestion management to assess the potential impacts of pricing policies on traffic flow and network performance (Tsekeris and Tsekeris, 2011).

4. RESULTS AND DISCUSSIONS

4.1. Traffic survey results

Traffic surveys were conducted at survey locations shown in Figure 1.1. These survey locations include locations on the highway, NH1 parallel to the highway and some national highways connecting to the highway. The traffic survey at these locations aims to assess traffic volume and calibrate the current traffic simulation model. There are counting locations, in which VT5 is located on the Ho Chi Minh - Trung Luong Expressway, while VT11 is on the Trung Luong - My Thuan Expressway. The remaining locations are situated on roads that connect to the expressway network.

Figure 3. Traffic counting locations

Figure 4. Traffic Data Collection Using Camera-Based Monitoring

The traffic situation was captured by camera then manually counted on computers by surveyors team. The vehicle classification system used in this study categorizes vehicles into five toll groups (Types 1 to 5) based on their characteristics, including size, weight, and function. This classification determines toll rates and aligns with the national tolling framework to ensure fair pricing for different vehicle types. The grouping is as follows:

- Type 1: Includes passenger cars with up to 9 seats and light trucks with a gross weight of under 1.5 tons. These vehicles are subject to the lowest toll rates due to their small size and minimal road wear impact.
- Type 2: Consists of buses with 10 to 30 seats and medium-sized trucks (1.5 - 3 tons). These vehicles are larger than Type 1 but still fall within moderate tolling categories as they contribute slightly more to road maintenance costs.
- Type 3: Covers buses with over 30 seats and larger trucks (3 - 10 tons). These vehicles are heavier and occupy more road space, leading to higher toll charges to reflect their greater infrastructure usage.
- Type 4: Includes heavy trucks (10 - 18 tons) and semi-trailers with one container. These vehicles place significant stress on the road network, justifying higher toll rates to account for maintenance and wear.
- Type 5: Comprises the heaviest vehicles, such as trucks exceeding 18 tons and semi-trailers carrying two containers. These vehicles have the highest toll rates, as they contribute the most to road deterioration and require greater infrastructure investment.

Table 1. Vehicle classification in five toll groups

Vehicle Type/Toll groups	Veh. Type 1	Veh. Type 2	Veh. Type 3	Veh. Type 4	Veh. Type 5
Car (under 12 seats)	X				
Small Coach/Bus (from 12 - 25 seats)		X			
Medium Coach/Bus (from 25 to 30 seats)		X			
Large Coach/Bus (from 31 seats and above)			X		
Small truck (<2T)	X				
Small truck (2-4T)		X			
Medium truck (4-10T)			X		
Medium truck (10-18T)				X	
Large truck (>18)					X
Trailer (20ft)				X	
Trailer (40ft)					X

Vehicles are then converted to Passenger Car Units according to the ratio proposed in Vietnam's road design standards. The traffic volume counting at 14 locations results are as follows:

Figure 5. Total traffic volume in PCU at 14 survey locations

According to survey data at 2 points on the highway, the total number of vehicles per day is about more than 56,000 vehicles, of which cars account for 61.3%, passenger cars account for 15.2% and the rest are trucks and trailers. Traffic volume during peak hour (7-8 am) accounts for about 6.85% of the total daily traffic volume for passenger transport and about 3.88% for freight transport.

4.2. O-D interview survey

The O-D (origin-destination) interview survey was conducted in parallel with the vehicle counting survey. The objectives of the O-D interview survey at traffic survey points are to capture information about trips such as origin, destination, mode of transport used, trip frequency, route choice, travel time, travel cost, and average loading factor.

After the survey, the OD matrix is built for each type of vehicle according to the classification in Table 2.

Table 2. Some statistics of interview survey 2023

Vehicle	Average Capacity Utilization Factor (passenger/vehicle)	Average travel time (minutes)
Car	1.78	263.39
Small coach (<25 seats)	12.27	235.6
Medium coach (< 30 seat)	22.23	235.26
Large coach (> 30 seat)	32.71	245.10
Small truck (<10 T)	5.36 T	231.28
Medium truck (10 – 18 T)	8.48 T	228.29
Large truck (> 18 T)	18.85 T	219.51

4.3. Forecasting passenger and freight transport growth rate

The demand for passenger and freight transport by provinces in the study area in 2023 is summarized in the table below. In terms of passenger transport volume, Tra Vinh, Tien Giang, Vinh Long, Dong Thap and Long An are provinces with low travel demand. For freight transport, Ho Chi Minh City, Binh Duong, Dong Nai and Tay Ninh are provinces with high freight transport demand, due to the distribution of many industrial parks, logistics hubs in these provinces.

Demand growth is strongly correlated with provincial economic growth (GRDP). Using statistical data on passenger and freight transport by road from 2000 to 2021 and GRDP by province from 2010 to 2021. Based on these correlations, the average annual growth coefficient was derived and applied to forecast passenger and freight transport demand for each province within the study area.

Table 3. Volume of Passenger and Freight transport in the study area

No.	Province	Volume		No.	Province	Volume	
		Passenger (Mil..trip)	Freight (Th..ton)			Passenger (Million.trip)	Freight (th.ton)
1	Tay Ninh	24,86	14.563,93	10	Vinh Long	23,28	2.025,00
2	Binh Duong	35,45	63.039,36	11	Dong Thap	23,37	2.817,00
3	Dong Nai	91,44	40.277,04	12	An Giang	92,00	8.246,50
4	Vung Tau	49,56	8.183,08	13	Kien Giang	35,24	2.110,00
5	HCMC	1.006,41	109.385,51	14	Can Tho	28,71	2.221,80
6	Long An	21,13	6.054,39	15	Hau Giang	67,59	2.237,56
7	Tien Giang	14,78	2.445,82	16	Soc Trang	45,30	4.977,10
8	Ben Tre	40,50	3.473,00	17	Bac Lieu	93,23	2.873,46
9	Tra Vinh	9,60	2.774,50	18	Ca Mau	41,11	720,39

Source: National Statistics, 2023

Table 4. Average growth rate of passenger and freight transport

No.	Province	Average growth rate		No.	Province	Average growth rate	
		Psg. Transp.	Freight Transp.			Psg. Transp.	Freight Transp.
1	Tay Ninh	8.64%	10.86%	10	Vinh Long	4.01%	14.38%
2	Binh Duong	16.06%	8.13%	11	Dong Thap	5.87%	8.63%
3	Dong Nai	10.17%	19.61%	12	An Giang	11.71%	11.45%
4	Vung Tau	7.86%	9.12%	13	Kien Giang	8.54%	15.38%
5	HCMC	12.05%	8.05%	14	Can Tho	3.20%	10.88%
6	Long An	8.26%	11.47%	15	Hau Giang	7.14%	2.95%
7	Tien Giang	1.92%	5.44%	16	Soc Trang	7.74%	7.49%
8	Ben Tre	8.67%	6.01%	17	Bac Lieu	9.58%	11.81%
9	Tra Vinh	2.08%	9.91%	18	Ca Mau	4.66%	10.98%

Source: Study team

Statistical analysis indicates that the annual growth rate of freight transport is 10.14%, while passenger transport grows at 7.68% per year. The higher growth rate of freight transport compared to passenger transport reflects the traffic characteristics of the study area and aligns with the observed traffic volume trends on the Trung Luong - My Thuan Highway.

4.4. Traffic Simulation in VISUM software

In this study, the traffic model was built based on a 4-step traffic modeling and use VISUM software for simulation. This is a commercial macroscopic traffic simulation and transportation planning software developed by PTV group. VISUM represents transport networks as nodes (intersections) and links (road segments) and incorporates trip generation, distribution, mode choice, and route assignment models to simulate travel demand at urban and regional levels.

The software applies user equilibrium (UE) and stochastic user equilibrium (SUE) assignments to model driver route choices based on congestion and travel costs. It also integrates various traffic flow models, such as the Bureau of Public Roads (BPR) function, to estimate travel times under different demand scenarios. VISUM is commonly used in toll road analysis, public transport planning, and infrastructure assessments. By incorporating real-world traffic data and socioeconomic factors, it supports the evaluation of transportation policies and pricing strategies while allowing for demand forecasting and network optimization.

4.4.1. Zoning

The study area covers the entire Mekong Delta region, including 18 provinces and other areas, divided into 185 districts and key cargo ports, which are the areas generating and attracting traffic demand in the traffic model (see Figure 6 showing the traffic zoning (attracting/generating) in the study area). Current demand in the region and surrounding areas includes intra-regional and inter-regional demand, as shown on the map in Figure 4 below.

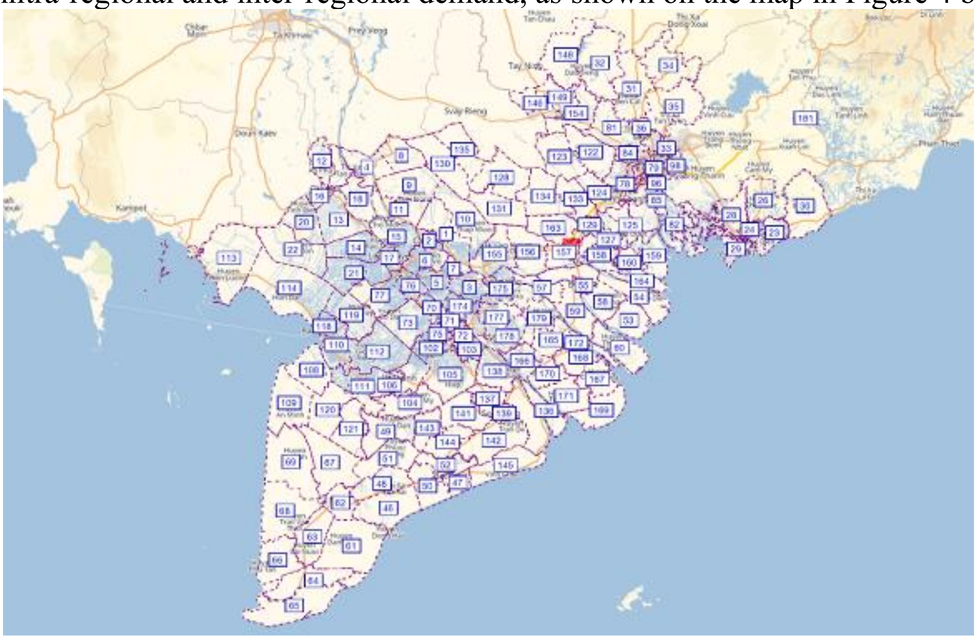

Figure 6. Traffic zoning of the study area

4.4.2. Networking

The road network in the study area is simulated up to the provincial road level, meaning that only highways, national highways, provincial roads, and major arterial roads are represented in the model. Smaller roads, including rural roads and internal roads, are excluded from the simulation. The classification of roads in the model ensures a focus on primary routes that significantly influence regional traffic flow and connectivity.

In the simulation, existing roads are represented in blue, while planned roads—including those scheduled for expansion or new construction during the 2024–2030 period are marked in orange. The road network attributes include the number of lanes, road capacity, maximum and minimum speed limits, traffic flow direction, allowed vehicle types, and toll rates (if applicable). These attributes play a crucial role in determining network efficiency, congestion levels, and the feasibility of toll pricing strategies within the study area.

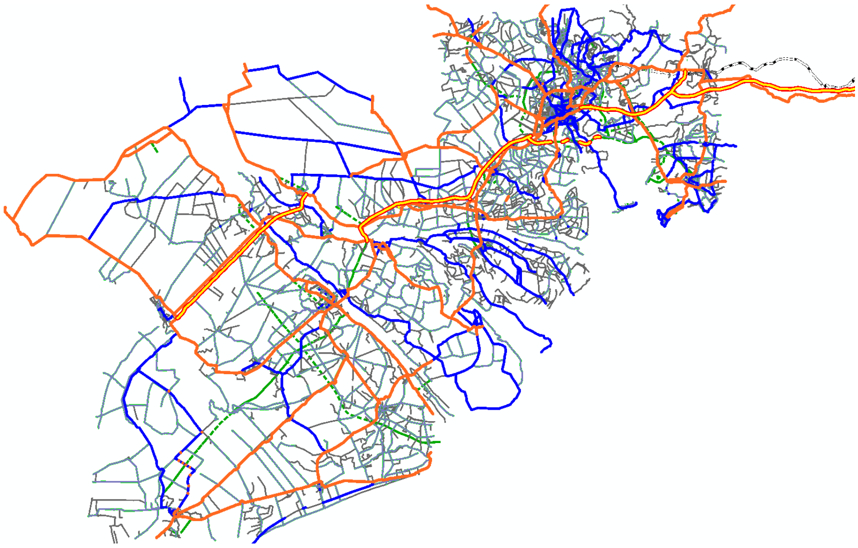

Figure 7. Current traffic network in 2023 and planning in 2030

4.4.3. Toll collection situation

In Vietnam, there are currently two toll collection methods implemented on highways: open tolling (per-entry fee collection at toll stations) and closed tolling (distance-based charging). Vehicles are categorized into five classes based on size and type, with toll rates varying accordingly. Toll rates significantly influence both route choice and mode choice, impacting overall traffic distribution and demand.

Under government regulations, toll rates are subject to a maximum limit and can be increased by up to 10% every three years, as permitted for highway investors. The maximum toll rates for each collection method are:

- Open tolling (per-entry toll collection at toll stations): For vehicles of type 1 (passenger cars), the toll is capped at 2.1 USD per trip, while for type 5 (trailers), it is capped at 8.00 USD per trip.
- Closed tolling (distance-based collection): The maximum allowable toll is 0.08 USD/km for type 1 and 0.5 USD/km for vehicle of type 5.

Additionally, for the 2030 demand forecast, the model incorporates newly expanded and upgraded road sections scheduled for completion in 2030. Future highway projects will also be tolled in accordance with state regulations, ensuring consistency in traffic demand estimation and infrastructure planning.

4.4.4. Time value

The time value for vehicle passengers in this study is estimated based on personal monthly income by trip mode, derived from the database in 2018 as part of the Ho Chi Minh City traffic modeling project. The 2023-time value is then adjusted using the RGDP deflator to account for economic growth and inflation. For freight transport, the average time value per vehicle incorporates the time cost of loading cargo, while also considering the empty truck ratio, ensuring a more accurate representation of transport efficiency and cost implications.

Table 5. Time value estimation of different vehicles

Vehicle	Value of Time (USD/hour/passenger)		Ave. vehicle occupancy (2016)	Gross Time value of cargo (USD/hour/vehicle)	Value of Time (USD/hour/vehicle) 2023	Value of Time (USD/hour/vehicle) 2030
	2018	2023				
Bicycle	0.72	0.74	1.1	-	0.80	1.4
Motorcycle	1.68	1.82	1.5	-	3.06	5.1
Car	3.98	4.52	1.8	-	13.11	22.7
Small Coach	1.26	1.38	12.3	-	23.18	37
Medium coach			22.2	-	31.33	54
Large coach			32.7	-	44.99	73
Small truck	2.57	2.82	1.8	2.2	7.28	11.3
Medium truck			1.8	7.5	12.58	20.4
Large truck/trailer			1.6	10.7	15.21	22.5

Source: Estimation of study team

4.4.5. Vehicle Operating Cost

The Vehicle Operating Cost (VOC) prepared for the Mekong Delta road network is estimated as an aggregate of detailed cost components, following the same vehicle classification as the survey. The VOC values, originally developed for the Mekong Delta road network, have been adjusted to 2018 prices using the RGDP deflator to ensure consistency in cost estimation.

Table 6. Vehicle Operating Cost (VOC) in 2023

	Motorcycle	Passenger car	Small Coach	Medium Coach	Large Coach	Small truck	Medium truck	Large truck / Trailer
VOC (USD/1,000 km)	630	231	472	524	613	458	597	882

Source: Estimation of study team based on study of JICA

4.4.6. Traffic assignment model parameters

Based on the survey interview data, the parameters of the trip distribution model and mode choice model have been determined and are presented in Table 6 below.

Table 7. Model Parameters for Passenger and Freight Transport

Model	Model Parameters
Trip Distribution model	GCij = 0.26*Time + 2.82
Mode choice model	Car = -0.18528*Time - 0.05961*Distance - 6.783372
	Small Coach = -0.19752*Time - 0.06125*Distance - 6.259564
	Medium Coach = -0.18121*Time - 0.06024*Distance - 7.209865
	Large Coach = -0.17710*Time - 0.05734*Distance - 6.880687
Trip distribution	Uij = 0.28*Distance + 3.10
Mode choice model	Small Truck = -0.2979*Time - 0.0639*Distance - 1.707134
	Medium Truck = -0.5258*Time - 0.0962*Distance - 1.998282
	Large Truck/Trailer = -0.0701*Time - 0.0317*Distance - 1.415986

4.4.7. Model calibration

Based on traffic count survey data and related datasets, the model calibration process was conducted to ensure accuracy in traffic flow representation. The model calibration process was first conducted for each vehicle type individually and then refined for all vehicle types combined. The calibration was based on traffic count data collected at 14 survey locations, with two directional movements at each location, resulting in a total of 28 comparison points between simulated traffic volumes and observed traffic counts. The R^2 coefficient for each vehicle type ranges from 0.45 to 0.65, indicating a moderate correlation between the simulated and observed traffic volumes. The calibration results are presented in the figures below, illustrating the alignment between observed and simulated traffic volumes.

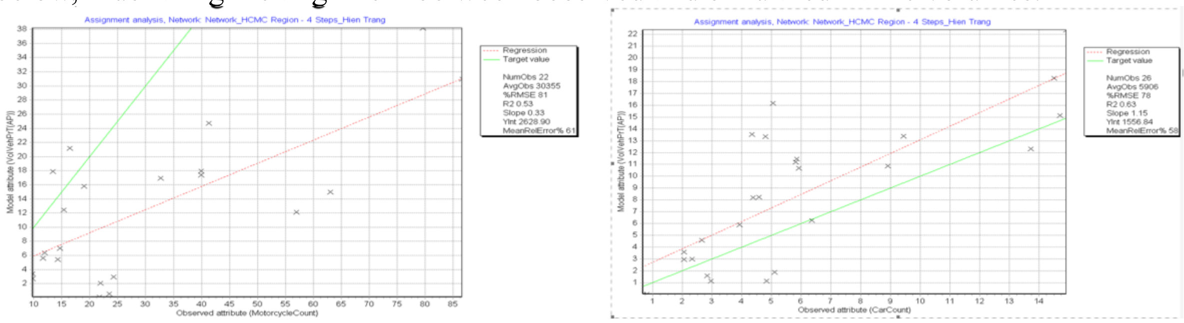

Figure 8. Traffic calibration results for motorcyle (left) and car.

4.5. Traffic simulation results in 2023

The following section presents the traffic simulation results for the baseline year 2023. The analysis includes daily traffic distribution and peak-hour traffic conditions, providing insights into overall network performance, congestion levels, and capacity utilization under existing conditions.

In 2023, traffic congestion was observed in Ho Chi Minh City, particularly at gateway areas leading to the city center and within the central districts. For the study corridor, the level of congestion and traffic flow quality varied across different segments. On the Ho Chi Minh City - Trung Luong - My Thuan Highway, the average Level of Service (LOS) ranged from LOS B to LOS C. However, statistical data indicate that congestion significantly increases during periods of surging travel demand, such as public holidays, the Lunar New Year (Vietnamese Tet), peak tourism seasons, or in the event of unexpected traffic incidents.

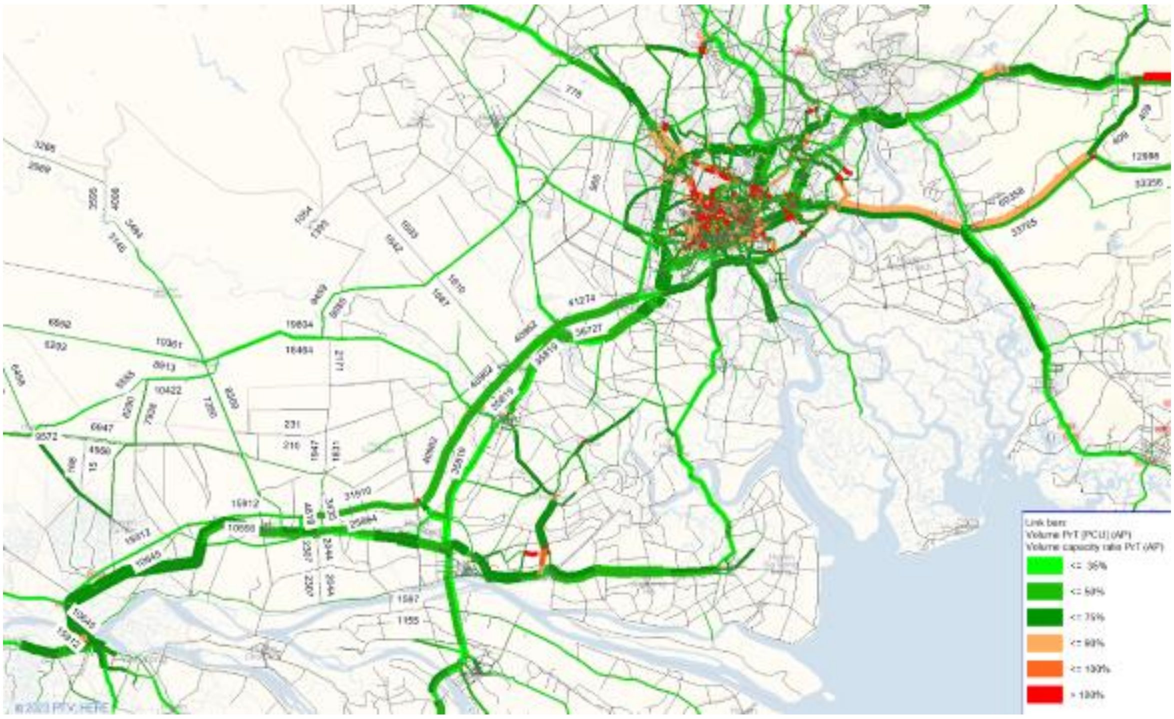

Figure 9. Daily Traffic Simulation Model for the Study Area

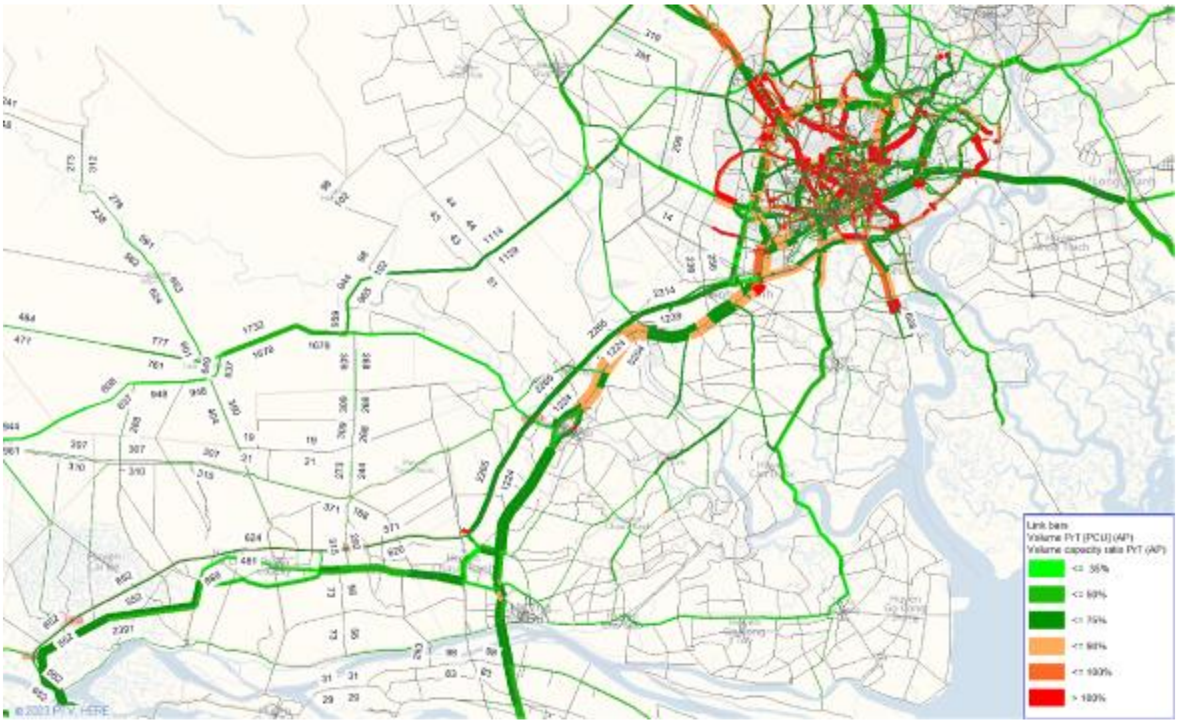

Figure 10. Peak hour Traffic Simulation Model for the Study Area

Table 8. Evaluation of traffic situation on some road segments in 2023

Road	Direction	Daily Traffic simulation			Peak-hour traffic simulation		
		PCU/day	V/C	LOS	PCU/hour	V/C	LOS
NH1A (HCMC)	Can Tho	29195	0.34	B	1724	0.36	B
	HCMC	30852	0.36	B	1582	0.33	B
Ringroad HCMC	Can Tho	41277	0.48	B	2056	0.43	B
	HCMC	36727	0.43	B	2411	0.50	C
S1. Highway Ho Chi Minh – T. Luong	Can Tho	43675	0.51	C	2197	0.46	B
	HCMC	41722	0.48	B	2079	0.43	B
S2. Highway Trung Luong – M. Thuan	Can Tho	11059	0.19	A	521	0.16	A
	HCMC	10881	0.19	A	515	0.16	A

The results indicate that Highway Section 1 (HCMC – Trung Luong) currently experiences very high traffic volumes, exceeding 80,000 PCU/day, due to the temporary suspension of toll collection. In contrast, Section 2 (Trung Luong – Can Tho), where tolls are still in place, has a significantly lower traffic volume of approximately 20,000 PCU/day. The Level of Service (LOS) on Section 1 is at LOS B, whereas on Section 2, it remains at LOS A, indicating excellent traffic conditions.

A tolling scenario was simulated for Section 1 (Ho Chi Minh – Trung Luong highway), applying a toll rate equivalent to that of Section 2. The results show a notable shift in heavy vehicle traffic (categories 3, 4, and 5), with these vehicles diverting to the toll-free National Highway 1 (NH1) instead. The average traffic volume reduction across the entire corridor was approximately 27.5% in PCU when the section Ho Chi Minh City – Trung Luong resumed toll collection in 2023.

Overall, while NH1 and the ring road remain functional, congestion issues may arise in peak periods. The Ho Chi Minh – Trung Luong Expressway is nearing its capacity limits, particularly in the Can Tho direction, necessitating future expansion planning. Meanwhile, the Trung Luong – My Thuan Expressway operates efficiently with room for future growth, requiring no immediate upgrades. Strategic planning should focus on traffic monitoring, capacity expansion in high-demand corridors, and congestion management strategies to ensure an efficient expressway network.

The simulation results indicate that toll charges have a significant impact on traffic volume, particularly for heavy vehicles. Medium and heavy trucks (Vehicle Types 3 and 5) experience the largest reductions, with declines of up to 50% in Segments 1 and 2. This suggests that freight operators are highly sensitive to toll costs and are likely to divert to alternative toll-free routes, such as National Highway 1 (NH1). In contrast, passenger cars (Type 1) and light commercial vehicles (Type 2) show moderate reductions, with the highest drop in Segment 1 (-14.62%), indicating that short-distance travelers are somewhat affected by tolls but less likely to reroute than freight vehicles.

Traffic reduction also varies across segments. Segments 1 (Cho Dem – Ben Luc) and 2 (Ben Luc – Than Cuu Nghia) on the Ho Chi Minh – Trung Luong highway show the highest total reductions, exceeding 22%, reinforcing that these sections serve a high proportion of toll-sensitive vehicles. Meanwhile, Segment 3 (on Trung Luong – My Thuan highway) shows minimal reduction (-0.23%), suggesting that some corridors are essential for mobility regardless of toll pricing.

Interestingly, in Segments 5 and 6, large coach and some heavy vehicles show an increase in volume, implying that toll pricing does not uniformly discourage all vehicle types. This may be due to expressway reliability, lack of viable alternative routes, or operational constraints for certain transport modes.

Table 9. Traffic volume decreasing with toll applied in HCM-TL highway

Highway Segment	Veh. Type 1	Veh. Type 2	Veh.Type 3	Veh. Type 4	Veh. Type 5	Total volume
Seg.1 Cho Dem – Ben Luc						
Toll free	30868	4950	8713	1594	2074	48199
Toll charge	26354	3500	4547	1388	1165	36954
Decreasing rate	-14.62%	-29.29%	-47.81%	-12.92%	-43.83%	-23.33%
Seg.2 Ben Luc – Than Cuu Nghia						
Toll free	29782	5612	9239	1567	2039	48239
Toll charge	26806	3560	4625	1412	1185	37588
Decreasing rate	-9.99%	-36.56%	-49.94%	-9.89%	-41.88%	-22.08%
Seg.4 Than Cuu Nghia – Cai Lay						
Toll free	14156	2177	2899	277	309	19819
Toll charge	14069	2123	2896	266	418	19773
Decreasing rate	-0.61%	-2.48%	-0.10%	-3.97%	35.28%	-0.23%
Seg.5 Cai Lay – Cai Be						
Toll free	12254	1662	1996	152	169	16232
Toll charge	11330	1425	1395	212	283	14644
Decreasing rate	-7.54%	-14.26%	-30.11%	39.47%	67.46%	-9.78%
Seg.6. Cai Be – QL30						
Toll free	11981	1508	1847	148	165	15648
Toll charge	10918	1269	1478	212	123	14000
Decreasing rate	-8.87%	-15.85%	-19.98%	43.24%	-25.45%	-10.53%

The findings suggest that toll pricing should be carefully designed to prevent excessive diversion of freight traffic to local roads. Strategies such as time-based toll discounts for trucks, dynamic pricing, and targeted incentives for expressway use could help balance demand. Additionally, segments with minimal toll impact may benefit from alternative revenue mechanisms, such as public-private partnerships for infrastructure funding.

4.6. Traffic Demand Forecasting in 2030

Following the calibration and validation of the 2023 traffic network, a macroscopic traffic demand forecast for 2030 was conducted using PTV VISUM. This simulation aims to assess future travel demand, network performance, and the impact of toll pricing policies on the Ho Chi Minh City – Trung Luong – My Thuan Highway and the surrounding road network. The forecasting methodology integrates socioeconomic growth factors, planned infrastructure expansions, and toll scenarios, ensuring a data-driven and comprehensive evaluation of future traffic conditions.

By 2030, with the completion of planned transportation infrastructure and the continued growth in travel demand, significant changes in regional traffic patterns are expected. In particular, in the Ho Chi Minh City metropolitan area, the development of ring roads will help divert traffic flow, thereby reducing congestion in the city center and improving overall network efficiency.

Due to strict toll regulations imposed by the Vietnamese government, there is limited variation between the toll pricing scenarios. The scenarios considered in this study are as follows:

- Scenario 1: Toll rates equivalent to those applied on the Trung Luong - My Thuan Highway.
- Scenario 2: Toll rates matching those of the North-South Highway (CT01).
- Scenario 3: Toll rates set at the level permitted by the Ministry of Transport.

Among these, Scenario 3 represents the highest toll rate.

Table 10. Toll rates scenarios of HCM-TL highway in 2030

Scenario	Veh. Type 1	Veh. Type 2	Veh.Type 3	Veh. Type 4	Veh. Type 5
Scenario 1	0.08	0.12	0.15	0.24	0.34
Scenario 2	0.08	0.11	0.14	0.23	0.32
Scenario 3	0.10	0.15	0.18	0.27	0.36

The forecasted daily traffic volumes for different segments of the highway under three toll pricing scenarios in 2030 reveals several key trends. The analysis highlights variations in traffic distribution across segments, the impact of toll pricing on travel demand, and changes in route choice behavior due to toll implementation.

The simulation results show that Segments 1, 2, and 3 (on the Ho Chi Minh – Trung Luong highway) experience the highest traffic volumes, with daily traffic exceeding 70,000 vehicles per day across all scenarios. These segments are critical corridors where congestion levels may require future capacity expansions. In contrast, Segments 4, 5, and 6 show significantly lower traffic volumes, with Segment 6 recording the lowest at around 30,000 vehicles per day. This suggests that traffic demand gradually declines as vehicles move further away from major urban centers.

Table 11. Traffic volume forecasted in 2030 at some road segments (PCU/day)

Road	Segment	Toll Sce. 1	Toll Sce.2	Toll Sce.3
Section 1: HCMC – Trung Luong	Seg 1. Cho Dem – Ben Luc	118697	122564	112634
	Seg 2. Ben Luc – Tan An	114994	118908	110496
	Seg. Tan An – Than Cuu Nghia	106995	111001	102612
Section 2: Trung Luong – My Thuan	Seg. 4 Than Cuu Nghia – Cai Lay	80786	83709	73964
	Seg 5. Cai Lay – Cai Be	55764	57936	52847
	Seg. Cai Be – QL 30	55040	56948	52156
NH1A	Tan Tao – Cho Dem	81287	83455	80648
Ringroad HCMC	Binh Thuan – Cho Dem	97115	100868	96207
Ringroad Long An prov.	RR No.3 – Long An	37340	38992	36823
Highway	Ben Luc – Long Thanh	47130	48524	46234

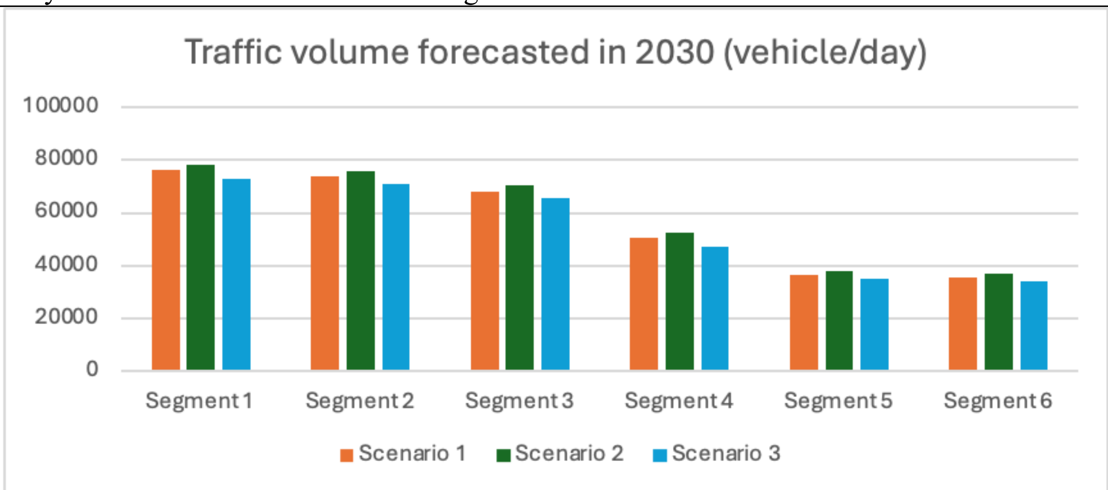

Figure 11. Traffic volume forecasted in 2030 at six segments

The results indicate that differences in traffic volume between toll scenarios are relatively small, suggesting that travel demand is not highly sensitive to toll price variations within the tested range. Scenario 1, which applies the lowest toll rates, generally results in the highest traffic volumes. Conversely, Scenario 3, which imposes the highest toll charges, leads to a slight reduction in traffic across all segments. The reduction is particularly noticeable in Segments 4, 5, and 6, indicating that higher toll rates lead to greater vehicle diversion to alternative routes, particularly in lower-demand areas where highway travel may not be a necessity.

The similarity in traffic volumes between Scenarios 1 and 2 suggests that moderate toll adjustments do not significantly influence route choice. However, Scenario 3, with the highest tolls, results in a more pronounced reduction in downstream traffic flow, indicating that some long-distance trips may be rerouted to avoid toll charges. This suggests that toll pricing strategies may be more effective in influencing route choice in areas with alternative toll-free options, whereas in high-demand corridors, users are less responsive to pricing changes due to limited alternative routes.

If toll collection is implemented on the Ho Chi Minh City – Trung Luong Highway in 2030, the forecast suggests a traffic volume reduction of approximately 10% compared to 2023. Meanwhile, traffic volume on the Trung Luong – My Thuan Highway is projected to increase. This shift in traffic demand can be attributed to two primary factors. First, economic and social development in the region is driving overall growth in travel demand, particularly for freight and passenger transport. Second, the introduction of tolls on the Ho Chi Minh City – Trung Luong section may encourage greater acceptance of toll payments for the Trung Luong – My Thuan section, leading to a more consistent travel pattern across both segments. This suggests that the presence of tolls may standardize user behavior, reducing irregular traffic fluctuations between highway sections.

The results indicate that while toll pricing does influence traffic volume, the effect remains moderate within the tested scenarios. Higher toll rates tend to reduce overall traffic, particularly in lower-demand segments, as users shift to alternative routes. However, core segments such as Segments 1, 2, and 3 continue to experience high traffic volumes under all scenarios, reinforcing the need for capacity expansion and congestion management strategies in these critical corridors. Future policies should consider dynamic toll pricing, infrastructure improvements, and multimodal transport integration to optimize network performance and accommodate future demand growth.

4.7. Level of service and lane capacity required

With the increasing travel demand, highway expansion is essential to maintain the level of service (LOS) and ensure traffic flow remains within the designed speed limits. In this study, we analyze the LOS under the existing lane configuration and propose lane expansion solutions to ensure that vehicle speeds remain within the intended design parameters.

Based on the forecasted traffic volume, the required number of lanes in long term vision is determined. The lane calculation follows the standards specified in Vietnam standard design and Highway Capacity Manual (USA) 1994. The formula used is as follows:

$$N_{lx} = N_{gcđ} / Z.N_{th}$$

Where:

- N_{lx} *Required number of lanes*
- $N_{gcđ}$ *: Peak hour traffic volume (PCU/hour)*
- *Z: Capacity utilization factor (0.7 for urban roads and 0.55 for highways -level B)*
- N_{th} *: Actual lane capacity, the capacity ranges from 1,500 to 2,000 PCU/hour/lane.*

Using the forecasted peak-hour traffic volume, the required number of lanes for the two scenarios is calculated and presented in Tables 12 below.

Table 12. Number of lane suggested in 2030 for HCM-TL-MT highway

Road/Segment	PCU	Nth	Z (level B)	No. of lane	No. of lane suggestion
NH1A/Tan Tao- Cho Dem	6400	1800	0.70	5.08	6
Ringroad/Binh Thuan – Cho Dem	7181	1800	0.70	5.70	6
Highway HCM - Trung Lương	6327	2000	0.55	5.75	6
Highway Trung Luong – My Thuan	4289	2000	0.55	3.90	4
Ringroad No.3 – Long An	5379	2000	0.55	4.89	6
Highway Ben Luc – Long Thanh	4766	2000	0.55	4.33	6

`The computed lane requirements range from 4.89 to 5.75 lanes, leading to the recommendation of six-lane configurations for most road segments. The Trung Luong – Can Tho Highway has a lower computed requirement of 3.90 lanes, supporting the proposal for a four-lane highway. Notably, the Ring Road 3 (Long An section) requires 4.89 lanes, justifying an initial six-lane configuration until 2040, with an expansion to eight lanes by after 2030 to accommodate future growth.

A comparison of lane requirements under different toll pricing scenarios reveals that Scenario 2 results in slightly higher demand, leading to a greater required number of lanes. However, despite fluctuations in projected traffic volumes, the recommended lane configurations remain unchanged. This suggests that while toll pricing influences route choice and traffic distribution, it does not significantly alter long-term infrastructure needs.

Based on forecasted traffic demand and lane capacity standards, the following infrastructure expansion plans are proposed. The Tan Tao – Cho Dem segment should be expanded to six lanes, which is expected to meet traffic demand until 2030. However, given its urban location, additional lanes should be considered to separate motorcycles and non-motorized vehicles, ensuring traffic safety and operational efficiency. Similarly, the Binh Thuan – Cho Dem connection requires eight lanes to accommodate demand through 2030. For the Ho Chi Minh City – Trung Luong – My Thuan Highway, a six- to eight-lane expansion is recommended to meet travel demand by 2030. Additionally, Ring Road 3 (Long An section) and the Ben Luc – Long Thanh Highway should be six lanes until 2030, with an expansion to eight lanes in long term vision.

To optimize network performance and manage congestion effectively, several policy measures should be considered. Dynamic toll pricing can be implemented to redistribute peak-hour demand, reducing the need for frequent infrastructure expansions. Additionally, strengthening multimodal transport integration, particularly between highways, rail, and inland waterways, could divert freight traffic and ease pressure on road networks. Dynamic lane management, such as reversible lanes or High-Occupancy Vehicle (HOV) lanes, should also be explored to enhance capacity utilization.

The proposed lane expansions align with projected traffic growth, ensuring an efficient and resilient highway network. However, proactive policy interventions, adaptive tolling strategies, and multimodal transport integration will be essential to sustain network efficiency beyond in long term vision.

5. CONCLUSION AND IMPLICATIONS

This study provides a comprehensive simulation-based analysis of traffic demand under various toll pricing scenarios for the Ho Chi Minh City – Trung Luong – My Thuan Highway. The findings highlight the significant impact of toll collection on travel behavior, the need for capacity expansion, and the importance of policy-driven congestion management strategies.

The study reveals that implementing toll collection on Section 1 (Ho Chi Minh – Trung Luong Highway) is expected to reduce traffic volume by approximately 10% compared to 2023. Notably, heavy vehicles (categories 3, 4, and 5) exhibit a strong tendency to shift to alternative toll-free routes, particularly National Highway 1 (NH1). In contrast, toll pricing has a moderate effect on passenger vehicles, as highway usage is primarily influenced by travel time savings rather than cost alone. By 2030, travel demand is projected to continue increasing due to regional economic growth, urbanization, and industrial expansion. The results indicate that key highway segments (Segments 1, 2, and 3) will maintain high traffic volumes, reinforcing the necessity for capacity expansion to prevent congestion. Additionally, Scenario 3 (highest toll rates) results in noticeable traffic reductions on less congested segments, highlighting that higher tolls have a greater influence in low-demand areas.

Regarding infrastructure development, the study determines that a six-lane expansion is required for most highway segments to maintain Level of Service (LOS B). Particularly, the Tân Tạo – Chợ Đệm and Bình Thuận – Chợ Đệm corridors should be expanded to eight lanes due to their urban location and mixed traffic conditions. Similarly, Ring Road 3 and the Ben Luc – Long Thanh Highway require an initial six-lane configuration, with expansion to eight lanes by 2050 to accommodate future growth.

To ensure efficient highway operations and accommodate future traffic demand, several policy interventions should be considered. First, dynamic toll pricing strategies should be implemented, including time-of-day tolling to encourage off-peak travel and discounted tolls for high-occupancy vehicles (HOVs) and freight operators to optimize highway usage. Second, multimodal transport integration is crucial in reducing congestion. Strengthening rail and inland waterway connectivity can divert freight traffic from highways, reducing road network pressure. Additionally, developing park-and-ride facilities along highway corridors will encourage mode shifts from private vehicles to public transit, further alleviating congestion. Third, capacity expansion and adaptive traffic management strategies should be prioritized. The expansion of lanes in high-demand corridors, particularly in urban highway segments near Ho Chi Minh City, is essential to accommodate growing demand. Moreover, adaptive lane management techniques, such as reversible lanes or dedicated truck lanes, could be implemented in congestion-prone areas to enhance traffic efficiency.

While this study provides some highlights, some limitations should be acknowledged. The simulation assumes static route choice preferences, whereas in reality, drivers may dynamically adjust their routes in response to congestion and toll pricing. Future studies should integrate dynamic route choice models to better reflect real-world conditions. Additionally, although the study evaluates the impact of different toll pricing scenarios, it does not fully explore the potential benefits of dynamic toll rates that adjust based on real-time traffic conditions. Implementing an optimized dynamic tolling system could enhance traffic flow and reduce congestion more effectively. However, developing such a model requires detailed empirical data on driver behavior and route choice elasticity. Future research should focus on conducting stated and revealed preference surveys to capture driver responses to dynamic pricing strategies and integrate these insights into simulation models. By incorporating behavioral analysis and real-time pricing mechanisms, future studies can refine tolling strategies to better balance traffic efficiency, user cost, and network sustainability.

The findings of this study could provide a data-driven foundation for designing toll policies, infrastructure investment plans, and congestion management strategies for Vietnam’s highway network. The results underscore the importance of balancing toll pricing, capacity expansion, and multimodal integration to ensure sustainable and efficient transportation development. Moving forward, future research should explore real-time pricing models, route choice behavior analysis, and smart mobility solutions to further enhance highway planning and operations.

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