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Traffic Engineering Management of the Canggu Highway Area as Tourism Access in Canggu Regency

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ABSTRACT

The Canggu Highway area is a major access route to the Canggu tourism destination in Badung Regency, Bali, where increasing tourism activities have intensified traffic movements and contributed to congestion, travel delays, and economic losses. This study aims to evaluate existing road network performance, develop traffic management and engineering strategies, estimate congestion costs, and assess potential performance improvements through simulation. The study covers nine road segments and three intersections in the Canggu Highway area. Traffic performance was analyzed using PTV Vissim microsimulation, with reference to the 2023 Indonesian Road Capacity Guidelines (PKJI), while congestion costs were estimated using the Tzedakis method, which considers travel time values and vehicle operating costs. Under existing weekday afternoon peak-hour conditions, the network exhibited an average delay of 134.18 seconds per vehicle and an average speed of 12.13 km/h. The proposed strategies comprise traffic signal coordination at the Kayu Tulang and Batu Bolong intersections, priority management at the Men Lari intersection, and improvements to pedestrian facilities. Simulation results indicate that these measures could reduce average delay to 99.37 seconds per vehicle and increase average network speed to 14.50 km/h. Estimated congestion costs could also decrease from IDR 3,965,472.11 per hour to IDR 2,636,383.25 per hour, representing a reduction of approximately 33.5%. These findings suggest that coordinated traffic control and improved pedestrian facilities have the potential to enhance modeled network performance and reduce congestion-related economic losses. The results can support local authorities in comparing and prioritizing traffic management interventions for the Canggu tourism area. However, field implementation and validation are required to confirm the effectiveness of the proposed strategies under actual traffic conditions. The findings also provide a basis for further evaluation of traffic management alternatives under different traffic demand conditions.

Keywords: *Traffic Engineering Management; PTV Vissim, Traffic Signal Coordination, Road Network Performance, Congestion Costs.*

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INTRODUCTION

Badung Regency is one of the principal tourism destinations in Bali Province, Indonesia, with tourism activities concentrated in areas such as Kuta, Nusa Dua, and Canggu. The rapid expansion of tourism-related businesses, accommodation facilities, restaurants, and recreational attractions has intensified travel demand and increased pressure on the existing transportation network. Canggu, in particular, has experienced substantial changes in land use and economic activity, transforming from an area traditionally associated with agriculture into a highly active tourism destination. Although this transformation generates economic opportunities, it also creates transportation challenges when infrastructure development and traffic management do not adequately accommodate increasing mobility demand.

Transportation congestion in tourism-intensive areas is influenced not only by traffic volume but also by road geometry, roadside activities, intersection operations, and the interaction between different road users. In their study of Jalan Raya Canggu, [1] identified traffic flow, road geometric conditions, and side friction as significant factors associated with congestion. Their findings indicate that traffic flow was the strongest of the three explanatory factors examined. This evidence suggests that congestion management in Canggu requires an integrated approach that addresses both traffic operations and the physical characteristics of the road corridor [1] . More broadly, [2] examined

transportation mode choice among domestic tourists in Bali and highlighted the relationship between tourism travel behavior, congestion, parking demand, and the need for adequate transportation infrastructure. Their findings also emphasize the importance of improving access to public transportation as part of sustainable tourism mobility strategies [1], [2].

The transportation problems in Canggu are particularly evident along Jalan Raya Canggu, a provincial road serving as an important access corridor to tourism destinations and connecting areas within Badung Regency and neighboring Tabanan Regency. The existing road network is affected by the interaction of traffic movements at intersections located relatively close to one another. Under such conditions, queues generated at one intersection may interfere with traffic discharge at adjacent intersections, particularly when traffic demand approaches or exceeds the effective operating capacity. The performance indicators reported in the initial assessment of the study area include a degree of saturation of 0.54 and an average speed of 14.64 km/h on the road section. At the Kayu Tulang intersection, the reported degree of saturation reaches 0.80, with a maximum queue length of 357.18 m and an average delay of 98.75 seconds per vehicle. These indicators demonstrate the need to examine the combined performance of road sections and intersections rather than treating each location as an independent traffic facility. The reported service levels should be interpreted according to the applicable assessment method and the specific performance indicators used.

Previous studies have demonstrated the potential of microscopic traffic simulation to evaluate intersection performance and compare alternative traffic management strategies. For example, investigated coordinated signal operations at adjacent intersections in Bandung using PTV Vissim. Their best-performing alternative reduced queue length by 14.9% and delay by 20.11%, illustrating the potential benefits of coordination where intersections are located within relatively short distances of one another [3] . Similarly, a study of the Paal 2 signalized intersection in Manado evaluated alternative signal timings and geometric adjustments using PTV Vissim. The best-performing scenario reduced queue length from 52.43 m to 29.99 m and improved the reported level of service from D to C [4] . These studies demonstrate that traffic signal optimization and intersection management can improve operational performance, although the effectiveness of each alternative depends on local traffic demand, road geometry, and control conditions [3], [4].

Traffic management interventions should also consider the needs of pedestrians, particularly in tourism areas where walking, vehicle access, roadside commercial activities, and crossing movements occur within the same corridor. In Canggu, inadequate pedestrian facilities may encourage pedestrians to use the road carriageway, increasing potential conflicts between pedestrians and motorized vehicles while also disrupting traffic flow. Research published in Case Studies on Transport Policy in 2024 developed an integrated VISSIM–Surrogate Safety Assessment Model (SSAM) approach to evaluate pedestrian–vehicle conflicts at urban crossings and examine the potential effects of mitigation measures [5]. This research supports the importance of considering pedestrian safety alongside vehicle delay and network efficiency. Accordingly, traffic management in Canggu should not be evaluated exclusively in terms of vehicle throughput; pedestrian accessibility and crossing safety should also be considered when selecting interventions [5].

The operational consequences of congestion extend beyond longer travel times. Reduced vehicle speeds and recurring delays can increase the time required to reach destinations, reduce productive time, and contribute to additional vehicle operating costs. These impacts are particularly relevant in tourism areas, where travel delays may affect visitors, workers, local residents, commercial deliveries, and service providers. Research on the Denpasar–Gilimanuk tourism corridor by [6] examined congestion-related travel delays, vehicle operating costs, and additional costs arising from inefficient traffic conditions. This demonstrates the relevance of evaluating congestion in economic as well as operational terms. Estimating congestion costs can therefore provide an additional basis for comparing traffic management alternatives, especially when public authorities must prioritize investments under limited budgets [6].

PTV Vissim provides a microscopic simulation environment for representing individual vehicle movements and assessing the effects of alternative traffic control and network configurations. When supported by appropriate field data, calibration, and validation, simulation can be used to compare existing conditions with proposed scenarios before physical implementation. Nevertheless, simulated improvements should not be interpreted as evidence that the same outcomes will necessarily occur after implementation. Actual performance may be influenced by driver compliance, changes in traffic demand, pedestrian behavior, roadside activities, and the operational characteristics of the implemented measures. Simulation findings should therefore be interpreted as estimates under specified modeling assumptions and verified through subsequent field evaluation.

Despite the availability of studies examining congestion factors in Canggu and the application of PTV Vissim to individual intersections, an integrated assessment of corridor-level traffic management alternatives, network performance, and congestion costs remains important for supporting decisions in tourism-intensive road

environments. Existing research on Canggu has primarily examined the factors associated with congestion, while other studies have evaluated signal coordination or intersection optimization in different urban settings. This study extends these lines of investigation by assessing the Canggu Highway network through a combined analysis of road sections, closely spaced intersections, traffic management alternatives, and congestion costs. The analysis is intended to provide a more comprehensive basis for comparing operational and economic outcomes across proposed interventions.

Accordingly, this study has three objectives: to evaluate the existing performance of the road network in the Canggu Highway area using PTV Vissim; to develop and assess traffic management alternatives, including intersection operation improvements, traffic signal coordination where applicable, and pedestrian facility improvements where represented in the model; and to estimate congestion costs under existing and proposed simulated conditions. The results are expected to assist local authorities in identifying critical locations, comparing the potential benefits of alternative interventions, and prioritizing traffic management measures for the Canggu tourism corridor. The proposed strategies should subsequently be assessed through field implementation and monitoring to determine their actual effectiveness.

METHODS

Research Design and Study Area

This study employed a quantitative descriptive-evaluative approach to assess traffic performance, pedestrian facility requirements, and congestion costs along the Canggu Highway corridor in Badung Regency, Bali, Indonesia. Quantitative data obtained from field surveys and secondary sources were analyzed using the Indonesian Road Capacity Guidelines [7] , pedestrian facility planning guidelines, and microscopic traffic simulation using PTV Vissim. The analysis compared existing traffic conditions with proposed traffic management scenarios to estimate their potential operational and economic effects. The simulation results represent modeled outcomes and are not interpreted as evidence of improvements already achieved through field implementation.

Research Location and Study Period

The study covered five road sections represented by nine road segments affected by the proposed traffic management measures. These segments comprised four segments along Jalan Raya Canggu, two segments along Jalan Raya Kayu Tulang, and one segment each along Jalan Raya Babakan Canggu, Jalan Raya Batu Bolong, and Jalan Padang Linjong.

Three intersections were included in the network model: Simpang Batu Bolong, a signalized intersection controlled by traffic signals, APILL, and Simpang Kayu Tulang and Simpang Men Lari, which were modeled as unsignalized intersections. Pedestrian demand and the availability of pedestrian facilities were also examined along all road sections.

Field data collection was conducted on a weekday in December 2025, during the morning and evening peak periods. The survey focused on weekday peak-hour conditions to capture traffic demand associated with commuting, tourism-related travel, commercial activities, and other daily mobility needs in the Canggu Highway area. The morning and evening peak periods were selected to assess traffic volume, vehicle movements, intersection performance, travel speed, queue length, and delay under relatively high traffic demand.

The collected data were used to establish the traffic demand and operational characteristics represented in the PTV Vissim base model. Observed traffic volumes, turning movements, travel speeds, queue lengths, and delays also served as reference data for model calibration and performance evaluation. As the survey covered a single weekday, the findings primarily represent traffic conditions during the observed peak periods and may not fully reflect variations across different weekdays, weekends, or seasonal tourism periods.

Field Surveys and Data Collection

Primary data were collected through direct field observations using the following survey procedures [7], [8]:

1. Traffic volume counts: Classified traffic counts were conducted to record the number of vehicles entering and leaving the study network by vehicle type and direction. Counts were aggregated into 15-minute intervals to identify temporal variations and peak-hour traffic demand.
2. Classified turning movement counts: Turning movements at each intersection were recorded separately for left-turning, though, and right-turning vehicles, together with the relevant vehicle classifications. These data were used to define turning movement proportions, traffic inputs, and intersection demand in the simulation model.
3. Moving Car Observation (MCO): Travel times and operating speeds were measured by traversing the selected road segments under prevailing traffic conditions. The observations were used to establish reference travel speeds and travel times for model calibration and performance evaluation.

4. Queue length and delay observations: Intersection queues and vehicle delays were recorded during the selected observation periods. The observations provided reference values for evaluating the accuracy of the simulated intersection operations.
5. Pedestrian surveys: Pedestrian volumes, walking movements, crossing locations, existing sidewalk conditions, effective sidewalk widths, obstructions, and available crossing facilities were documented. The data were used to identify deficiencies and determine the requirements for pedestrian infrastructure.
6. Vehicle operating cost data: Data on the components of vehicle operating costs (*Biaya Operasional Kendaraan, BOK*), including the relevant vehicle classes, fuel consumption, maintenance, tire consumption, and other applicable cost components, were obtained from [insert the actual data source and reference year]. These data were used to estimate the operating costs associated with the observed and simulated traffic conditions.
7. Secondary data included road network geometry, road classification, function and status, relevant spatial planning documents, regional gross domestic product (Gross Regional Domestic Product, GRDP/PDRB) data for Badung Regency, and vehicle operating cost parameters. These data were obtained from the relevant local government agencies and official technical publications, with the source and reference year recorded for each dataset.

Data Processing and Analysis

Road Network Performance Analysis

Road and intersection performance were assessed with reference to PKJI 2023, which provides procedures for evaluating road capacity and operational traffic performance [7] . The existing road geometry, traffic demand, vehicle composition, turning movements, and intersection control arrangements were represented in PTV Vissim.

The network performance indicators comprised average vehicle delay, average network speed, total distance traveled, and total travel time. Intersection performance was assessed using observed and simulated queue lengths, delays, and traffic discharge conditions. The Speed Performance Index (SPI) was calculated to compare the modeled average travel speed with the corresponding free-flow speed. The SPI was calculated as [9]:

$$\mathrm{SPI} = \frac{V_{avg}}{V_{ff}} \times 100\% \quad (1)$$

where V_{avg} is the average observed or simulated travel speed (km/h), and V_{ff} is the corresponding free-flow speed (km/h). A lower SPI indicates that the average travel speed is further below the free-flow reference speed. The index was interpreted together with delay, travel time, and other performance indicators rather than as a stand-alone measure of congestion [8].

Pedestrian Facility Analysis

Pedestrian facility requirements were assessed with reference to the Technical Guidelines for Pedestrian Facility Planning, established under Directorate General of Highways Circular No. 18/SE/Db/2023 and Technical Guideline No. 07/P/BM/2023 [9] . The assessment compared existing sidewalk and crossing conditions with the applicable technical requirements.

The assessment covered pedestrian demand, effective sidewalk width, roadside obstructions, continuity of pedestrian routes, accessibility, crossing demand, and the availability of suitable crossing facilities. Recommendations were developed for sidewalk provision or improvement, pedestrian crossing facilities, and supporting accessibility features according to the characteristics of each road segment.

An effective sidewalk width of 1.85 m was considered as a proposed design width in accordance with the applicable pedestrian facility planning guidance for the relevant design context. This value was not treated as a universal requirement for every road environment. The final width should be checked against the applicable provisions, pedestrian demand, roadside activities, accessibility requirements, and available right-of-way. The assessment distinguishes between the proposed design width and the effective width currently available to pedestrians.

Congestion Cost Analysis

Congestion costs were estimated by combining the economic value of additional travel time with the additional vehicle operating costs associated with congested conditions. The value of time (VOT) was estimated using the income approach, while vehicle operating costs were derived from the applicable vehicle operating cost data.

The analysis compared existing traffic conditions with the modeled proposed scenario. For each vehicle class, congestion-related costs were estimated from the difference between the congested condition and a defined reference condition. The reference condition was based on [insert the actual reference used in the study, such as free-flow travel time and the corresponding operating speed.

The total congestion cost was calculated as [10], [11]:

$$CC = \sum_{i-1}^{m} Q_i \left[\Delta T_i \times VOT_i + \left(VOC_{c,i} - VOC_{r,i}\right)\right] \quad (2)$$

Where:

CC = total congestion-related cost for the analysis period (IDR per hour, if hourly traffic volumes and hourly costs are used);
i = vehicle class;
m = number of vehicle classes;
Q_i = number of vehicles of class i during the analysis period;
ΔT_i = additional travel time per vehicle relative to the reference condition (hours per vehicle);
VOT_i = value of time for vehicle class i (IDR per vehicle-hour);
$VOC_{c,i}$ = vehicle operating cost per vehicle under congested conditions (IDR per vehicle);
$VOC_{r,i}$ = vehicle operating cost per vehicle under the reference condition (IDR per vehicle).

If travel time and operating costs are calculated per vehicle-kilometer or per kilometer, they must first be converted consistently to the same trip or analysis-period basis. The same vehicle classes, traffic demand, price year, and analysis period were applied to the existing and proposed scenarios to ensure a consistent comparison [10] .
The income-based value of time was estimated as:

$$VOT_i = \frac{I_i}{H_i} \quad (3)$$

where I_i is the representative income per person per month (IDR/month) and H_i is the corresponding number of productive or working hours per month (hours/month). If the adopted method uses vehicle occupancy or passenger-based travel time, the value of time must be adjusted accordingly and the adjustment documented. The income reference, working-hour assumption, vehicle occupancy, and applicable vehicle operating cost methodology should be stated explicitly in the final manuscript [11] .
The percentage reduction in congestion cost between the existing and proposed scenarios was calculated as:

$$R_{CC} = \frac{CC_{existing} - CC_{proposed}}{CC_{existing}} \times 100\% \quad (4)$$

where $CC_{existing}$ is the estimated congestion cost under existing modeled conditions and $CC_{proposed}$ is the estimated cost under the proposed traffic management scenario [12] .

This analysis provides an economic comparison of alternative traffic management measures. Because the proposed conditions are evaluated through simulation, the estimated cost reduction represents potential savings under the modeled assumptions rather than realized savings following implementation [12], [13].

PTV Vissim Model Development, Calibration, and Validation

The PTV Vissim model was developed to represent the geometry, traffic demand, vehicle composition, turning movements, intersection controls, and interactions between vehicles within the Canggu Highway network. The model consisted of nine road segments and three intersections. Links and connectors were constructed using field measurements and available road network data. Vehicle inputs, vehicle routes, turning proportions, and traffic control arrangements were established from the classified traffic counts and intersection observations.

Model Calibration

Model calibration was designed to improve the agreement between simulated and observed traffic conditions. The process consisted of the following steps.

First, the road geometry, links, connectors, lane configurations, vehicle routes, traffic inputs, and intersection controls were checked against field conditions [14], [15]. Second, vehicle composition, traffic demand, turning proportions, and desired speed distributions were adjusted using the survey data. Third, driving behavior parameters, including the configured car-following and lane-changing parameters, were examined and adjusted where necessary. Finally, the simulated traffic volumes, travel speeds or travel times, queue lengths, and delays were compared with the corresponding field observations [13] .

$$E = \frac{|X_s - X_o|}{X_o} \times 100\% \quad (5)$$

where E is the absolute percentage error, X_s is the simulated value, and X_o is the observed field value.

The calibrated model was assessed using the selected performance indicators and documented acceptance criteria. The final manuscript should report the observed values, simulated values, percentage errors, and final calibrated

parameters. The specific car-following model, parameter values, and acceptance thresholds must be taken from the actual Vissim configuration and the calibration procedure used in the study[16], [17].

Model Validation and Scenario Evaluation

Where independent field observations were available, they were used to validate the calibrated model. Validation compared simulated and observed traffic performance under conditions not used for calibration. If independent observations were unavailable, the model assessment should be reported as a goodness-of-fit evaluation rather than independent validation [18], [19]. After the base model was established, the final configuration was applied consistently to the existing-condition and proposed-condition scenarios. The proposed scenarios incorporated only the traffic management measures actually represented in the simulation, such as changes to intersection operations, traffic signal coordination where applicable, and adjustments to traffic movement priorities [14] .

Each scenario was evaluated using comparable traffic demand, vehicle composition, analysis periods, and recorded random seed settings. The performance indicators included average delay, average network speed, total travel time, total distance traveled, and queue length. The resulting traffic performance and congestion costs were compared to identify the scenario with the most favorable combined operational and economic outcomes. The final scenario was selected based on the stated evaluation criteria and the consistency of its performance across repeated runs. All improvements were interpreted as potential outcomes of the simulation under the specified assumptions and traffic demand, rather than as evidence of benefits already achieved through implementation in the field.

RESULTS

Analysis of Road Network Modeling of Current Conditions

Travel modeling is an analysis to determine the need or demand for travel for an overview of travel routes. To facilitate analysis in the early stages, a trip distribution analysis is carried out. This travel distribution analysis is used to identify travel in and out of the Canggu Highway Area. In the initial stage, it is necessary to create traffic zones, which are as follows:

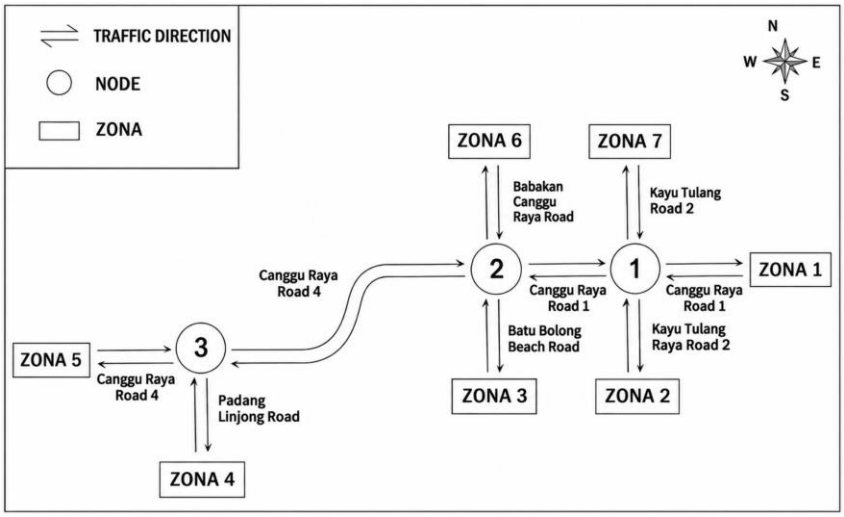


Figure 1. Zone Map of The Study Area

Table 1. Study Area Zones

Zone	Road Name
1	Canggu Raya Road 1
2	Kayu Tulang Raya Road 2
3	Batu Bolong Beach Road
4	Padang Linjong Road
5	Canggu Raya Road 4
6	Babakan Canggu Raya Road
7	Kayu Tulang Road 2

The zones of the study area show seven traffic zones used as the basis for the formation of networks and travel distribution in the Canggu Highway Area. The division of zones represents the segments that are the point of origin or destination of vehicle movement in the model.

Furthermore, the movement can be created a zone destination origin matrix obtained from the furness iteration, which is an approach to finding the destination origin journey by an indirect method [15].

Table 2. Vehicle Movement Matrix OD

O/D	1	2	3	4	5	6	7	ouch.	Ouch.	Ei
1	0	219	134	129	395	160	181	1218	1218	1,00
2	271	0	106	103	313	127	144	1063	1063	1,00
3	220	141	0	83	254	103	117	918	918	1,00
4	186	119	73	0	215	87	99	778	778	1,00
5	374	241	147	142	0	176	199	1278	1278	1,00
6	161	103	63	61	186	0	85	660	660	1,00
7	161	104	63	61	186	76	0	651	651	1,00
dd	1373	927	586	579	1549	728	824			
Dd	1322	892	564	557	1494	701	793			
Ed	0,96	0,96	0,96	0,96	0,96	0,96	0,96			

The origin-destination matrix (OD) describes the distribution of vehicle movements between zones. The values in each cell indicate the number of vehicles moving from the origin zone to the destination zone, while the oi and Oi values represent the total origin movement and the Ei values indicate the counterbalancing factor of the Furness iteration result.

After all calibration scenarios produce their respective traffic volume values, a validation stage is carried out using the GEH method to evaluate the degree of proximity between the volume of simulated results and the volume of survey results. Mathematically, it is written, namely: [16].

$$\text{GEH} = \sqrt{\frac{(\text{q simulated} - \text{q observed})}{0{,}5 \times (\text{q simulated} + \text{q observed})}} \tag{6}$$

The following is the conclusion of the calculation of the Geoferry E. Havers (GEH) statistical formula.

Table 3. Description of GEH results

GEH < 5.0	Accepted
5.0 < GEH < 10.0	Warning: Possible model errors or bad data
GEH > 10.0	Rejected

This table is the GEH value interpretation criteria used to validate the Vissim PTV model. GEH values of less than 5.0 are categorized as acceptable, so that the more GEH values below that limit indicate the model's suitability to the traffic volume of the survey results.

After calibration is carried out on the model that has been carried out on Vissim, the Vissim Results data are validated using the survey results so that the following validation results are obtained:

Table 4. Validation of Vehicle Volume in The Study Area

No.	Road Name	Traffic Direction	Survey (veh/h)	Model (veh/h)	GEH Value
1	Canggu Raya Road 1	Entering (E–W)	1,218	1,071	4.345
		Exiting (W–E)	1,322	1,374	1.416
2	Canggu Raya Road 2	Entering (E–W)	1,022	881	4.571
		Exiting (W–E)	1,116	1,191	2.208
3	Canggu Raya Road 3	Exiting (E–W)	1,245	1,084	4.718
		Entering (W–E)	1,186	1,221	1.009
4	Canggu Raya Road 4	Exiting (E–W)	1,494	1,343	4.009
		Entering (W–E)	1,278	1,317	1.083
5	Kayu Tulang Raya Road 1	Entering (N–S)	651	617	1.350
		Exiting (S–N)	793	729	2.320
6	Kayu Tulang Raya Road 2	Exiting (N–S)	892	792	3.446
		Entering (S–N)	1,063	1,037	0.802
7	Babakan Canggu Raya Road	Entering (N–S)	660	647	0.509
		Exiting (S–N)	701	709	0.301
8	Batu Bolong Beach Road	Entering (N–S)	564	594	1.247
		Exiting (S–N)	918	931	0.428

9	Padang Linjong Road	Exiting (N–S)	557	528	1.245
		Entering (S–N)	778	763	0.540
Average					**1.974**

The validation results showed that the GEH value in all directions of the section was below 5.0 with an average of 1.974. Thus, the PTV Vissim model is considered valid and can be used as a basis for simulating existing conditions as well as evaluating traffic management and engineering proposals.

From the results of the validation using the GEH statistical test, there is no value that exceeds 5 so that the model can be considered valid or in accordance with existing conditions, this method is the basis for implementing traffic design management proposals [20], [21].

Table 5. Performance of The Existing Road Network

Parameters	Parameter Values	Units
	Weekday afternoon rush hour	
Average Delay	134,18	Seconds/Kend
Network Speed (Average Speed)	12,13	Km/H
Total Distance	6137,54	Kend-Km
Total Travel Time	505,8873	Kend-Jam
Speed Peerformance Index	69	%

In the existing conditions of afternoon rush hour weekdays, the network showed an average delay of 134.18 seconds/vehicle and a network speed of 12.13 km/h. The Speed Performance Index value of 69% shows that the actual speed of the network is still far below the free flow condition, so handling is needed to improve smooth movement.

Analysis of Handling Proposals Through PTV Vissim Transportation Modeling

Beddington in Noviana. R. [17] explained that traffic engineering management is a series of businesses and activities that include planning, procurement, installation, regulation, and maintenance of road equipment to complete, support, and maintain safe, secure, orderly, and smooth traffic. Traffic management and engineering is one of the strategic efforts in mitigating transportation problems that occur in the Canggu Highway area. Based on the results of the identification of problems that have been carried out, the main purpose of this study is to improve the performance of the road network by paying attention to the Speed Performance Index (SPI). The performance of the road network is to evaluate the performance of the road network as a whole, while the SPI is by analyzing the comparison between the speed of the free flow and the actual speed as an indicator of the level of service of the road section. In addition, this study also focuses on efforts to optimize delays at intersections, especially on major roads, considering that delays are one of the important parameters that reflect the efficiency of traffic movement on the road network. Therefore, it is necessary to implement appropriate and integrated traffic management and engineering, both on roads and intersections, in order to improve the smooth flow of traffic, as well as minimize travel time [18].

Coordination of the intersection of Kayu Tulang and Batu Bolong

Signaled intersections or often referred to as intersections that use Traffic Signaling Devices (APILLs) as vehicle flow control devices and control cycle times and phases at intersections. Signalized intersections, as one of the commonly used traffic management methods, have an important role in distributing vehicle flows alternately and preventing traffic flow conflicts. In the application of APILL there are various APILL engineering, one of which is the Coordinated APILL Intersection. Coordinated APILL is a condition where [19]a green wave occurs which is a method of coordinating signals at several adjacent intersections, with the aim of creating continuous vehicle movement, so that vehicles passing at a certain speed can obtain the green phase of the next intersection in a row The application of this system provides benefits in improving the smooth flow of traffic, especially through reducing vehicle delay time along the road corridor.[20]

The proposed intersection of Kayu Tulang and Simpang Batu Bolong is carried out by optimizing the cycle time and green time at each intersection approach after the most optimal cycle time is known based on the calculation of PKJI 2023, then the selection of cycle time for intersection coordination is carried out after the optimal cycle time is known, then the distribution of green time is carried out in accordance with the existing current using the optimal signal control tools on the PTV Vissim software. For more clarity, it is as follows.

Coordination is carried out by utilizing an offset of 15 seconds which is the most optimal condition after the simulation is carried out on Vissim. The coordination diagram for the peak hours of the afternoon on weekdays is as follows [22], [23]:

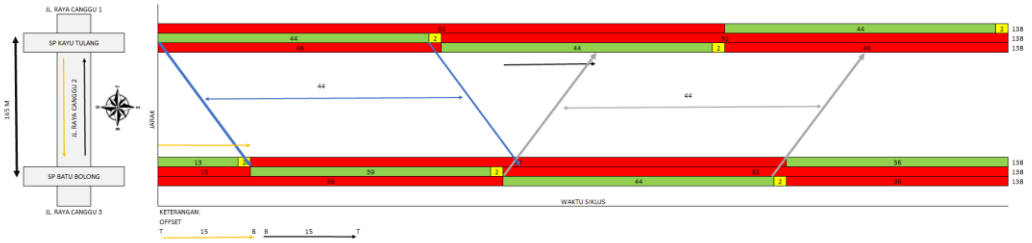


Figure 2. Men Lari Junction Suspension

Based on the analysis of the type of intersection control that exists at the intersection Men Lari is in the category of Priority intersection for this reason, the handling at this intersection with Priority on the main road, namely the Eastern Approach and the West Approach which get priority to run, with the addition of a stop line and priority signs on the southern approach to warn vehicles at the minor approach to stop and prioritize the major current. The proposed signs are as follows:

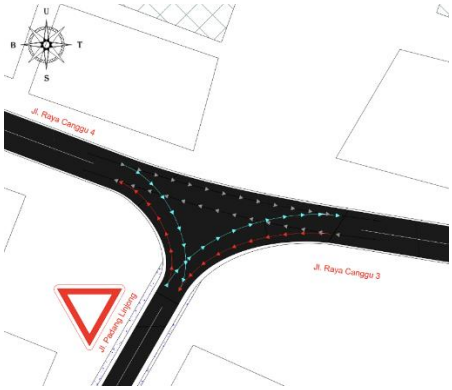


Figure 3. Proposed Priority Traffic Control at Men Lari Intersection

Analysis of Pedestrian Facility Needs

Pedestrian facilities are based on the analysis of pedestrian needs [21]Focused on the Canggu Highway Section with the addition of sidewalks with a width of 1.85 on the left and right sides. For crossing facilities, which are placed at each intersection approach, namely in the form of Zebrra Cross to support the proposal in the form of intersection coordination so that there are no obstacles on the road, it is recommended to provide crossing facilities at the intersection approach, for more clarity, it can be seen in the following table [24]:

Table 6. The Need for Rigid Pedestrian Facilities (Sidewalks)

No.	Road Name	Recommendation (Left Side)	Recommendation (Right Side)
1	Canggu Raya Road 1	1.85 m	1.85 m
2	Canggu Raya Road 2	1.85 m	1.85 m
3	Canggu Raya Road 3	1.85 m	1.85 m
4	Canggu Raya Road 4	1.85 m	1.85 m
5	Kayu Tulang Raya Road 1	1.85 m	1.85 m
6	Kayu Tulang Raya Road 2	Maintain the existing recommendation	Maintain the existing recommendation
7	Babakan Canggu Raya Road	Maintain the existing recommendation	Maintain the existing recommendation
8	Batu Bolong Beach Road	Maintain the existing recommendation	Maintain the existing recommendation
9	Padang Linjong Road	1.85 m	1.85 m

The recommendation for pedestrian facilities shows the need for sidewalks 1.85 m wide on both sides of some of the main sections, while other sections are maintained according to the current recommended conditions. The recommendations are prepared based on the needs of pedestrians and the technical provisions of the pedestrian facilities used in the study.

Table 7. The Need for Pedestrian Crossing Facilities

No.	Road Name	PV^2	Recommendation
1	Canggu Raya Road 1	164,805,718	Zebra Crossing
2	Canggu Raya Road 2	191,297,056	Zebra Crossing
3	Canggu Raya Road 3	100,465,937	Zebra Crossing

4	Canggu Raya Road 4	162,108,180	Zebra Crossing
5	Kayu Tulang Raya Road 1	27,635,625	Not Yet Required
6	Kayu Tulang Raya Road 2	22,086,779	Not Yet Required
7	Babakan Canggu Raya Road	106,955,744	Zebra Crossing
8	Batu Bolong Beach Road	80,656,000	Not Yet Required
9	Padang Linjong Road	10,358,415	Not Yet Required

The PV^2 value is used to determine the need for crossing facilities. Based on the results of the analysis, Zebra Cross is recommended on Raya Canggu Road 1–4 and Raya Babakan Canggu Road, while in other sections crossing facilities are not needed based on the calculation results.

Table 8. Performance of The Road Network After Handling

Parameters	**Parameter Values**	**Units**
	Afternoon Rush Hours on Weekdays	
Average Delay	99,37	Seconds/Kend
Network Speed (Average Speed)	14,5	Km/H
Total Distance	6329,42	Kend-Km
Total Travel Time	436,47	Kend-Jam
Speed Peerformance Index	74	%

After the implementation of the traffic management and engineering proposals, the average delay dropped to 99.37 seconds/vehicle and the network speed increased to 14.50 km/h. The Speed Performance Index increased from 69% to 74%, indicating an improvement in network performance. The reduction in average delay from 134.18 to 99.37 seconds per vehicle indicates an improvement in the operational performance of the modeled road network. Similarly, the increase in average network speed from 12.13 to 14.50 km/h suggests that vehicles experienced fewer or shorter interruptions during their journeys. These changes may be associated with improvements in traffic signal coordination and intersection management, which can reduce unnecessary stopping and improve the progression of vehicle platoons between intersections. However, these mechanisms should be interpreted as possible explanations rather than confirmed causal effects unless supported by approach-level signal, queue, and travel-time outputs from the simulation. Therefore, the performance improvement should be evaluated not only through network-average indicators but also through changes in delay, queue length, and travel time on individual road segments.

Congestion Cost Analysis

a. Time value analysis

Time value analysis using the revenue method (Income Approach) is based on the Gross Regional Domestic Income (GDP) of Badung Regency in 2025 of IDR 75,098,200,000,000. The total productive population of Badung Regency based on Badung is 339,430 people while the annual working hours use working hours based on Law of the Republic of Indonesia Number 6 of 2023 For more clarity, you can see the following equation:[22]

b. Vehicle Compensation Fee (BOK)

In analyzing vehicle operational costs, there are components of operating costs, including: fuel consumption costs, oil consumption costs, spare parts consumption costs, maintenance labor wage costs, tire usage costs. Based on [23], so that the Bok amount for each type of vehicle is obtained as follows [25], [26], [27]:

Table 9. Non-Fixed Costs

No.	**Road Name**	**SM**	**MP**	**KS**
1	Canggu Raya Road 1	949.11	2,744.25	5,372.88
2	Canggu Raya Road 2	914.40	2,573.50	5,388.89
3	Canggu Raya Road 3	907.24	2,538.27	5,381.11
4	Canggu Raya Road 4	906.84	2,536.30	5,436.83
5	Kayu Tulang Raya Road 1	873.99	2,374.67	5,341.85
6	Kayu Tulang Raya Road 2	890.36	2,455.21	5,401.80
7	Babakan Canggu Raya Road	886.78	2,437.60	5,353.56
8	Batu Bolong Beach Road	878.75	2,398.10	5,316.32
9	Padang Linjong Road	888.54	2,446.26	5,384.66

Non-fixed costs (BTT) are the components of vehicle operating costs calculated per kilometer for motorcycles (SM), passenger cars (MP), and medium vehicles (KS). The difference in values between segments reflects the difference in operational cost components used in calculating congestion costs.

Cost of Loss Due to Current Condition Congestion

The cost of Loss due to congestion during the peak hours of the working day is modeled with the Tzedekis Formula, in modeling the cost of congestion with the following equation: for example, for passenger cars on the Canggu 1 Highway Section:[22]

Table 10. Cost of Losses Due to Congestion In Current Conditions

No.	Road Name	Existing Speed (km/h)	Delay (hours)	Congestion Cost (IDR/hour) – SM	Congestion Cost (IDR/hour) – MP	Congestion Cost (IDR/hour) – KS	Total (IDR/hour)
1	Canggu Raya Road 1	16.20	0.02968	756,367	1,132,900	106,064	1,995,332
2	Canggu Raya Road 2	20.22	0.00312	96,834	123,573	8,156	228,563
3	Canggu Raya Road 3	21.22	0.00182	62,263	61,891	5,812	129,966
4	Canggu Raya Road 4	21.79	0.00223	88,025	104,738	9,758	202,521
5	Kayu Tulang Raya Road 1	27.61	0.00247	67,181	51,522	–	118,703
6	Kayu Tulang Raya Road 2	24.50	0.00060	20,463	18,899	–	39,362
7	Babakan Canggu Raya Road	24.68	0.02145	418,580	579,899	62,352	1,060,831
8	Batu Bolong Beach Road	26.01	0.00307	73,695	79,130	8,491	161,316
9	Padang Linjong Road	24.68	0.00059	11,385	15,912	1,580	28,878
				Total			**3,965,472.11**

In the existing conditions of afternoon working hours, the total cost of losses due to congestion reached IDR 3,965,472.11 per hour. This value is the accumulation of congestion costs for all study segments based on speed, delay, vehicle operational costs, and vehicle characteristics. Although the total modeled congestion cost decreases after the implementation of the proposed traffic management measures, the results show that the change is not uniform across all road segments. In particular, the reported congestion cost on Segment 2, Jalan Canggu, increases from Rp228,563/hour to Rp1,417,135/hour. This increase indicates that the network-wide improvement does not necessarily translate into an improvement on every segment. Possible explanations include changes in traffic flow distribution, queue accumulation at downstream intersections, differences in vehicle throughput, or changes in travel time and vehicle operating costs. Nevertheless, the available aggregate cost figures are insufficient to establish whether congestion has actually shifted from one segment to another. Further analysis of segment-level traffic volume, average delay, queue length, travel time, and vehicle composition are required to identify the cause of the increase.

Table 11. Cost of Losses Due to Congestion In Current Conditions

Road Segment	Existing Cost (Rp/hour)	After Treatment (Rp/hour)	Change (Rp/hour)	Interpretation
Segment 2 – Canggu Road	228,563	1,417,135	+1,188,572	Requires further investigation
Segment 6	39,362	625,535	+586,173	Requires further investigation
Other segments	According to original results	According to original results	Calculate from data	Evaluate individually
Total network	3,965,472.11	2,636,383.25	−1,329,088.86	Total cost decreases

Cost of Loss Due to Congestion Proposed Conditions

After handling and performance is obtained, after handling is carried out, the calculation of the cost of losses experienced by the driver after handling for more can clearly be seen in the following table:

Table 12. Cost of Congestion Losses After Handling

No.	Road Name	Proposed Speed (km/h)	Delay (hours)	Congestion Cost – SM (IDR/hour)	Congestion Cost – MP (IDR/hour)	Congestion Cost – KS (IDR/hour)	Total (IDR/hour)
1	Canggu Raya Road 1	21.61	0.00163	52,789	76,515	7,807	137,111

2	Canggu Raya Road 2	21.64	0.01831	602,469	763,335	51,332	1,417,135
3	Canggu Raya Road 3	22.97	0.00119	43,703	43,094	4,133	90,930
4	Canggu Raya Road 4	23.72	0.00090	38,180	45,053	4,290	87,523
5	Kayu Tulang Raya Road 1	27.55	0.00051	13,803	10,587	–	24,390
6	Kayu Tulang Raya Road 2	24.54	0.00952	325,222	300,312	–	625,535
7	Babakan Canggu Raya Road	27.44	0.00249	53,254	73,097	8,056	134,407
8	Batu Bolong Beach Road	27.05	0.00190	47,140	50,447	5,462	103,048
9	Padang Linjong Road	25.92	0.00032	6,441	8,963	901	16,304
				Total			2,636,383.25

After the implementation of the proposal, the total cost of losses due to congestion decreased to Rp2,636,383.25 per hour. A decrease of 33.5% compared to existing conditions shows that the proposed traffic management and engineering have a positive economic impact through reducing delays and improving network speed. Overall, the simulation results indicate that the proposed traffic management scenario improves several network-wide performance indicators, including average delay, average speed, and total congestion cost. However, the interpretation of these improvements requires consideration of differences in performance between individual road segments. The selection of the 15-second offset also needs to be supported by a direct comparison with alternative settings using consistent simulation conditions. Furthermore, the increases in congestion costs on specific segments require additional investigation using detailed traffic and queue outputs [28], [29]. These analyses are important to distinguish genuine network-wide improvements from localized deterioration and to ensure that the proposed traffic management measures are evaluated on the basis of both aggregate and segment-level performance.

DISCUSSION

The results show that the proposed traffic management measures improve the performance of the Canggu Highway network. The average vehicle delay decreases from 134.18 to 99.37 seconds per vehicle, representing a reduction of 25.94%, while the average network speed increases from 12.13 to 14.50 km/h, representing an improvement of 19.54%. These findings indicate that better traffic signal coordination and intersection management can help vehicles move more smoothly and reduce waiting times. The results support [9], who reported a 43.5% reduction in average delay through traffic signal optimization in Bangkok. Similarly, [10] found that coordinated traffic signals improved vehicle movement and reduced traffic delays, while [11] demonstrated that adaptive signal control could reduce queue accumulation between nearby intersections. Although these studies reported different levels of improvement, they support the same conclusion that managing intersections as a connected network is more effective than treating them separately. However, the improvement in Canggu remains a simulation result and requires field testing to confirm its effectiveness under actual traffic conditions [3].

The findings also show that better traffic management can provide economic benefits. The estimated total congestion cost decreases from IDR 3,965,472.11 to IDR 2,636,383.25 per hour, representing a reduction of approximately 33.52%. This suggests that reducing traffic delays may also reduce the economic losses experienced by road users. These findings are consistent with [8], who demonstrated the importance of evaluating traffic management through both operational and economic performance. However, the present study also identifies an important difference: congestion costs increase on Canggu Raya Road 2 and Kayu Tulang Raya Road 2 despite the overall network improvement. This finding is consistent with the concerns raised by [7], who showed that improvements in overall traffic performance may be accompanied by unequal benefits across different parts of a road network. [8] also found that coordinated traffic signals do not always improve every intersection because road geometry and local traffic conditions can limit their effectiveness. These comparisons suggest that traffic management should not be evaluated only through average network performance. Each road segment must also be examined to ensure that reducing congestion in one location does not create additional problems elsewhere.

Beyond vehicle movement and economic benefits, the study also highlights the importance of pedestrian facilities and sustainable transportation in tourism areas. The proposed improvements include sidewalks with a width of 1.85 meters on selected road segments and pedestrian crossings at locations where crossing demand supports their

provision. These recommendations are related to [5], who found that improved pedestrian safety measures could reduce predicted vehicle–pedestrian conflicts by 26% to 51%. However, the present study has not directly measured changes in pedestrian safety, so the benefits of these facilities still require further evaluation. The findings are also extended by [6], who emphasized the importance of public transportation accessibility for tourists in Bali, [4], [14], who demonstrated that combining traffic signal control with vehicle routing strategies could improve network performance. These studies suggest that reducing traffic congestion in Canggu requires more than improving traffic signals. It also requires safe pedestrian facilities, better public transportation, and effective traffic distribution. Therefore, the main contribution of this study is the combined evaluation of road network performance, traffic management measures, pedestrian facility needs, and congestion costs in a tourism area. The findings provide useful information for transportation planning, although additional field validation, evaluation of individual road segments, and testing under different traffic demand conditions are necessary before the proposed measures can be implemented confidently.

CONCLUSION

The results indicate that the Canggu road network experiences suboptimal traffic performance during weekday afternoon peak hours, characterized by an average delay of 134.18 seconds per vehicle and an average network speed of 12.13 km/h. To address these conditions, this study evaluated proposed traffic management measures using PTV Vissim microsimulation. The proposed measures include traffic signal coordination at the Kayu Tulang and Batu Bolong intersections, priority control at the Men Lari intersection, and improvements to pedestrian facilities. The simulation results show that implementing these measures reduces the average delay to 99.37 seconds per vehicle, representing a decrease of approximately 26.0%, while the average network speed increases to 14.50 km/h, an improvement of approximately 19.5%. In addition, the estimated total congestion cost decreases from IDR 3,965,472.11 per hour under existing conditions to IDR 2,636,383.25 per hour under the proposed scenario, corresponding to a reduction of approximately 33.5%. These findings suggest that the proposed traffic management measures can improve network performance and reduce the economic impacts of congestion under the simulated conditions. Nevertheless, the findings should be interpreted within the limitations of the simulation model. Further field implementation, calibration, and validation are necessary to assess the practical effectiveness of the proposed measures and determine whether similar improvements can be achieved under actual traffic conditions.

REFERENCES

[1] P. Srisurin, A. Guerra, and P. Jarumaneeroj, “Traffic Simulation Models to Enhance Signal Timing in an Oversaturated Network: A Comparative Study of Optimizing Individual Intersections versus the Entire Network,” *Int. J. Technol.*, vol. 15, no. 6, pp. 1678–1696, 2024, doi: 10.14716/ijtech.v15i6.7123.

[2] J. Zhu, C. Ma, Y. Shi, Y. Yang, Y. Guo, and X. Yang, “Asynchronous decentralized traffic signal coordinated control in urban road network,” *Comput. Civ. Infrastruct. Eng.*, vol. 40, no. 7, pp. 895–916, 2025, doi: 10.1111/mice.13362.

[3] E. Tang, S. Narupiti, and B. Long, “Adaptive Signal Control for Reducing the Effects of Queues Spillback,” *J. East. Asia Soc. Transp. Stud.*, vol. 16, 2025, doi: 10.11175/easts.16.PP3884.

[4] S. Lin, J. Hu, W. Ma, C. Zheng, and R. Li, “Integrated real-time signal control and routing optimization: A two-stage rolling horizon framework with decentralized solution,” *Transp. Res. Part C Emerg. Technol.*, vol. 165, 2024, doi: 10.1016/j.trc.2024.104734.

[5] M. S. Hussain, G. Bahrha, and A. K. Goswami, “An integrated VISSIM-SSAM approach to predicting and mitigating pedestrian crashes and severity along urban crossings,” *Case Stud. Transp. Policy*, vol. 15, 2024, doi: 10.1016/j.cstp.2024.101153.

[6] D. M. P. Wedagama, N. Z. binti Ubaidillah, and D. Dissanayake, “Transportation Mode Choice Models for Domestic Tourists in Bali,” *J. East. Asia Soc. Transp. Stud.*, vol. 15, pp. 1441–1452, 2024, doi: 10.11175/easts.15.1441.

[7] S. Cui, Y. Xue, K. Gao, K. Wang, B. Yu, and X. Qu, “Delay-throughput tradeoffs for signalized networks with finite queue capacity,” *Transp. Res. Part B Methodol.*, vol. 180, 2024, doi: 10.1016/j.trb.2023.102876.

[8] S. Boontaveeyuwat and N. Wongwai, “Scenario-based evaluation of phase optimization, coordinated signal control, and flyover alternative with integrated economic and environmental appraisal: A multi-intersection corridor study in Eastern Thailand,” *Transp. Res. Interdiscip. Perspect.*, vol. 34, 2025, doi: 10.1016/j.trip.2025.101751.

[9] P. Srisurin, A. Guerra, and P. Jarumaneeroj, “Traffic Simulation Models to Enhance Signal Timing in an Oversaturated Network: A Comparative Study of Optimizing Individual Intersections versus the Entire Network,” *Int. J. Technol.*, vol. 15, no. 6, 2024, doi: 10.14716/ijtech.v15i6.7123.

[10] J. Zhu, C. Ma, Y. Shi, Y. Yang, Y. Guo, and X. Yang, "Asynchronous decentralized traffic signal coordinated control in urban road network," *Comput. Civ. Infrastruct. Eng.*, vol. 40, no. 7, pp. 895–916, 2025, doi: 10.1111/mice.13362.

[11] E. Tang, S. Narupiti, and B. Long, "Adaptive Signal Control for Reducing the Effects of Queues Spillback," *J. East. Asia Soc. Transp. Stud.*, vol. 16, 2025, doi: 10.11175/easts.16.PP3884.

[12] J. Yu, P.-A. Laharotte, Y. Han, and L. Leclercq, "Decentralized signal control for multi-modal traffic network: A deep reinforcement learning approach," *Transp. Res. Part C Emerg. Technol.*, vol. 154, p. 104281, 2023, doi: 10.1016/j.trc.2023.104281.

[13] J. Fang, Y. You, M. Xu, J. Wang, and S. Cai, "Multi-Objective Traffic Signal Control Using Network-Wide Agent Coordinated Reinforcement Learning," *Expert Syst. Appl.*, vol. 229, p. 120535, 2023, doi: 10.1016/j.eswa.2023.120535.

[14] S. Lin, J. Hu, W. Ma, C. Zheng, and R. Li, "Integrated real-time signal control and routing optimization: A two-stage rolling horizon framework with decentralized solution," *Transp. Res. Part C Emerg. Technol.*, vol. 165, p. 104734, 2024, doi: 10.1016/j.trc.2024.104734.

[15] P. Chen, J. Xu, Y. Mei, and L. Wei, "Network-wide critical routes identification and coordinated control based on automatic vehicle identification data," *Transp. Res. Part C Emerg. Technol.*, vol. 172, p. 105019, 2025, doi: 10.1016/j.trc.2025.105019.

[16] S. B. Gunjo, D. D. Guta, and S. Damene, "Modeling the economic cost of congestion in Addis Ababa City, Ethiopia," *Environ. Syst. Res.*, vol. 13, p. 16, 2024, doi: 10.1186/s40068-024-00344-9.

[17] P. Ranpura, R. Gujar, and S. Singh, "Development of Mixed Traffic Microsimulation Model Calibration for Signalized Intersections," *Transp. Res. Procedia*, vol. 82, pp. 2898–2910, 2025, doi: 10.1016/j.trpro.2024.12.226.

[18] T. Xu, S. Barman, and M. W. Levin, "Smoothing-MP: A novel max-pressure signal control considering signal coordination to smooth traffic in urban networks," *Transp. Res. Part C Emerg. Technol.*, vol. 166, p. 104760, 2024, doi: 10.1016/j.trc.2024.104760.

[19] S. Lin, J. Dai, and R. Li, "Network-level signal predictive control with real-time routing information," *Transp. Res. Part C Emerg. Technol.*, vol. 147, p. 104007, 2023, doi: 10.1016/j.trc.2022.104007.

[20] N. Xie and H. Wang, "Distributed adaptive traffic signal control based on shockwave theory," *Transp. Res. Part C Emerg. Technol.*, vol. 173, p. 105052, 2025, doi: 10.1016/j.trc.2025.105052.

[21] R. Hao, Y. Wang, Z. Wang, L. Yang, and T. Sun, "A Coordinated Adaptive Signal Control Method Based on Queue Evolution and Delay Modeling Approach," *Appl. Sci.*, vol. 15, no. 17, p. 9294, 2025, doi: 10.3390/app15179294.

[22] C. Wu, Q. Cao, G. Ren, Y. Deng, and S. Zhang, "Variable multi-path signal progression for arterial coordination considering queue clearance and spillback prevention," *Transp. Lett.*, vol. 18, no. 5, pp. 1024–1048, 2026, doi: 10.1080/19427867.2026.2613225.

[23] Y. Han, Z. Han, F. Ding, F. Li, H. Wang, and X. Wang, "Field-tested signal controller to mitigate spillover using trajectory data," *Comput. Civ. Infrastruct. Eng.*, vol. 39, no. 9, pp. 1354–1369, 2024, doi: 10.1111/mice.13144.

[24] F. Abbracciavento, F. Zinnari, S. Formentin, A. G. Bianchessi, and S. M. Savaresi, "Multi-intersection traffic signal control: A decentralized MPC-based approach," *IFAC J. Syst. Control*, vol. 23, p. 100214, 2023, doi: 10.1016/j.ifacsc.2022.100214.

[25] T. Wang, Z. Zhu, J. Zhang, J. Tian, and W. Zhang, "A large-scale traffic signal control algorithm based on multi-layer graph deep reinforcement learning," *Transp. Res. Part C Emerg. Technol.*, vol. 162, p. 104582, 2024, doi: 10.1016/j.trc.2024.104582.

[26] W. Su, C. Mu, L. Xue, X. Yang, and S. Zhu, "An improved traffic coordination control integrating traffic flow prediction and optimization," *Eng. Appl. Artif. Intell.*, vol. 143, p. 109969, 2025, doi: 10.1016/j.engappai.2024.109969.

[27] X. Chen, X. Lin, Q. Meng, and M. Li, "Coordinated traffic control of urban networks with dynamic entrance holding for mixed CAV traffic," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 178, p. 103264, 2023, doi: 10.1016/j.tre.2023.103264.

[28] B. Li, J. Li, J. Yin, Z. Wang, and J. Gao, "Max Pressure Signal Control Method for Collaborative Optimization of Motor and Nonmotor Vehicles," *J. Transp. Eng. Part A Syst.*, vol. 151, no. 7, 2025, doi: 10.1061/JTEPBS.TEENG-8889.

[29] M.-X. Qin, T.-Q. Tang, S.-W. Wen, and X.-T. Yuan, "Risk analysis of pedestrian crosswalks in airport drop-off zones based on integrated VISSIM-SSAM model," *Accid. Anal. Prev.*, vol. 224, p. 108279, 2026, doi: 10.1016/j.aap.2025.108279.