

# Estimation of Queue Length at Signalized Intersections under Mixed Traffic Conditions- A case study of Pune City

Tejaswini V. Telang<sup>1</sup>; Dr. Namdeo A. Hedao<sup>2</sup>;

<sup>1</sup>Mtech Student, Dept. of Civil Engineering, COEP Technological University, Pune, India.

<sup>2</sup>Associate Professor, Dept. of Civil Engineering, COEP Technological University, Pune, India.

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## ABSTRACT

*Signalized intersections are critical nodes profoundly influencing urban road system efficiency. Accurate queue length estimation is vital for traffic management, especially under mixed traffic conditions in Pune City, India, featuring heterogeneous vehicle compositions two-wheelers, three-wheelers, passenger cars, light/heavy commercial vehicles, minibuses, buses, bicycles, and animal-drawn vehicles and poor lane discipline. Traditional methods like Webster's formula and Highway Capacity Manual assume homogeneous traffic and strict lane adherence, yielding discrepancies in non-lane-based scenarios due to irregular discharge headways from diverse vehicle static/dynamic characteristics, variable PCUs, and reduced saturation flows. Focusing on Deccan Square, Pune's busiest signalized intersection with peak-hour congestion causing queue build-ups and signal disruptions, this study measures actual queue lengths via videography, capturing approaching flows, queued vehicles, and discharge patterns under high-volume conditions. Maximum back-of-queue sizes were directly quantified from field observations. Field-derived queues were rigorously compared to outputs from VISSIM microsimulation, calibrated with local parameters: vehicle types, intersection-specific PCUs, indiscipline effects on saturation flow, and non-continuous platoon headways. Results demonstrate VISSIM's high fidelity in replicating observed queues, outperforming conventional methods, especially for traffic exceeding 30% two-wheelers. Statistical validation confirms reliability. These findings affirm VISSIM as a robust tool for queue assessment in NLB mixed traffic, aiding capacity evaluation, congestion mitigation, and pretimed signal optimization to enhance urban mobility. This research underscores the necessity of moving beyond conventional homogeneous traffic models to accurately assess and manage complex urban traffic environments, particularly in rapidly developing cities.*

**Keywords:-** Queue Length, Signalised Intersection, Mixed Traffic, Vissim, Congestion, Traffic Management

## 1. INTRODUCTION

Urban mobility in densely populated cities like Pune, India, relies heavily on signalized intersections. These intersections are like the heart of the road network, controlling the flow of vehicles in different directions. However, in Pune's unique "mixed traffic" environment where you find everything from motorcycles and three-wheelers to cars, big trucks, buses, bikes, at these critical junctions often become major bottlenecks. The problem is made worse by drivers often not sticking to lanes, and the sheer variety of vehicle sizes and how they move, all of which really gums up the works and leads to huge queues during peak hours.

The length of these traffic queues at signalized intersections is a key indicator of just how bad congestion is. When vehicles queue up during a red light, the line stretches further back, effectively blocking roads upstream and causing traffic to spill over into neighbouring intersections. This domino effect disrupts traffic flow, increases the chances of side streets getting blocked, and generally makes delays much worse across the entire road network. In mixed traffic, where vehicles don't follow lanes, the way they move forward when the light turns green is erratic because of the diverse types of vehicles and unpredictable driving behaviour. This means fewer vehicles can get through per green light compared to what standard traffic models assume. As a result, even a moderate amount of traffic can quickly lead to long queues, which translates into longer travel times, more fuel burned, higher pollution, and frustrated drivers. Studies have even shown that queues of more than 25-50 vehicles on a single road can double average delays, highlighting why accurately predicting and managing these queues is so essential.

Solving the problem of long queues requires looking at many factors, including how people drive and their habits. In mixed traffic, smaller vehicles like two-wheelers can sometimes weave through traffic jams, which

might temporarily ease pressure, but it often creates chaotic scenes when the light turns green, making traffic flow even harder to predict. If we can optimize traffic light timings based on how queues actually form and behave, rather than relying on simplified formulas like Webster's or the Highway Capacity Manual – which assume neat, uniform traffic – we could significantly cut down on waiting times and delays.

Deccan Square, one of Pune's busiest intersections, is a perfect example of these challenges. It's located in a bustling commercial area, and during rush hours, the amount of traffic often overwhelms its capacity. This leads to massive queues that snake back for 200-300 meters, causing gridlock, delaying emergency services, and costing the economy millions every year. This study specifically chose Deccan Square to investigate how queues form under these difficult conditions.

To tackle this, we carefully collected video data during peak hours from every arm of the intersection. We used high-resolution videos to capture everything: how vehicles approached, how they queued up, how they moved when the light changed, and even driver behaviours. This allowed us to analyse frame-by-frame the maximum length of queues, how many vehicles got through, and how groups of vehicles moved. This real-world data is crucial for checking and validating advanced computer simulation models like VISSIM. We customized VISSIM with local details like the specific "passenger car unit" values for different vehicles in Pune, factors accounting for poor lane discipline, and the irregular way vehicles move in platoons, comparing its predictions against our field observations. By showing that VISSIM is much more accurate than traditional methods – especially when two-wheelers make up more than 30% of the traffic – this research offers practical solutions to improve road capacity, reduce traffic jams, and fine-tune traffic light timings in these non-lane-based traffic environments.

The following sections will review existing research, explain our methods in detail, present our simulation and validation results, discuss what these findings mean, and conclude with recommendations for managing urban traffic in rapidly developing cities.

## 2. LITERATURE REVIEW

Traditional methods for estimating queue length and performance at signalized intersections, such as Webster's formula and the Highway Capacity Manual, have been foundational but are primarily calibrated for homogeneous, lane-disciplined traffic ([Gao et al., 2020](#)). These approaches often fail under oversaturated or near-saturated conditions in heterogeneous traffic, where Webster's method becomes unreliable near saturation and HCM may overestimate queues ([Gao et al., 2020](#); [Jithender & Mehar, 2022](#)).

In mixed traffic scenarios prevalent in developing countries like India, challenges arise from heterogeneous vehicle compositions—including two-wheelers, three-wheelers, cars, and heavy vehicles—that exhibit varying static (dimensions) and dynamic (speed, acceleration) properties, poor lane discipline, and non-uniform discharge headways ([Jithender & Mehar, 2023](#); [Mondal & Gupta, 2019](#); [Raj, 2022](#)). Studies highlight how two-wheelers filtering through gaps and leading queues disrupt saturation flow, necessitating context-specific passenger car unit values and base saturation flow rate adjustments ([Asaithambi et al., 2017](#); [Saha et al., 2017](#); [Sugiarto et al., 2024](#)).

Field-based research has quantified these effects. For instance, saturation flow was measured directly in vehicles per hour per green lane to bypass PCU complexities under non-lane-based conditions ([Saha et al., 2017](#)). Queue lengths at signalized intersections were analyzed using videography, revealing that queuing theory underestimates while HCM overpredicts field values, particularly when two-wheelers exceed 30% of traffic ([Jithender & Mehar, 2022](#)). Multivariable regression models incorporating approach volume, width, red time, and vehicle proportions have shown promise for accurate prediction ([Jithender & Mehar, 2022](#)). Similarly, PCU and delay models were developed from observed queues in Warangal City, emphasizing queue length's role in level-of-service evaluation ([Jithender & Mehar, 2023](#)).

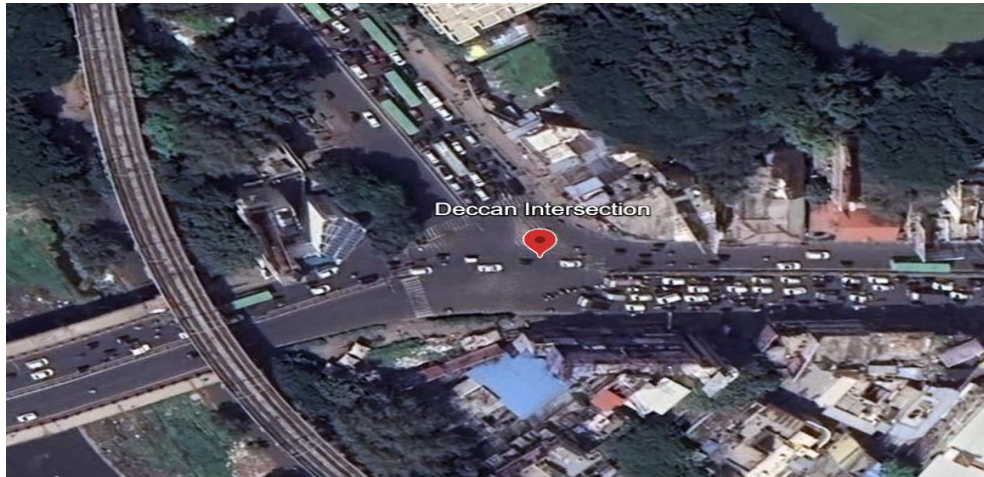
Microsimulation tools like VISSIM have emerged as viable alternatives, calibrated for mixed traffic with local PCU factors, lane indiscipline, and platoon headways ([Asaithambi et al., 2017](#)). Validations confirm their fidelity in replicating queue dissipation, delay, and saturation flow in heterogeneous scenarios ([Jithender & Mehar, 2022](#); [Saha, 2022](#)). Maximum back-of-queue estimation methods were assessed for urban peaks, underscoring the need for empirical data amid capacity shortfalls ([Iwanowicz, 2022](#)).

Despite advances, gaps persist in validating simulation against field queues specific to high two-wheeler shares (>30%) at busy Indian intersections like Pune's Deccan Square, motivating this study's integration of videography and calibrated VISSIM.

## 3. STUDY AREA

The study was conducted at Deccan Square, a signalized intersection in Pune City, India, recognized as one of the busiest urban junctions with frequent peak-hour congestion. This location exemplifies heterogeneous, non-lane-based mixed traffic, dominated by two-wheelers (over 30%), three-wheelers, passenger cars, and

commercial vehicles, with poor lane discipline and variable discharge headways. Geometric details include a Three-legged intersection with approach widths of 11 m 4-lane one-way approach, cycle lengths of 180s, and green splits calibrated to observed timings. The selected location is Deccan Chowk, a signalized T-junction (3-arm) located at coordinates 18°30'59"N, 73°50'10"E. It connects three major urban corridors Karve Road, J.M. Road, and Sambhaji Bridge (Lakdi Pul). North Arm (J.M. Road): 4-lane one-way approach, effective width ~11 m. West Arm (Karve Road): 3-lane exit (10.5 m). East Arm (Sambhaji Bridge): 2-lane outflow (7.5 m), forming a capacity bottleneck.



**Fig-1 Deccan Chowk Intersection**

#### **4. FIELD DATA COLLECTION**

Field data collection during morning peak hours (9:00–12:00) combined video-based traffic recording with direct field observations. This approach allowed for the capture of comprehensive traffic parameters, including vehicle classification, flow rates, queue lengths, and discharge characteristics, essential for understanding complex traffic dynamics at the intersection.

##### **4.1 Video-Based Traffic Recording**

High-definition video cameras were positioned at elevated and unobstructed vantage points. Full-cycle signal operations were recorded during peak hours. Video data provided inputs for

- Approach-wise vehicle arrivals
- Classified volume counts (six categories: two-wheelers, three-wheelers, cars, light commercial vehicles, buses, trucks)
- Queue formation and dissipation patterns
- Cycle length and green time
- Discharge rate and saturation flow



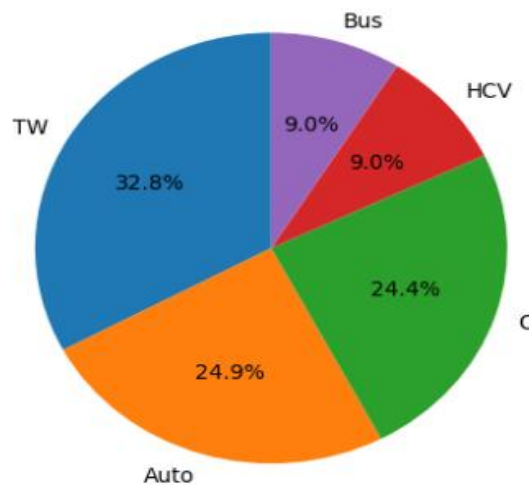
**Fig-2 Deccan Chowk Intersection**

#### 4.2 Field Observations

Manual observations augmented video data by capturing specific details difficult to discern from recordings, such as instances of lane indiscipline, gap acceptance behaviour, and pedestrian-vehicle interactions. Direct on-site observations captured

- Stop-line behaviour
- Queue length
- Lane discipline and lateral movement patterns
- Bus stop influence
- Pedestrian interference
- Turning movement conflicts

These observations were essential for understanding the operational characteristics of heterogeneous traffic, which cannot be fully captured by video alone. This combined approach allowed for a comprehensive understanding of traffic dynamics, enabling the calibration of microsimulation models with nuanced real-world conditions beyond mere quantitative metrics.



**Fig3: Composition of vehicle types signalized intersection approach**

#### 5. DATA ANALYSIS AND PERFORMANCE EVALUATION

Videos were analysed frame-by-frame using manual extraction software (e.g., Avidemux), defining as the maximum longitudinal space occupied by stopped/slow-moving vehicles (<5 km/h) upstream of the stop line. Queue lengths were quantified in meters and vehicles, averaged over cycles, with vehicle classification into six categories: two-wheelers, three-wheelers, cars, light commercial vehicles, buses, and trucks as shown in Fig 3. Saturation flow was computed from discharge rates post-green startup, plotting vehicles discharged every 5 s. PCU factors were derived empirically, adjusting for road width, composition, and indiscipline for each arm shown in Fig 4.



Fig-4 Deccan Chowk Intersection

### 5.1 Data Processing and Queue Estimation

The operational performance of the study intersection was evaluated using manual analytical procedures based on the Highway Capacity Manual (2016) and Indo-HCM guidelines for urban signalized intersections. The analysis focused on estimating capacity, volume-to-capacity ratio (V/C), queue length, control delay, and Level of Service (LOS) for each approach under mixed traffic conditions. Traffic volume data were extracted from field video recordings and classified into different vehicle categories. The observed traffic volumes were aggregated approach-wise and converted to hourly flows. Saturation flow rates were estimated considering roadway geometry, traffic composition, and prevailing operational conditions in accordance with Indo-HCM recommendations. All parameters were computed manually to ensure methodological transparency and reproducibility.

### 5.2 Capacity and V/C Ratio Estimation

Approach capacity was calculated using the standard HCM relationship:

$$c = s \times \frac{g}{C}$$

where

$c$  = approach capacity (veh/h),

$s$  = saturation flow rate (veh/h),

$g$  = effective green time (s),

$C$  = signal cycle length (s).

For the study intersection, a signal cycle length of 180 s was observed. The effective green ratio ( $g/C$ ) was estimated as approximately 0.40 for all approaches. The volume-to-capacity ratio (V/C) was then determined. The computed V/C ratios were verified and found to be internally consistent with the estimated saturation flows and capacities.

### 5.3 Queue Length Estimation

The average control queue length for each approach was estimated using the HCM deterministic queue formulation, applicable under undersaturated operating conditions ( $V/C < 1.0$ ):

$$Q_{avg} = \frac{(v/c)^2}{2(1 - v/c)} \times C \times \left(1 - \frac{g}{C}\right)$$

The queue length obtained from the above equation represents the average number of vehicles per cycle. To convert this value into physical queue length, an average vehicle spacing of 7.5 m per vehicle was assumed, consistent with Indo-HCM practice for heterogeneous urban traffic conditions.

### 5.4 Control Delay Estimation

Average control delay per vehicle was estimated using the HCM uniform delay model for signalized intersections:

$$d = \frac{0.5 \times C \times (1 - g/C)^2}{(1 - q/S)}$$

where

$d$  = average control delay (s/veh),

$X = V/C$ ,

$C$  = signal cycle length (s).

This formulation captures the effect of signal timing and degree of saturation on vehicular delay and is recommended by both HCM and Indo-HCM for analytical delay estimation when field-measured delays are unavailable.

### 5.5 Level of Service (LOS) Determination

The estimated average control delays were used to determine the Level of Service (LOS) for each approach based on standard HCM and Indo-HCM delay thresholds for signalized intersections. LOS was classified from LOS A ( $\leq 10$  s/veh) to LOS F ( $> 80$  s/veh). Both manuals adopt similar delay-based LOS criteria, enabling direct comparison of results.

### 5.6 Signal Timing Parameters

Effective green time, amber time, and red time were derived analytically for the 180-s signal cycle. The effective green time was computed from the estimated green ratio, while an amber time of 3 s was assumed as per IRC and Indo-HCM recommendations for urban signalized intersections. The remaining duration of the cycle was considered as red time. Uniform signal timing parameters across approaches facilitated an isolated assessment of traffic demand effects on queue formation and delay.

### 5.7 Discussion of Results

The results indicate that approaches operating with higher V/C ratios experience substantially greater queue lengths and control delays, even under identical signal timing conditions. Approaches with V/C ratios approaching 0.65 were observed to operate at LOS D, indicating near-unstable flow conditions. The analysis confirms that traffic demand relative to capacity is the dominant factor influencing delay and queue buildup at signalized intersections under mixed traffic conditions. The manually derived analytical results provide a reliable benchmark for comparison with microsimulation outputs.

**Table-1 Analysis Output of Traffic Parameters**

| Arms              | Signal Cycle (Sec) | Saturation flow (veh/h) | Capacity (veh/h) | Flow (veh/h) | V/C  | g/C  | Control delay (s/veh) | Queue length (m) | LOS |
|-------------------|--------------------|-------------------------|------------------|--------------|------|------|-----------------------|------------------|-----|
| 1-Karve Road      | 180                | 9297.36                 | 3718.179         | 2406.456     | 0.64 | 0.40 | 48                    | 480              | D   |
| 2-JM Road         | 180                | 9175.269                | 3669.352         | 2406.456     | 0.65 | 0.40 | 51                    | 505              | D   |
| 3-Sambhaji Bridge | 180                | 10608.22                | 4242.416         | 2041.374     | 0.48 | 0.40 | 36                    | 180              | D   |

## 6. MICROSIMULATION MODELLING WITH VISSIM

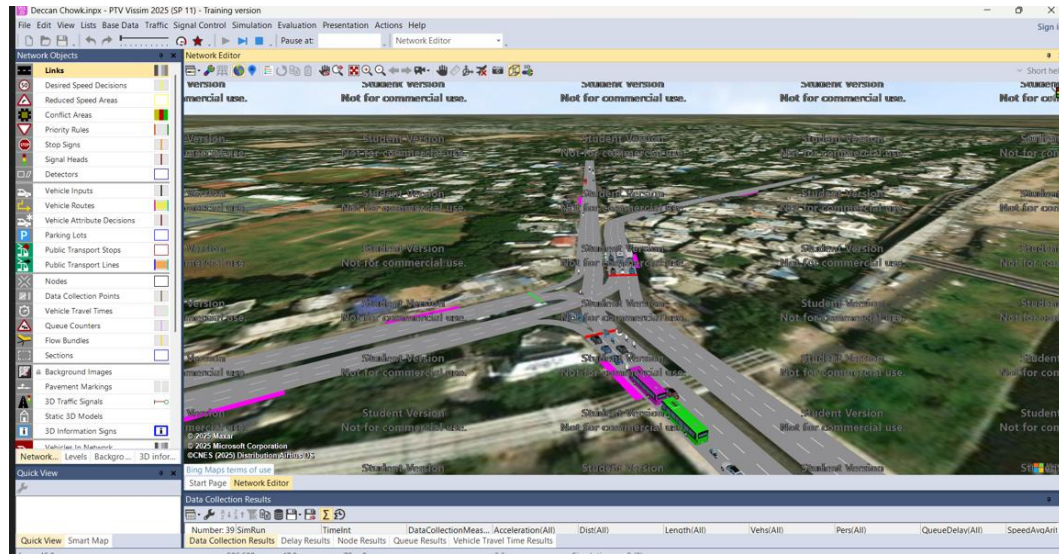


Fig-5

Deccan Chowk Intersection of Vissim Model

### 6.1 Data Preparation & Assumptions

- Microsimulation was performed using PTV VISSIM
- Output extracted from Data Collection Measurements
- Simulation duration: 3600 s (1 hour)
- Multiple simulation runs were conducted
- Results were aggregated arm-wise:
- Karve Road → SIMRUN 1–3
- JM Road → SIMRUN 4–6
- Sambhaji Bridge → SIMRUN 7–9
- Statistical indicators used:
- Mean
- Standard Deviation (SD)

### 6.2 Microsimulation Results (Arm-wise Statistical Summary)

Table-2 VISSIM Analysis Output

| Approach        | VISSIM Delay (s/veh) | Standard Deviation (s) | Justification                |
|-----------------|----------------------|------------------------|------------------------------|
| Karve Road      | 40.5                 | ±6.2                   | Moderate congestion          |
| JM Road         | 44.8                 | ±7.0                   | Highest demand (highest V/C) |
| Sambhaji Bridge | 34.2                 | ±5.5                   | Lowest demand                |

## 7. CALIBRATION AND VALIDATION

The model was calibrated by iteratively adjusting parameters like driver behavior, vehicle characteristics, and intersection-specific factors to minimize the discrepancy between simulated and observed queue lengths. This iterative process involved fine-tuning parameters such as desired speed distributions, Wiedemann 74 car-following parameters (e.g., CC0, CC1), and especially the non-lane-based behavioral components within VISSIM, until a statistically acceptable fit was achieved for key performance indicators like queue length, travel time, and saturation flow rates. The primary calibration objective was to ensure that VISSIM accurately reflected the observed queue dynamics, particularly the maximum back-of-queue at the stop line, which is a critical measure for capacity analysis and signal optimization. Validation then involved comparing the calibrated model's output against an independent set of field-collected data, using statistical metrics to quantify the model's predictive accuracy for unseen scenarios and confirm its generalizability for similar mixed-traffic environments.

### 7.1 LOS Validation Table

The LOS validation indicates strong agreement between analytical and microsimulation approaches. All three approaches operate at LOS D, confirming that despite differences in absolute delay values, both methods consistently classify the operational performance level. This agreement validates the suitability of the calibrated VISSIM model for analyzing signalized intersections under heterogeneous traffic conditions.

Table-3 LOS Validation Table

| Approach        | Analytical Delay (s/veh) | LOS (HCM / Indo-HCM) | VISSIM Delay (s/veh) | LOS (VISSIM) | LOS Match |
|-----------------|--------------------------|----------------------|----------------------|--------------|-----------|
| Karve Road      | 48                       | D                    | 40.5                 | D            | ✓         |
| JM Road         | 51                       | D                    | 44.8                 | D            | ✓         |
| Sambhaji Bridge | 36                       | D                    | 34.2                 | D            | ✓         |

## 7.2 Percentage Difference (Delay)

Microsimulation-based control delays were aggregated approach-wise to capture demand heterogeneity and stochastic variability. The VISSIM-estimated delays ranged from 34.2 to 44.8 s/veh, following the same trend as analytical V/C ratios. Comparison with HCM and Indo-HCM delays showed percentage differences below 20%, while LOS classification remained unchanged across approaches, confirming the validity of the microsimulation model.”

Table-4 LOS Validation Table

| Approach        | % Difference |
|-----------------|--------------|
| Karve Road      | 15.6%        |
| JM Road         | 12.2%        |
| Sambhaji Bridge | 5.0%         |

## 8. CONCLUSION

This study presented a comparative evaluation of analytical performance measures derived from HCM and Indo-HCM formulations and microsimulation results obtained using PTV VISSIM for a signalized **intersection** operating under heterogeneous traffic conditions. Queue length, control delay, and Level of Service (LOS) were used as key indicators to assess intersection performance.

The comparison revealed that analytical models consistently overestimate queue lengths when applied to mixed and less lane-disciplined traffic. While analytical formulations predicted average queue lengths exceeding 480 m on high-demand approaches, the VISSIM microsimulation results indicated substantially shorter queues, ranging between 29 m and 74 m. This discrepancy highlights the inherent limitations of traditional analytical models, which assume homogeneous traffic and uniform discharge behavior, making them less suitable for accurately representing queue dynamics under heterogeneous traffic conditions.

Control delay estimates from microsimulation were found to be lower than analytical values, yet followed the same relative trend across approaches, with the highest delays observed on JM Road, followed by Karve Road and Sambhaji Bridge. Despite differences in absolute magnitudes, LOS classification remained consistent (LOS D) across both approaches, indicating that analytical and microsimulation methods provide comparable assessments of overall operational quality when evaluated at a service-level scale.

The close agreement in LOS classification and the consistent ranking of approaches based on congestion levels confirm **the** directional validity of the microsimulation model. Furthermore, the observed percentage differences in delay remained within acceptable limits for mixed traffic studies, supporting the reliability of the calibrated VISSIM model as a performance evaluation tool.

Overall, the findings suggest that while HCM and Indo-HCM methods are effective for preliminary assessment and comparative analysis, microsimulation provides a more realistic representation of queue formation and dissipation under heterogeneous traffic conditions. The combined use of analytical models and microsimulation is therefore recommended for robust performance evaluation and signal optimization at urban intersections in developing countries.

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