International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Research Article)

Managing curb activities and performance analysis of a network based on VISSIM

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International Journal of Science and Research Archive, 2025, 15(03), 1853-1862

Publication history: Received on 20 May 2025; revised on 28 June 2025; accepted on 30 June 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.15.3.1978

Abstract

Urban intersections such as the confluence of 21st, 22nd, and 23rd Streets in Washington, D.C., exemplify the growing congestion challenges faced by modern cities. This intersection, a critical node in the city's transportation network, accommodates a diverse mix of commuters, tourists, and pedestrians. The increasing prevalence of ride-sharing platforms like Uber and Lyft has significantly altered traffic dynamics at this location, contributing to more frequent curbside stops and exacerbating peak-hour congestion. The limited curb space, originally intended for transient use, is now a frequent bottleneck, further complicated by unpredictable pedestrian-vehicle interactions, thereby raising safety concerns.

This study investigates the effects of implementing additional parking spaces at the intersection during a surge event at the George Washington Memorial Hospital. Using PTV VISSIM, a microscopic traffic simulation software, the study analyzes changes in key performance metrics including Level of Service (LOS), vehicle delay, and queue length. The research also evaluates the impact of modifying signal timing parameters green, yellow, and red intervals on overall network performance. A comprehensive literature review is provided to contextualize the simulation findings. It is important to note that the current model does not account for pedestrian volumes. Traffic volume data were obtained from DC Open Data to calibrate the simulation. The study concludes by discussing the implications of curbside usage and signal timing optimization in urban traffic management.

Keywords: Level Of Service; Parking Spaces; Curbside; Signals; Network Performance; VISSIM

1. Introduction

The urban transportation landscape has undergone a dramatic transformation in recent years, particularly with the emergence and rapid growth of ride-sharing platforms such as Uber, Lyft, and Didi. These platforms have revolutionized mobility, offering convenience and flexibility to users, but simultaneously straining curbside infrastructure. As these services expand, the challenges for city planners and local governments intensify, especially concerning congestion management and equitable allocation of curb space.

Numerous studies have examined the dynamics of ride-sharing and its implications on curbside activities. Historically, curb space allocation has relied on static strategies such as fixed parking fees and designated zones for specific uses. However, with the rise in ride-hailing and delivery services, the curbside has become increasingly congested, necessitating dynamic and adaptive curb management strategies [1]. PTV VISSIM, a multi-modal microscopic traffic simulation software developed in Karlsruhe, Germany, is commonly used in traffic engineering and urban planning. It provides a platform to model and simulate interactions between various transport modes and control mechanisms, including vehicle behaviors, signal heads, and conflict areas.

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The increase in curbside congestion caused by ride-sharing is well documented. Henao and Marshall [2] observed a significant rise in congestion during peak hours in cities with high ride-sharing activity. Zargayouna and Zeddini [3] framed ride-sharing optimization as an integer linear programming problem, aiming to minimize provider costs. Beyond cost, participant objectives such as minimizing vehicle-miles traveled [4], reducing wait times [5], and maximizing match efficiency [6] are critical to dynamic ride-sharing systems. These criteria should be addressed collectively in ride-sharing optimization models.

Agatz et al. [4] introduced a dynamic ride-sharing method with an objective to reduce total vehicle-miles, aligning with broader goals of emission reduction and traffic decongestion. Naoum-Sawaya et al. [5] and Stiglic et al. [6] emphasized the importance of travel time and matching efficiency. If no ride match is found within a specific timeframe, users are likely to abandon the system. Many studies allow users to specify acceptable pickup windows, reflecting the need for user-centric flexibility [4].

Ride-sharing contributes positively to sustainable transport by promoting reduced car ownership, higher occupancy rates, and increased public transport integration. Spatial-temporal models have been leveraged to analyze ride-sharing demand patterns across time and geography. These models help forecast demand surges and identify congestion hotspots, facilitating proactive urban planning. The integration of geolocation data enables predictive modeling, allowing drivers and planners to make informed decisions.

The curb serves as a nexus between transportation functionality and urban utility. Historically designed for drainage and demarcation, curbs now accommodate various functions from parking to commerce. In dense urban areas, competing demands on curb space have prompted calls for efficient allocation, pricing mechanisms, and regulatory frameworks. Public agencies often share responsibility for curb space management, reflecting its multidimensional use and strategic importance.

Li et al. [7] proposed a dynamic curb allocation model to adapt to varying traffic patterns, reducing congestion through optimal allocation strategies. Mahmoudi and Zhou [8] characterized the ride-sharing problem as a Pickup and Delivery Problem with Time Windows (PDPTW), a complex optimization challenge. Mourad et al. [9] surveyed optimization models for shared mobility, highlighting challenges in solution quality and computation time.

The Institute of Transportation Studies at the University of California, Davis, investigated ride-hailing impacts across major U.S. cities [10]. Their findings indicated high adoption among younger users and a preference for ride-hailing to avoid parking and reduce the risks associated with drinking and driving. Urban areas recorded higher adoption rates compared to suburban zones.

Beyond ride-sharing, signal timing optimization is pivotal in mitigating traffic congestion. Poor signal timing contributes to delays, longer queues, and increased emissions. Salvo and Sanfilippo [11] demonstrated that synchronizing signal cycles significantly reduced travel times at busy intersections in Palermo.

Khang et al. [12] utilized Genetic Algorithms (GA) with the SUMO simulation platform to optimize traffic signal plans, outperforming traditional methods in reducing traffic losses. Singh et al. [13] applied a MATLAB-based GA to develop an adaptive real-time signal control system, which showed superior performance over fixed-time systems.

Wu et al. [14] developed an optimized signal cycle model incorporating driver anxiety, pedestrian crossing time, and vehicle delay. Their tests on intersections in Xi'an City confirmed the model's effectiveness in reducing delay and queue length. Roy et al. [15] used VISSIM simulations to evaluate various congestion mitigation strategies at a busy intersection in Dhaka, Bangladesh. Their results showed significant improvements in level of service through signal enhancements and infrastructure modifications.

Lee et al. [16] further advanced real-time adaptive signal optimization using GAs, showing superior results compared to traditional signal planning tools. These studies collectively affirm the need for advanced modeling tools and adaptive strategies to address the evolving dynamics of urban transportation networks influenced by ride-sharing and other modern mobility solutions.

2. Methodology

2.1. Limitations of Study

The network didn't take account of pedestrian volumes and pedestrian counts, as said initially, the curb is the connector and the delimiter between the stakeholders who access the curb from the roadside and the stake holders who access the curb from the sidewalk (pedestrians).

2.2. Study Area

The study area is a three-legged intersection and is intersected by I-St NW, a two-lane two-way street, and 23rd St NW, a four-lane two-way street. It is a signal-controlled intersection. (Figure 1). The other intersections were not considered. 23rd street and I street intersection is used as case study due to the event happening at the George Washington University Hospital. Which experiences heavy vehicle and pedestrian traffic. But the pedestrian traffic was not considered in this simulation.

(Google earth)

Figure 1 23rd and I St Intersection

2.3. Data Collection

At the intersection under consideration, the vehicle counts for every vehicle entering the test network were compiled. To obtain the best results for the research, these counts were conducted during the morning and evening peak hours when the vehicle volume is anticipated to be highest. These volumes will show the maximum demand and flow. Cameras fixed on tripods were positioned at a height suitable for precisely measuring the number of cars entering each intersection and the direction in which they were traveling. Volumes per hour were recorded instead of gathering the 15mins vehicle count and multiply by 4. Upon gathering of these data, it was realized that the vehicular counts weren't sufficient enough to make this proper analysis. I compared it with the AADT from Open Data Dc and found a huge difference in the vehicular count. Hence, the figures from the database were implemented and was adjusted with the peak hour factor and directional factor on 23rd street and I street intersection to maximize the base data.

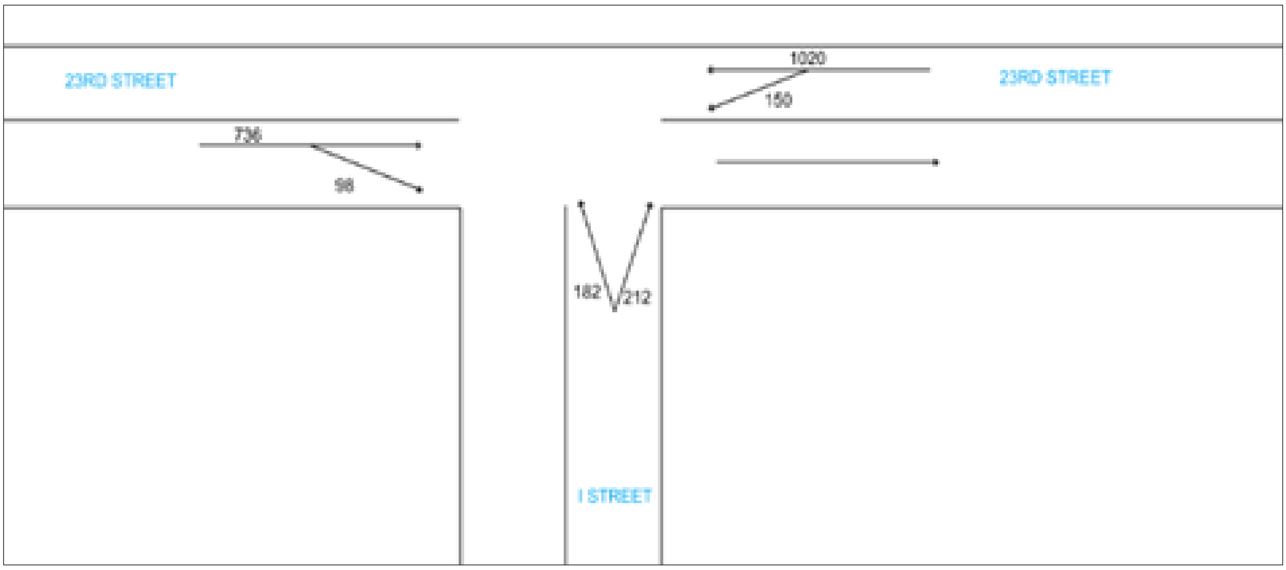


Figure 2 Vehicle counts per hour on 23rd Street and I Street

With the help of the predefined calibration parameter values and the gathered and examined data, the base model of the corridor was created. The intersection has a cycle length of 105 seconds. 23rd St and I street intersection is a three-legged, fully signalized, and extremely busy intersection. Figure 3 depicts the intersection's current signal program. A substantial number of cars were able to cross the intersection during each direction's green period under the current signal plan.

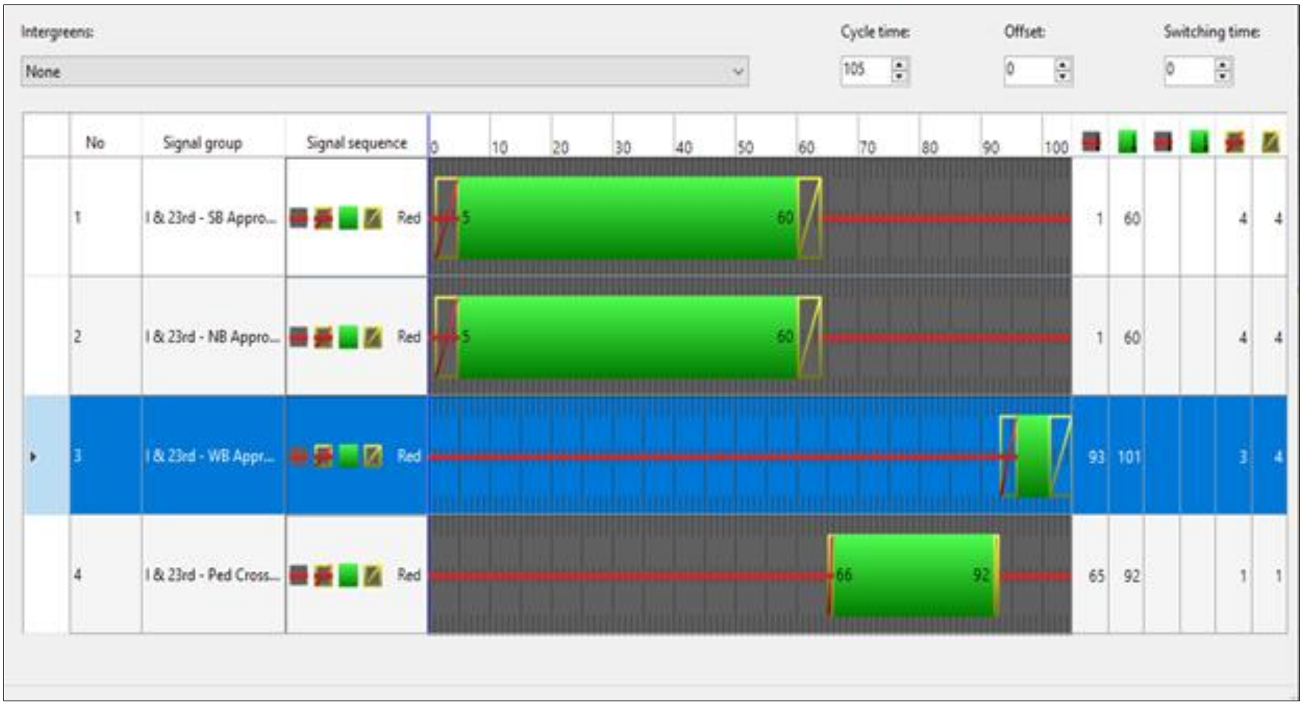


Figure 3 Existing Signal Program for 23rd and I St

As illustrated in Figure 3, a total cycle length of 105 seconds and a green time of 60 seconds is allocated to the through traffic. The base model is shown in Figure 4 below.

Figure 4 Base Model

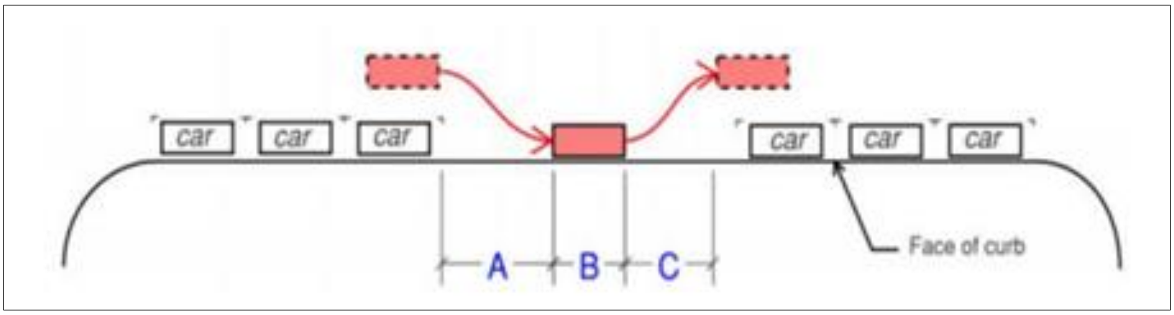
2.4. Optimization Method

The VISSIM simulation software was employed to evaluate the impact of optimized traffic signal timing on intersecti

on performance. A new signal program was developed using a stage-based signal controller that incorporated priority rules tailored to the specific traffic flow characteristics of the study area. Signal timing optimization was then conducted to determine the most efficient control settings, which were subsequently applied to the model. The outcomes from this optimized scenario were compared against baseline simulation results as well as a modified model utilizing the previous signal plan to assess performance improvements across various traffic metrics.

Several key simulation parameters were defined to ensure the robustness and accuracy of the model. The simulation period encompassed both a seeding period used to allow traffic flow to stabilize before analysis and an analysis period, during which performance data were collected. The simulation resolution, representing the number of steps per simulation second, was set to a minimum of ten to ensure smooth and realistic vehicle behavior. Additionally, the random seed parameter was configured to introduce stochastic variability in vehicle arrivals, allowing for realistic traffic conditions. Consistency in outcomes for specific runs was ensured by fixing the seed value, while multiple simulations were differentiated using a random seed increment. For instance, a sequence starting at 100 with an increment of 10 yielded seeds of 100, 110, and 120, facilitating a robust sensitivity analysis of the model's performance under variable traffic scenarios

Five parking spaces were incorporated into the base model. Parking lots can be added to Vissim with the use of parking lot functionality. Links are placed connecting the existing roadway in the form of a curb, for cars to have seamless entry into these parking spaces and not causing any obstruction to the flow of traffic. Fehr & Peers [17] developed a formula to calculate how much space a vehicle requires to make a stop at a curbside for loading activities. The formula is based on various behaviors of vehicles, sizes and the space needed to steer to the curb and back to the travel lane. Figure 5 illustrates the space needed.



(Fehr & Peers 2019)

Figure 5 Single vehicle space requirement for loading activity, A = entry distance, B = vehicle length and C = exit distance

The total distance required is equal to A + B + C for a single loading space in a midblock if the allocated curbside space is between parked cars or other obstructions. The calculation would be different if the curbside loading space was placed in the beginning of a block or at the end of a block. One of the findings in (Fehr & Peers 2019) is that approximately 6 meters is a good value for A, B and C each which would offer suitable space (meaning 18 meters in total).

3. Results and Discussion

The performance evaluation of the 23rd and I Street corridor in Washington, D.C., was conducted using the VISSIM microscopic simulation model. The baseline scenario, modeled without additional roadside parking or signal optimization, revealed several key performance indicators. The maximum queue length reached 51.04 seconds, while the average vehicle delay was recorded at 15.5 seconds. The average queue length stood at 9.64 seconds, and the average stop delay was 10.86 seconds. Emission outputs included 74.314 grams/hour of CO and 14.46 grams/hour of NOx, with a fuel consumption rate of 1.046 gallons per hour. Overall, the Level of Service (LOS) under baseline conditions was rated as Level B, indicating moderate traffic efficiency as shown in Table 1

Table 1 Results from Base Model

Parameters	Simulation Results
Queue Length Max	51.04 seconds
Average Vehicle Delay	15.5 secs
Average Queue length	9.64 secs
Average Stop Delay	10.86
Total CO Emissions	74.314 grams/hour
Total NOx Emissions	14.46 grams/hour
Total Fuel	1.046 gallons/hour
Level of Service	B

3.1. Robustness Analysis of Base Model

To assess the reliability of the base model, a robustness analysis was performed through ten simulation iterations using varied random seed values, each running for a total of 1800 seconds. The consistency of simulation outputs was evaluated using standard deviation metrics. A standard deviation of 0.7 was observed for queue length, while average stop delay showed a deviation of 0.56. These relatively low values suggest a high degree of consistency and reliability in the model's outputs.

Subsequently, a modified version of the base model was created by incorporating roadside parking lots. These lots were configured for forward-forward parking to minimize interference with through traffic. Additionally, parking attraction values were adjusted to promote usage of the forward-most spaces first, thereby ensuring efficient turnover. The simulation of this unoptimized parking lot model indicated a decline in network performance. While the LOS remained at Level B, average vehicle delay increased to 19.62 seconds, and the average queue length more than doubled to 17.45 seconds. Stop delay rose to 12.37 seconds, while CO and NOx emissions surged to 145 grams/hour and 57.08 grams/hour, respectively. Fuel consumption also increased slightly to 1.09 gallons per hour. These outcomes highlight the adverse effects of roadside parking on traffic dynamics, primarily due to reduced road capacity, increased conflict points, and disruptions from parking maneuvers. The simulation results clearly demonstrate how these factors introduce inefficiencies, leading to higher congestion and elevated emissions as shown in Table 3.

Table 2 Unoptimized Parking Lot Model Results

Parameters	**Simulation Results**
Queue Length Max	40.80 secs
Average Vehicle Delay	19.62 secs
Average Queue Length	17.45 secs
Average Stop Delay	12.37 secs
Total CO Emissions	145 grams/hour
Total NOx Emissions	57.08 grams/hour
Total Fuel	1.09 gallons/hour
Level of Service	B

Figure 6 Parking lot model

3.2. Manually Optimized Model

To counteract these negative outcomes and accommodate the increased demand associated with a nearby event at the George Washington University Hospital, a manually optimized model was developed. In this configuration, the signal cycle length was reduced from 105 to 85 seconds, and greater green time was allocated to the northbound and southbound through lanes.

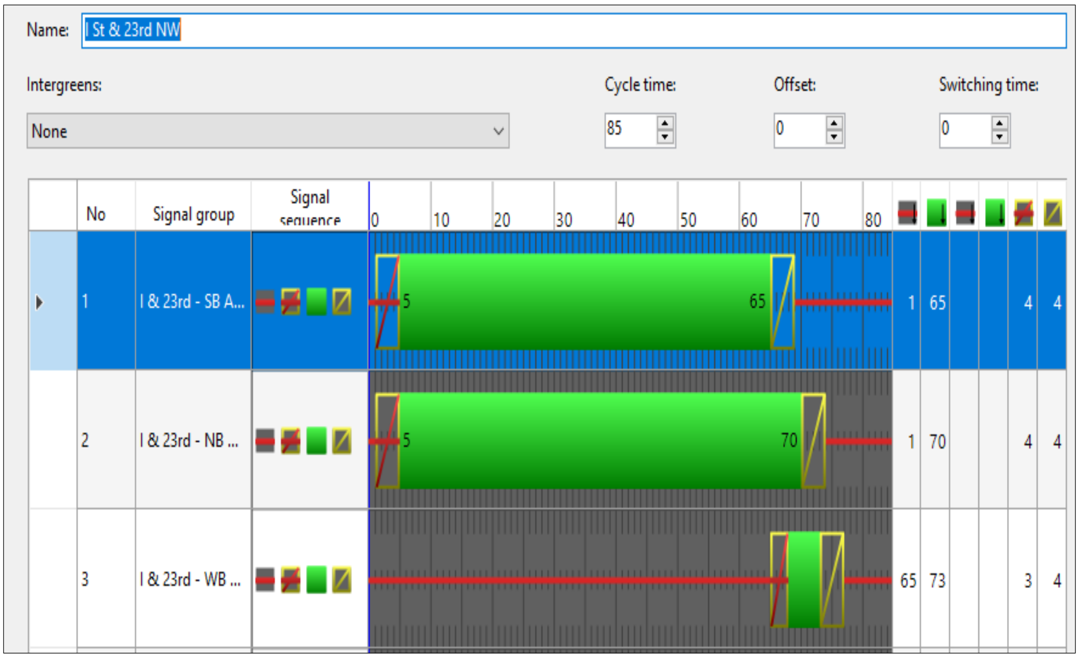


Figure 7 Manually Optimized Signal Program

Table 3 The results gotten from the simulation with the manually optimized signalization

Parameters	Simulation Results
Queue Length Max	36.1 secs
Average Vehicle Delay	5.7 secs
Average Queue Length	3.8 secs
Average Stop Delay	4.5 secs
Total CO Emissions	98.7 grams/hour
Total NOx Emissions	16.47 grams/hour
Total Fuel	1.08 gallons/hour
Level of Service	A

Table 3 Optimized Parking Lot Model Results

The resulting simulation showed marked improvements across all key performance metrics. The maximum queue length dropped to 36.1 seconds, and average vehicle delay fell sharply to 5.7 seconds. Queue length and stop delay were significantly reduced to 3.8 and 4.5 seconds, respectively. While CO emissions increased slightly to 98.7 grams/hour, they remained substantially lower than in the parking lot scenario, and fuel consumption held steady at 1.08 gallons per hour. Most notably, the LOS improved to Level A, indicating a high level of operational efficiency and minimal congestion.

Table 4 Comparison between Base model and Manually Optimized Signal Program

Parameters	**Manually Optimized Signal Timing**	**% Difference with Base Model**
Queue Length Max	36.1 secs	29.2
Average Vehicle Delay	5.7 secs	63.2
Average Queue Length	3.8 secs	60.5
Average Stop Delay	4.5 secs	58.5
Total CO Emissions	98.7 grams/hour	-32.8
Total NOx Emissions	18.47 grams/hour	-27.7
Total Fuel Consumption	1.08 gallons/hour	-3.8

The comparative analysis between the base and optimized models revealed a 63.2% reduction in average vehicle delay and a 60.5% reduction in average queue length. CO and NOx emissions were also reduced by 32.8% and 27.7%, respectively. These improvements underscore the effectiveness of signal timing optimization as a strategy to enhance network performance, even in the presence of added curbside demand. Nevertheless, it is important to recognize that certain real-world complexities, such as pedestrian volumes, were not captured in the model. This limitation suggests that while the results are promising, they may understate the challenges associated with pedestrian-vehicle interactions. Future models should incorporate pedestrian flows to provide a more comprehensive analysis of urban intersection performance under varying demand conditions.

4. Conclusion

This study investigated the impact of ride-sharing-induced curbside activity and signal timing optimization on traffic performance at a congested urban intersection in Washington, D.C. Using PTV VISSIM for microscopic traffic simulation, three modeling scenarios were evaluated: a baseline configuration, a modified network with added roadside parking, and a manually optimized model with adjusted signal timing parameters. The results demonstrate that the introduction of curbside parking significantly degrades network performance by increasing delays, queue lengths, and emissions due to decreased road capacity and increased maneuvering disruptions.

Conversely, signal timing optimization achieved by reducing the cycle length and reallocating green time to through traffic resulted in substantial improvements in all key performance metrics. Average vehicle delay and queue lengths were significantly reduced, and emissions were lowered despite the added demand, indicating a more efficient and responsive intersection design. These findings underscore the importance of proactive signal management and adaptive curbside policies in mitigating congestion and supporting sustainable urban mobility, particularly during surge events driven by factors such as hospital access or high ride-sharing demand.

However, the study's scope is limited by the exclusion of pedestrian activity, which plays a critical role in real-world traffic dynamics, especially at urban intersections. Future research should integrate pedestrian modeling and explore the synergistic effects of signal coordination, dynamic curb allocation, and emerging mobility technologies to provide more holistic solutions for urban traffic management.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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