Exploring the Potential of Vehicle-to-Everything (V2X) Technology for Smarter Traffic Management in the Philippines

John Carlo Crisostomo
Electrical and Electronics Engineering Institute
University of the Philippines - Diliman
Mandaluyong City, Philippines
john.carlo.crisostomo@eee.upd.edu.ph

Jaybie De Guzman
Electrical and Electronics Engineering Institute
University of the Philippines - Diliman
Quezon City, Philippines
jaybie.de.guzman@eee.upd.edu.ph

***Abstract*—Traffic congestion remains a critical issue in the Philippines. Current traffic management systems, such as outdated fixed-timing signals, have proven ineffective as vehicle density continues to increase. Emerging technologies such as V2X communication offer the potential to improve traffic efficiency through real-time data exchange between vehicles and infrastructure. Despite its adoption in other countries, the Philippines lacks both the infrastructure and research necessary to evaluate the feasibility of V2X-based solutions. This study aimed to evaluate the effectiveness of adaptive traffic light control using V2X communication in alleviating traffic congestion within the University of the Philippines (UP) Diliman campus. A traffic and network simulation environment was used to model two scenarios under varying traffic conditions: one with V2X-enabled vehicles operating under adaptive signal control, and another using conventional fixed-time traffic signals. Real-world road layouts and estimated traffic parameters were incorporated to ensure realistic behavior. The V2X scenario demonstrated a significant reduction in vehicle waiting times and an increase in average travel speeds compared to the non-V2X scenario. These results indicate the potential of V2X technology to improve traffic flow in urban settings. This study provides a foundational simulation-based analysis of V2X implementation in the Philippine context. The findings suggest that further research-including simulations with partial V2X penetration rate, real-world traffic data, and broader communication types-is essential to inform infrastructure development and smart transportation policy.**

***Keywords*—V2X technology, smart traffic management, traffic congestion solutions, adaptive traffic signal control, Philippines urban traffic**

I. Introduction

Traffic congestion remains a major urban challenge worldwide, particularly in densely populated and rapidly urbanizing areas. In developing countries such as the Philippines, increasing vehicle ownership and limited road infrastructure worsen this challenge, leading to longer travel times [1]. A significant contributing factor to this congestion is the outdated traffic management system—many intersections in the Philippines still rely on fixed-timing signals that operate without regard for real-time traffic conditions. These static systems are often identified as bottlenecks due to their inability to adapt to fluctuating traffic demand [2]. In response, attention has shifted towards intelligent traffic systems (ITS), which utilize digital technologies to optimize traffic flow and improve efficiency. Among these, V2X technology-particularly Vehicle-to-Infrastructure (V2I)- emerges as a promising solution, enabling real-time data exchange between vehicles and infrastructure to support adaptive traffic signal systems [3].

In several countries, V2X has been tested or deployed as part of smart mobility initiatives. Simulation studies have demonstrated its effectiveness in reducing vehicle delays and improving traffic flow [4]. Locally, research on V2X remains virtually nonexistent. Instead, most ITS efforts in the Philippines utilize technologies such as cameras and sensors, often combined with optimization algorithms as an upgrade to existing fixed-timing signals [5]. While these systems offer improvements, they require significant investment in physical infrastructure and computational efforts. In contrast, although V2X also demands investment in physical infrastructure, it offers greater scalability, flexibility, and responsiveness in dynamic traffic environments.

Urban traffic congestion in the Philippines is intensified by outdated fixed-timing traffic signals and the lack of adaptive systems that respond to real-time road conditions. Despite the global shift toward V2X systems, local infrastructure remains underdeveloped, and related research is scarce. This lack of V2X readiness is further compounded by the unavailability of reliable traffic data, which limits the ability to design and test advanced solutions. To address these challenges, this study simulates a V2X-based adaptive traffic signal control system using the road network of the University of the Philippines (UP) Diliman campus. With its diverse traffic conditions and limited formal infrastructure, the campus serves as a representative of urban traffic challenges in the country, making it a suitable experimental setting for simulation-based exploration of V2X technologies.

The remainder of this paper is organized as follows: Section II reviews related work on V2X technology and adaptive

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traffic systems. Section III provides an overview of the V2X communication system. Section IV details the methodology used. Section V presents the results and discussion. Finally, Section VI concludes the study and outlines future research directions.

II. Related Work

Several international studies have demonstrated the potential of V2X technology, particularly V2I, in enhancing adaptive traffic signal control. For instance, Qiao et al. proposed a V2I-based traffic signal optimization method that improved traffic efficiency by reducing delays and stops, particularly under high traffic volumes. Their study highlighted V2I communication as a potential form of traffic detection that can further enhance traffic signal control. They also found that a wider communication range contributed to fewer vehicle stops [6].

Similarly, Mari et al. explored V2I communication as a method for adaptive traffic signal control. Their system was built on a basic timed cycle, where traffic lights followed fixed durations for red, yellow, and green lights. However, this timing could be adjusted in real time based on vehicle data. Using a finite state machine, the system monitored whether a vehicle was approaching. If it detected an approaching vehicle and the minimum red light duration had already passed, it could skip the rest of the red phase and switch to green earlier. This made the traffic light more responsive to actual traffic flow. They tested this system through simulations and small-scale real-world experiments, which confirmed that their V2I setup could successfully exchange traffic signal data with vehicles and adapt the light changes accordingly. These results highlight the potential of V2I-based adaptive control systems similar to the one explored in this study [7].

Locally, research on V2X in the Philippines remains scarce. Most ITS initiatives rely on physical detectors such as cameras and inductive loops, often paired with computing algorithms like model predictive control (MPC) algorithms to enhance fixed-timing traffic lights. For instance, Uy et al. explored an MPC-based adaptive traffic system where green times of stoplights were computed and applied in a SUMO simulation of the Katipunan Avenue–Aurora Boulevard intersection in Metro Manila. Their study demonstrated a 57.43% reduction in average queue time and a 41.85% reduction in queue length compared to fixed-timing signals, with vehicle detection handled through the built-in induction loop detectors in SUMO [8]. Unlike fixed detectors, V2X systems can scale with vehicle deployment and function with minimal roadside installations once base infrastucture is in place. However, despite these improvements, many countries are shifting toward V2X-enabled systems, which offer richer data exchange, better scalability, and real-time responsiveness beyond the limitations of traditional detection methods.

Simulation tools such as Veins, which combines SUMO (Simulation of Urban Mobility) and OMNeT++ (Objective Modular Network Testbed in C++), provide a flexible framework for evaluating V2X systems. Most studies investigating

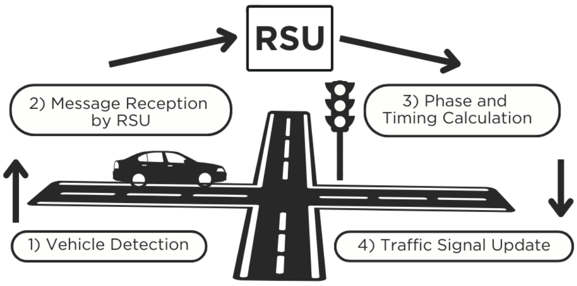

Fig. 1: High-level system diagram of the V2X-based adaptive signal control.

V2X communication use this combination due to its modularity and interfacing capabilities. The Luxembourg SUMO Traffic scenario is an example of a publicly available, data-rich simulation environment used to assess V2X performance under realistic traffic conditions [4]. However, many of these scenarios are tailored to specific locations and traffic patterns, making them less applicable to developing urban contexts like the Philippines, where formal traffic datasets are limited or nonexistent.

This study addresses this gap by simulating V2X-based adaptive traffic signal control using the actual road layout of UP Diliman. The use of freely available simulation tools and realistic traffic estimation aligns with prior work while localizing the findings to a developing urban setting.

III. V2X System Overview

This study simulates a simplified V2X communication framework focusing on V2I interactions. The envisioned system involves vehicles transmitting real-time data such as position, speed, and waiting time to nearby RSUs, which serve as intermediaries for traffic light controllers.

Upon receiving aggregated traffic information, the RSUs dynamically determine optimal green light durations based on observed demand and instruct the associated traffic light to adjust its phase timings. This closed-loop feedback system enables responsive signal control and improves traffic efficiency at intersections.

Figure 1 presents a high-level diagram of the V2X communication model used in the simulation.

IV. Methodology

A. Simulation Environment

This study utilized the Veins framework, which integrates OMNeT++ and SUMO. Communication between the two simulators was achieved through TraCI (Traffic Control Interface), a TCP-based protocol that provides real-time access to and control over the traffic simulation. TraCI was primarily used to dynamically modify traffic light states based on simulation events. As shown in Figure 2, the simulation software stack used in this study is illustrated.

B. Road Network

To design a realistic and computationally manageable simulation environment, this study adopted the urban layout of

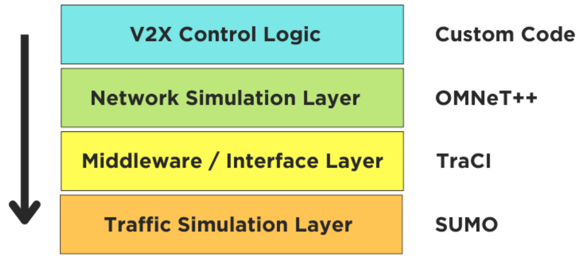

Fig. 2: Simulation software stack used in this study.

a university campus in the Philippines—chosen due to the authors' familiarity with its traffic patterns, infrastructure, and daily activity flows.

The road topology was extracted using OpenStreetMap (OSM), which provides detailed and structured geographic data. The extracted OSM file included road geometries, intersections, and public infrastructure, providing the base map for simulation. The data was further processed and refined using the Java OpenStreetMap Editor (JOSM), allowing manual adjustments to road segments relevant to the simulation. During preprocessing, non-motorized paths (e.g. pedestrian walkways, inaccessible roads, and redundant internal links) were removed to improve simulation performance and reduce unnecessary computational overhead. The final map focused on essential vehicular routes to ensure accurate traffic flow modeling while maintaining simulation efficiency. Figure 3 shows the resulting road network used in the simulation.

In addition to roads and intersections, building geometries were also retained to generate polygonal structures, which were imported into the network simulator to act as physical obstacles in wireless communication, thereby improving V2X simulation realism.

C. Demographics and Traffic Demand

Traffic demand in this study was estimated based on demographic data and vehicle ownership rates relevant to the simulation area. The UP Diliman campus had a reported population of 30,444 in 2024 [9]. Using the national vehicle ownership rate of 48 cars per 1,000 people [10], the total maximum number of private vehicles within the simulation area was estimated at approximately 1,462.

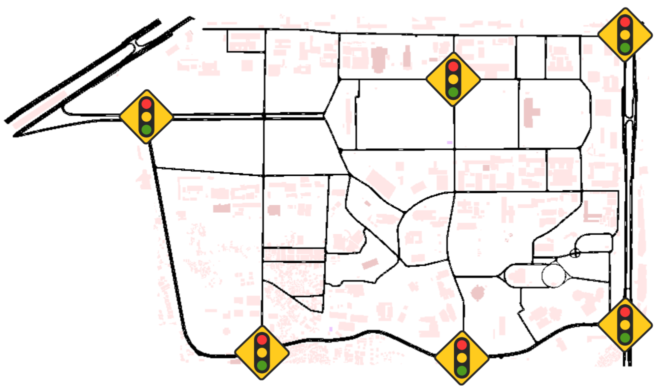

Fig. 3: UP Diliman road network used in the simulation.

The simulation included only private vehicles, excluding public utility, to isolate the effects of V2X on typical personal vehicle behavior. Vehicle volumes were categorized according to the Level of Service (LOS) criteria for arterial roads, representing varying congestion levels [11]. To reflect variability in traffic demand and allow for more flexible scenario generation, each LOS category was defined using a range centered around its estimated value:

- Low (LOS A): 778-–978 vehicles (878 ± 100)
- Medium (LOS C): 1,070–1270 vehicles (1,170 ± 100)
- High (LOS E): 1,362–1562 vehicles (1,462 ± 100)

Departure times were generated within peak periods (7:00 AM to 8:00 AM) to simulate realistic flow patterns during morning rush hours.

D. Routing

Vehicle routes were randomly generated using randomTrips.py, a SUMO utility that creates randomized origin-destination trips across the road network. A minimum trip distance of 1.6 km was enforced to ensure that vehicles traverse multiple intersections, enabling a more meaningful assessment of adaptive traffic control behavior. This value was determined as the maximum feasible minimum distance on the selected map, promoting longer travel paths without introducing routing errors. Generated trips were converted into routable vehicle paths using duarouter, SUMO's dynamic user assignment router. Duarouter computes the most suitable path for each vehicle based on the current road network, ensuring valid and executable vehicle routes throughout the simulation. Vehicles were configured to depart at their maximum allowable speed to reflect typical free-flow urban traffic. Fringe routing was enabled, allowing vehicles to start from the edges of the map, which increased origin diversity and traffic spread.

To maintain consistent traffic behavior and allow for clear observation of adaptive traffic signal performance, rerouting was disabled during the simulation.

E. Experimental Scenarios

This study simulated two primary scenarios for comparative analysis: a baseline without V2X integration and an adaptive V2X-enabled setup. In the non-V2X baseline, traffic lights followed a fixed-time control scheme using conventional round-robin phase scheduling, operating independently of real-time traffic conditions (see Figure 4).

In the V2X-enabled scenario, all vehicles were assumed to be equipped with devices capable of wireless communication with roadside units (RSUs). Vehicles periodically transmitted their waiting time and location data to nearby RSUs every 3 seconds. These RSUs—strategically placed at signalized intersections—acted as traffic light controllers, processing the incoming data and computing adaptive signal phase durations in real time (see Figure 5).

Both scenarios were evaluated under three different traffic conditions—low, medium, and high—corresponding to varying vehicle densities as mentioned in Section IV-C on the traffic demand model. This approach ensured a consistent basis for performance comparison between fixed-time and adaptive traffic control schemes.

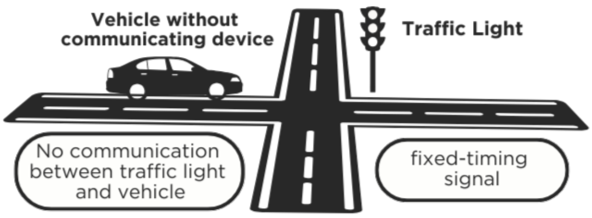

Fig. 4: Non-V2X: Fixed-timing signal without vehicle communication.

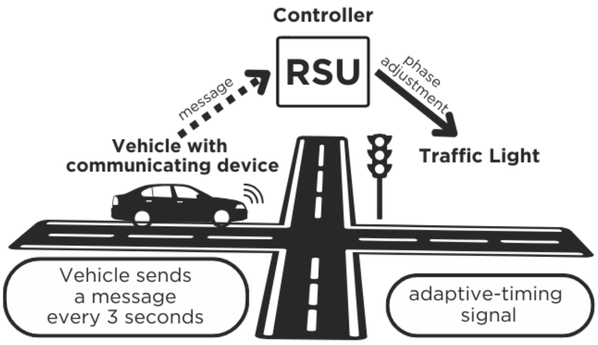

Fig. 5: V2X: Adaptive-timing signal with V2I communication.

F. Adaptive Signal Control Logic

The adaptive signal control algorithm implemented in each RSU dynamically adjusts green light durations based on real-time vehicle data received from nearby cars. The core principle followed a rule-based logic that mapped the number of waiting vehicles to a corresponding green light duration, enabling the system to respond to varying levels of congestion at intersections.

Green-light durations were assigned based on the following rules:

- If less than 4 vehicles were detected, the phase duration was set to a minimum of 4 seconds [12].
- If more than 30 vehicles were queued, the phase was capped at a maximum of 30 seconds [13].
- For vehicle counts between 4 and 30, the phase duration was set equal to the number of vehicles in seconds [14].

Figure 6 illustrates this logic in the form of a flowchart for better understanding and implementation.

To further improve responsiveness, a waiting time priority rule was introduced: if any vehicle had been waiting for more than 90 seconds, its lane would be prioritized for the next green phase, regardless of the vehicle count in other directions. This addressed the possibility of long-neglected queues in imbalanced traffic distributions.

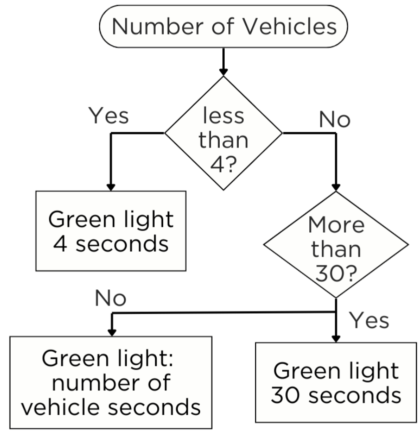

Fig. 6: Flowchart of the adaptive signal control logic based on vehicle count.

To avoid overly frequent switching, a cooldown mechanism was introduced whenever a vehicle-triggered phase change occurred. This stabilized signal behavior and reduced unnecessary toggling, especially in scenarios with borderline or fluctuating congestion levels.

The system also accounted for transitional signal states (i.e. yellow phases). If the controller detected that the current phase was a transition phase, it would immediately switch to the corresponding main-direction phase (north–south or east–west). If the active phase already matched the target direction, the updated green duration was applied without delay. Otherwise, the system would switch to the next phase and the update would occur after 5 seconds. This delay accounts for the 4-second yellow phase, ensuring that vehicles receive proper transition timing before the new green duration takes effect, thereby preventing abrupt or unsafe signal changes.

Finally, to ensure reliable green phase computation, the vehicle count for each lane was reset every 60 seconds. This periodic reset was introduced to address undercounting issues observed in earlier simulation trials, where vehicle counts were reset every time the phase changed. Since vehicles transmitted their data every 3 seconds, rapid phase changes sometimes occurred before all vehicles had the opportunity to resend their updated position and waiting time. As a result, some vehicles were not included in the decision-making process, leading to inaccurately low counts and suboptimal green durations. The timed reset mechanism ensured more accurate and consistent adaptive signal behavior.

G. Controlled Parameters and Evaluation Metrics

The simulation experiment controlled several key parameters to evaluate the effects of V2X-based adaptive traffic control. In addition to traffic density, a key condition that varied was the communication range between vehicles and RSUs. This range was adjusted across five values—100 m, 300 m, 500 m, 700 m, and 1000 m. These variations were applied only under high-density traffic conditions. Two main performance metrics were used:

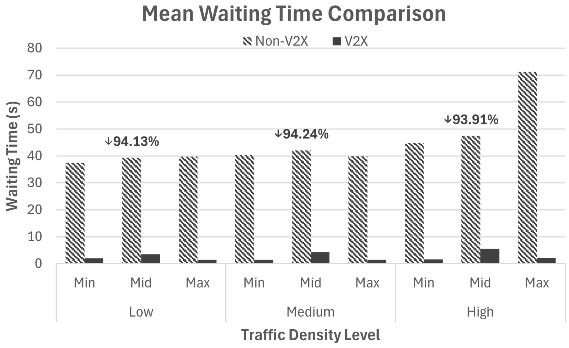

Fig. 7: Summary of mean waiting time of all traffic densities.

- Average waiting time, defined as the cumulative number of seconds during which the speed of a vehicle fell below 0.1 m/s.
- Average speed, calculated as the total length of the route divided by the trip duration of a vehicle.

Simulation results were extracted from the SUMO tripinfo.xml output file, which provides trip-level data for each vehicle, including waiting time, duration, departure times, and terminal points. Irrelevant data entries were filtered, and the desired metrics were parsed and aggregated for analysis.

V. Results and Discussion

A. Reduction in Waiting Time

Across all levels of traffic density, the V2X-enabled setup consistently outperformed traditional fixed-time schemes in simulation. In terms of average waiting time, the V2X system achieved significant reductions compared to the non-V2X setup. In low-density conditions, waiting times were reduced by 94.13% on average, ranging from 91.22% to 96.40%. For medium density, the average reduction was 94.24%, with a range of 89.87% to 96.52%. Under high-density scenarios, the V2X system achieved the most substantial improvement, with a maximum waiting time reduction of 96.91%, but with an average of 93.91%, and a range of 96.47% to 96.91%. This confirms the effectiveness of adaptive signal control in alleviating congestion.

These results demonstrate that real-time traffic light adaptation significantly reduces vehicle idling at intersections, improving overall urban traffic flow.

B. Increase in Average Speed

The V2X system also resulted in higher average vehicle speeds at all densities, with the most significant improvement observed in high-density conditions. Vehicles maintained more consistent momentum due to fewer and shorter stops at intersections. This indicates more fluid travel throughout the network.

C. Effect of Communication Range on Speed and Waiting Time

1) Average Vehicle Speed: Table I shows the average vehicle speed and its standard deviation (SD) and standard error of the mean (SEM) under different V2X communication ranges.

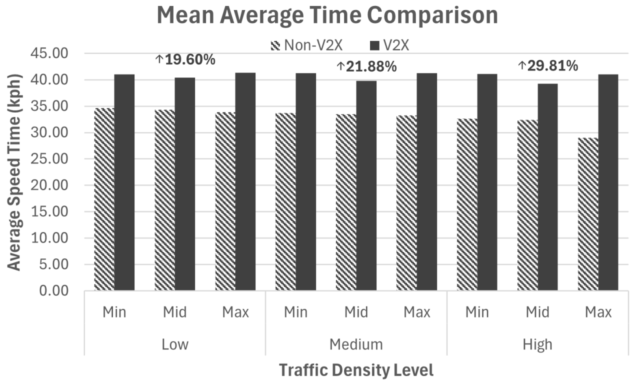

Fig. 8: Summary of mean average speed of all traffic densities.

The speeds were relatively consistent, averaging around 39 kph in all configurations. The highest speed of 39.25 kph was observed at 300 meters, with the lowest SEM of 0.26, indicating both high performance and consistency.

Although the speed means were close, the stable SEM at 300 meters further supports this range as optimal for both performance and reliability. Consistent performance across other ranges indicates robust V2X integration regardless of communication distance.

2) Average Waiting Time: As shown in Table II, the average waiting time varied more noticeably than the average speed. The lowest waiting time of 5.55 seconds occurred at 300 meters and also had the lowest SEM of 0.24. The highest waiting time was at 700 meters (6.26 s), accompanied by a higher SEM of 0.26, suggesting greater uncertainty or response inconsistency.

These results confirm that longer communication ranges do not necessarily improve performance. Overlapping RSU coverage or redundant data can disrupt effective signal timing adjustments, especially at 700m and 1000m. Thus, the 300—m range provides an optimal balance between early vehicle detection and effective signal responsiveness.

TABLE I: Mean Average Vehicle Speed under Different Communication Ranges

Range (m)	Average Speed (kph)	SD	SEM
100	39.22	9.88	0.26
300	**39.25**	**9.82**	**0.26**
500	39.01	9.80	0.26
700	39.18	9.82	0.26
1000	39.16	9.84	0.26

TABLE II: Mean Waiting Time under Different Communication Ranges

Range (m)	Average Waiting Time (s)	SD	SEM
100	6.07	10.73	0.28
300	**5.55**	**9.36**	**0.24**
500	6.07	10.73	0.28
700	6.26	9.93	0.26
1000	5.93	9.13	0.24

D. Discussion

The results show that V2X-enabled adaptive signal control can significantly improve urban traffic flow by reducing congestion and increasing vehicle speeds. Even with a simplified V2I communication setup—where vehicles periodically report waiting times and positions to RSUs—the system proved to be a scalable and effective alternative for congestion management. This is especially promising for developing cities with limited traffic infrastructure.

Several enhancements targeting system reliability and responsiveness were implemented during development. For example, the cooldown interval helped prevent erratic signal switching, particularly in fluctuating traffic conditions, contributing to more stable cycle patterns, as evidenced by lower SEM values at the 300m configuration. The 90-second override rule improved responsiveness by ensuring neglected vehicles were addressed promptly, minimizing excessive waiting times. Transition handling logic prevented unsafe or abrupt phase shifts, while the periodic vehicle count reset improved detection accuracy, thereby reducing undercounting in dense traffic conditions. Although not the primary focus of this study, these mechanisms were crucial in ensuring consistent adaptive behavior.

However, several limitations must be acknowledged. The simulation assumed a fully V2X-equipped environment with unidirectional communication from vehicles to RSUs. It also excluded dynamic routing, human driving variability (e.g. reaction times, decision-making), and mixed traffic types such as public transportation, motorcycles, and non-V2X vehicles. Moreover, only synthetic traffic data was used, and the model did not reflect actual urban behavior or network complexity.

These constraints may affect the generalizability of the results, particularly when applied to more complex and varied real-world traffic conditions. Nonetheless, the significant performance improvements observed demonstrate the practical viability of V2I-based adaptive signal control systems in traffic management.

VI. Conclusion

This work has demonstrated the potential of V2X-based adaptive signal control to improve traffic flow and mitigate urban congestion. By leveraging real-time vehicle data to dynamically adjust traffic signal durations, the system consistently outperformed traditional fixed-time schemes, particularly under medium to high traffic conditions.

Future work should focus on simulating more realistic deployment scenarios with partial V2X adoption, diverse vehicle types (including public transport and delivery vehicles), and real-world traffic datasets. Additionally, enabling dynamic rerouting behavior, multi-intersection coordination, and support for other V2X communication forms—such as Vehicle-to-Vehicle (V2V) and Vehicle-to-Pedestrian (V2P)—could further improve traffic responsiveness and safety. These extensions would provide a more comprehensive understanding of the scalability, reliability, and real-world applicability of the system.

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