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Evaluating the Performance of Right Turn Lanes at Signalized Intersection Using Traffic Simulation Model

Zainab Ahmed Alkaissi [1]*

[1] *Department of Highway and Transportation, College of Engineering, University of Mustansiriyah, Baghdad, Iraq.*

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Abstract

The issue of traffic congestion at signalized intersections is a concern in transportation systems due to the growth of urban areas and increased vehicular transportation. To study the evolution of congestion and evaluate the traffic performance operation of signalized intersections under problematic congested and improved conditions, the microscopic simulation VISSIM software is utilized. The objectives of this paper are to evaluate operational techniques, build a simulation model, and produce a well-calibrated and validated model. The methodology procedure to evaluate the signalized intersection involves the application of a traffic simulation model to observe real-time delays and stopped vehicles. Using the VISSIM software Version 9 to create an intersection model and redesign geometry with an exclusive right turn to enhance the intersection functionality and reduce delay. Our research focused on the Al-Nakhala signalized intersection located in the southern part of Palestine urban street in Baghdad city. This intersection is one of the busiest along the corridor due to significant land-use changes in the study area, including residential, educational, or commercial areas generating daily pressure from additional trips and saturating the absorptive capacity of the intersections. The proposed scenario of an exclusive right–turn could reduce the queue length and vehicle delay at the signalized intersection, resulting in a more efficient traffic operation. As a result of the reduction in vehicle delay, the Level of service (LOS) for the north, west, and east approaches improved from F to D. However, there was only a slight improvement for the south approach, with the LOS changing from E to F. Nonetheless, there was a noticeable reduction in queue length and vehicle delay ranging from 25% to 50%.

Keywords: Traffic Simulation; VISSIM; Signalized Intersection; Right-Turn; Vehicle Delay; Stopped Delay; Level of Service.

1. Introduction

The issue of traffic congestion at signalized intersections is a common challenge for transportation systems due to the expansion of urban areas and increased use of vehicular transportation. It is important to recognize that total elimination of congestion in transportation networks is not feasible, so efforts should be made to alleviate and manage congestion. Traffic congestion is a multifaceted issue involving various elements such as drivers and vehicles and road environments that interact with one another. In order to comprehend the congestion of traffic flow and its interaction with these elements, a microscopic traffic simulation proves to be valuable tool for evaluating and analyzing different traffic conditions.

The microscopic simulation model provided a detailed depiction of the travel and driving behavior of individual vehicles, allowing for the testing of adopted techniques or solution strategies to address congestion in a virtual reality environment to obtain valid simulation results for traffic operations and management. The microscopic traffic flow simulator (VISSIM) software is a discrete, stochastic, time-step-based model that incorporates the car-following model

* Corresponding author: dr.zainabalkaissi77@uomustansiriyah.edu.iq

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for vehicle movement based on the model of Wiedemann [1]. Fabianova et al. [2] utilized the VISSIM microscopic simulation software as a tool for designing and testing the capacity of a signalized intersection. They implemented a separate left turn to increase the traffic throughput of the intersection, and the results obtained showed a significant reduction in the number of vehicles waiting in the direction of critical congestion.

The rapid growth of Baghdad city has resulted in congestion at its major signalized intersections, which are crucial components of the urban road network. This study focuses on identifying a congested signalized intersection characterized by high vehicle delay and long queues of turning vehicles that disrupt traffic flow and are insufficient to handle future traffic volumes. Utilizing the microscopic simulation software VISSIM, we aim to analyze the evolution of congestion and assess the traffic performance at signalized intersections under both congested and improved conditions.

2. Background

Previous studies have focused on evaluating the operational performance of signalized intersections, particularly on turning lanes and signal redesign optimization to enhance intersection capacity. The previous studies [3-9] highlighted the negative impact of U-turning vehicles on intersection capacity. Their finding indicated an 8% reduction in when U-turn vehicles accounted for over 40% of total traffic volume.

Hellinga & Abdy [10] investigated the number of days for which traffic volume should be counted to establish the desired level of confidence using the Monte Carlo simulation technique. The results clarified that 3 days of peak hour volume observations were required to predict the average delay of an intersection with an error estimate of 50%, and 7 days of peak hour volume observations were required for an error estimate of 30% of the true mean. Essa & Sayed [11] examined the effectiveness of VISSIM and PRAMAICS software in simulating field-measured conflicts using the safety surrogate safety assessment model. The results revealed that the default simulation model showed a weak correlation with field-measured data, emphasizing proper calibration before utilizing the simulation model.

Nage & Khode [9] utilized VISSIM simulation software to compare delays at each intersection in the studied corridor, finding that changing the signal phase of signalized intersections and implementing signal controls at unsignalized intersections reduced delays. Intelligent transportation systems (ITS) and geometric redesign of intersections were identified as more effective solutions for corridor improvement [12]. Rahimi et al. [13] employed AIMSUM and SimTraffic microsimulation models to assess transportation network performance in terms of vehicle flow, travel speed, and total travel distance. Their findings indicated that AIMSUM had smaller errors, while SimTraffic provided more accurate travel time values. Singh & Rao [14] developed a calibrated and validated model using field-collected data to estimate delays, showing good compared to field data based on GEH statistics. Kotkar & Bhorkar [15] reviewed various improvements for urban corridors and traffic microsimulation models using VISSIM software, emphasizing the benefits of turning movement count surveys in reducing delays and queue lengths at intersections. They also investigated signal timing and enhancement service levels.

As shown previously, the adopted methodology and the obtained results included the following categories:

- The effect of U-turn vehicles on the reduction of capacity of signalized intersections.
- Traffic simulation models need proper calibration to provide accurate results for effective simulation modeling.
- Improvement of signalized intersections needed to develop the ITS system, which became a demand for traffic management.

Findings from previous studies have indicated that traffic microsimulation software is valuable for evaluating the operational performance of transportation systems, aiding in transportation planning, and accommodating the road network for future traffic volumes. However, most of the methods employed in the aforementioned research did not consider the impact of changes in traffic regulation based on local laws on the capacity of signalized intersections.

The contribution of this paper can be illustrated in the following:

- Proposed exclusive right-turn lane that separates through from right-turn movements temporarily and spatially.

Build a microscopic model to evaluate the traffic operational performance in terms of performance measures, vehicle delay, and stopped delay.

3. Methods

The methodology procedure for evaluating the signalized intersection involved using a traffic simulation model to monitor real-time delays and stopped vehicles. VISSIM software Version 9 was utilized to create the intersection model and adjust the geometry by adding an exclusive right turn lane to enhance intersection functionality and decrease delay time. The research methodology framework is depicted in Figure 1. Implementing an exclusive right turn lane at a signalized intersection will enhance the traffic flow of straight movements and increase their effectiveness. However, straight-through vehicles stopping in the straight-right lane during a red light may impede right-turning vehicles from navigating the intersection. The incorporation of an exclusive lane design aims to optimize spatial and temporal intersection usage, reduce vehicle delay, and enhance overall traffic efficiency.

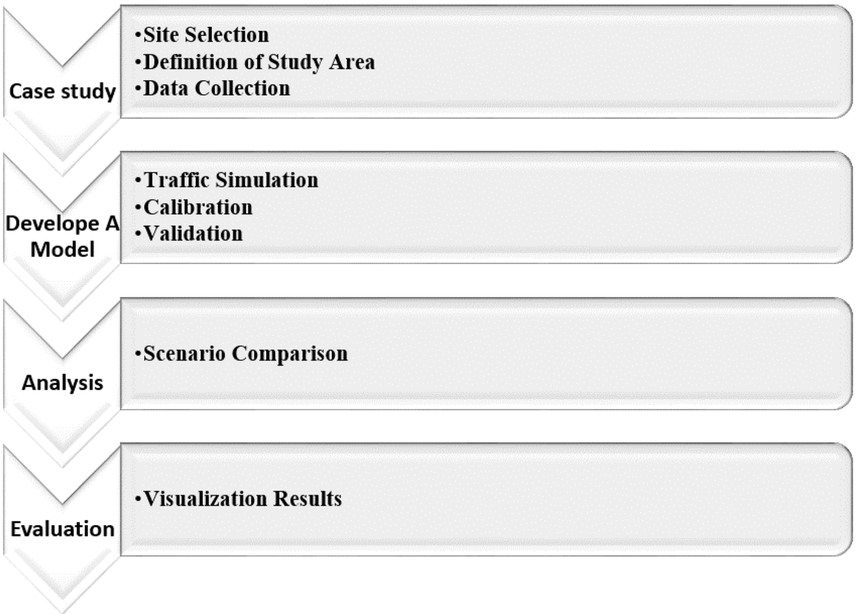
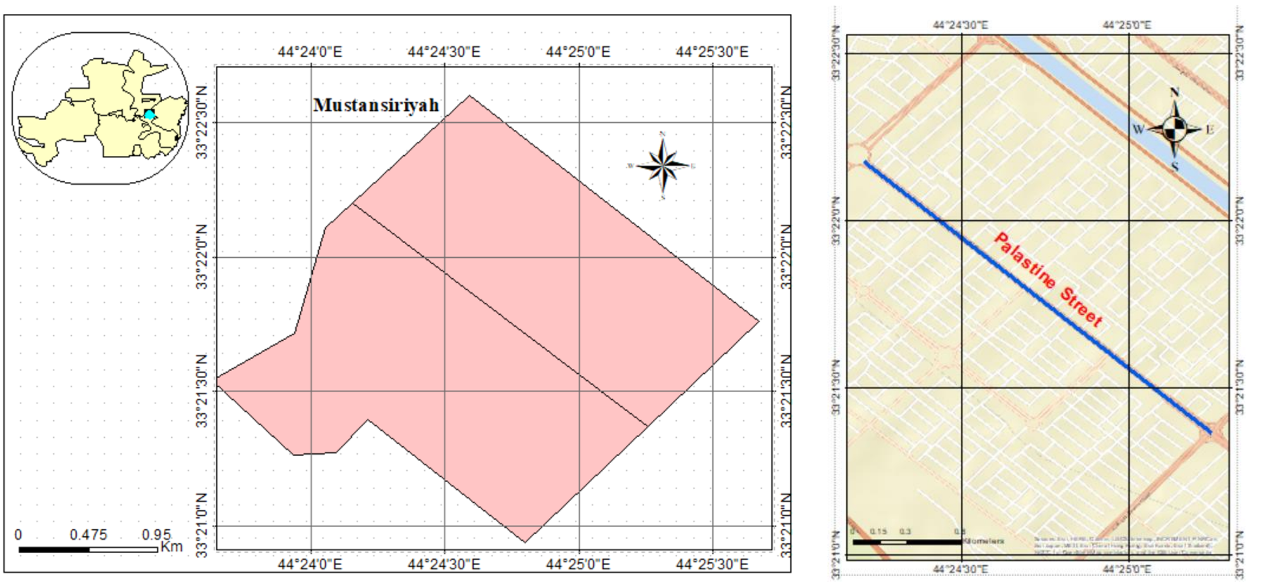


Figure 1. Research Methodology Framework of Model Development and Evaluation

3.1. Case Study

3.1.1. Site Selection

Palestine Street is a major street in Baghdad that caters to diverse land uses, encompassing commercial, educational, and residential sectors. Consequently, the segments and junctions throughout the corridor experience substantial daily traffic demand. Specially, this research centered on the Al-Nakhala intersection, at the confluence of Palestine Main Street and Al-Jihad Street, as depicted in Figure 2.



a. Area Map of Study b. Location of Signalized Intersection at Palestine street

Figure 2. Coordinated Map of Study Area [16]

3.1.2. Definition of Study Area

The Al-Nakhala signalized intersection located in the southern part of Palestine urban street in Baghdad city has been selected for this research as shown in Figure 2. This intersection is known to be one of the busiest along the corridor due to significant land-use changes in the surrounding areas, including residential, educational, and commercial sectors, leading to a daily flux of additional trips and saturating the absorptive capacity of the intersection's capacity, as documented in previous studies of the same area [17]. The Al-Nakhala intersection is a four-leg intersection, and the geometric characteristics are detailed in Table 1.

Table 1. Geometric Characteristics of Studied Intersection

Approach	Movement	No. of lanes	Average lane width (m)	Average Median Width (m)
Northbound	Right-Turn	1	3.6	3.5
	Through	1		
	Left- Turn	1		
Southbound	Right-Turn	1	3.6	3.5
	Through	1		
	Left- Turn	1		
Eastbound	Right-Turn	1	3.6	2
	Through	1		
	Left- Turn	1		
Westbound	Right-Turn	1	3.6	2
	Through	1		
	Left- Turn	1		

3.1.3. Data Collection

To collect traffic volume data, manual observations were conducted on Monday, April 16, 2019, and Tuesday, April 17, 2019, during peak hours (5:00 p.m. to 8:00 p.m.) under good weather conditions (sunny) to capture critical demand volume and verify traffic trends. Traffic signal information was also manually collected from field observations. The intersection operated with four stages controlled by a policeman, without any amber or all-red time phases noted, as the signal changed directly from red to green. It was observed that in Iraq, right–turn flow from all approaches is not required to adhere to the signal control due to the driving regulation following right-side driving rules.

From the observation and field survey of the Al-Nakhala intersection, we identified the main problems with traffic operations as follows:

- The queue of right-turn vehicles is generated due to the high through flow from the north approach, which splits into the right-turn traffic and causes impedance to their maneuvers.
- Left-turn movements from the south and west approaches countered obstructions from the unimpeded right-turning flows.

This resulted in an increase in travel time and average total delay at the signalized intersections, leading to a poor level of service.

3.2. Traffic Simulation

The VISSIM simulation software [1] was employed to simulate and assess the traffic operation of the Al-Nakhala signalized intersection. The simulation model integrated the geometric characteristics of the intersection, signal timing plan, and traffic volume data gathered from the field. The simulation duration was set for 60 minutes (3600 sec.), and the outcomes were scrutinized and confirmed. A static vehicle route was implemented to replicate traffic movements, and a reduced speed zone was included in each lane at the center of the intersection to adjust the field speed using the Widemann 99 car-following model. The Wiedemann 99 model was also utilized to simulate the default lane change behavior, as depicted in Figure 3.

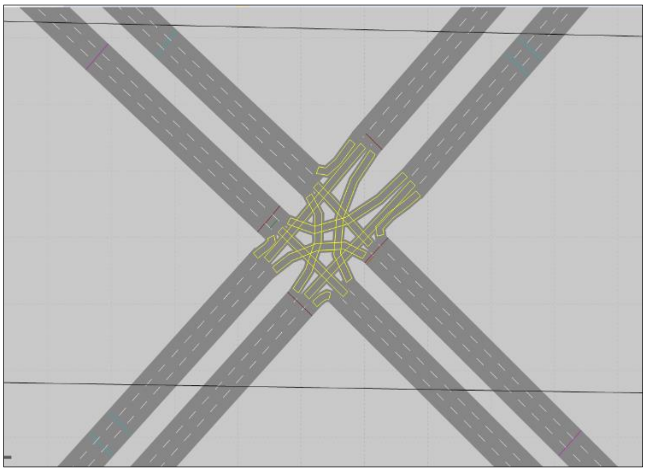


Figure 3. Reduced Speed Area for Signalized Intersection

3.2.1. Calibration and Validation

The intersection delay was obtained from the VISSIM model as the simulation output results and based on default parameters for the analyzed intersection. In general, the total delay of a signalized intersection is comprised of the geometric delay, control delay, stopped delay, and time in queue delay. The calibration process aimed to match the real-world data of the simulation model and to estimate realistic results of delay for the signalized intersection. The geometric delay was calibrated based on the time to pass the intersection and adjusted by specifying the desired speed of the reduced area inside the intersection as shown in Figure 3. The desired speed distribution was based on the surveyed field data using a global positioning system (GPS), and accordingly, the default speed distribution was justified by choosing the rectangular distributions from 12 km/hr to 38 km/hr [18].

The headway distribution at the intersection was primarily determined by the desired speed reduction in the middle of the intersection, which was justified by the reduced speed area, and the car following model parameters of the Wiedemann 99. The minimum headway CC1 represented the speed-dependent safety distance from the stop line that the driver aimed for. The average headway for the queue at the Al-Nakhala intersection for the CC1 parameter ranged from 2.5 seconds to 1.53 seconds, as depicted in Figure 4 [19].

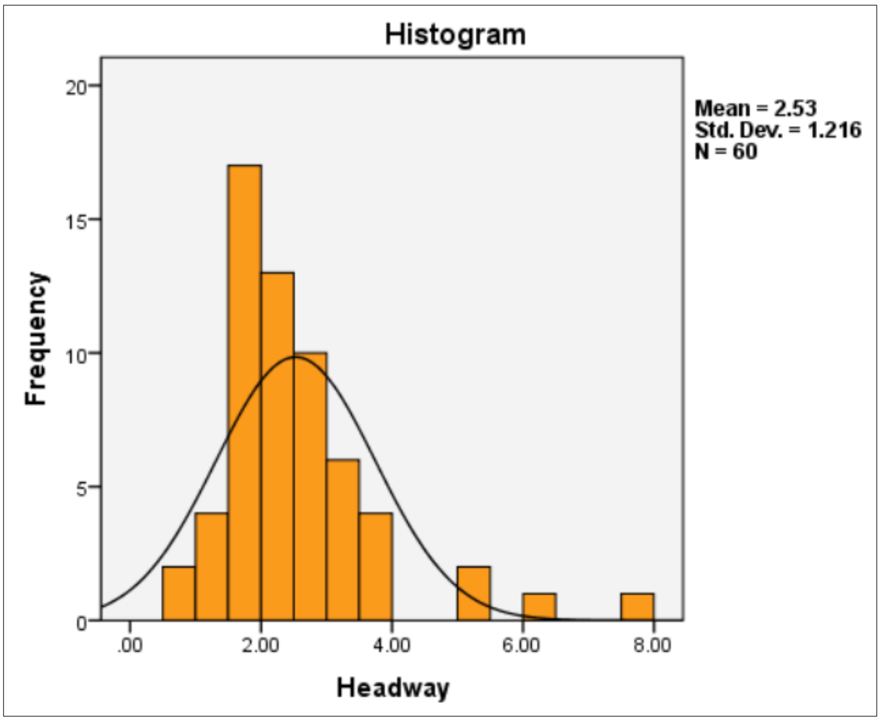


Figure 4. Time Headway Distribution for Signalised Intersection [19]

The simulation results for total delay, as illustrated in Figure 5, were derived from a post-calibration VISSIM model and compared with observed field data. The comparison is detailed in Table 2, showing that the percentage of error ranged from 3.81% to 9.84% for all approaches of the intersection model, which is below 10% and indicates close convergence between the observed field data and simulation delay results. Thus, the calibration model using VISSIM was deemed complete. In the subsequent phase of this methodology, to finalize the validation of the simulation model, the results of the stopped delay from the simulation of the calibrated model, as depicted in Figure 6, were juxtaposed with observed field data presented in Table 3. The percent error obtained from the validation model for all approaches was less than 10%, signifying that the simulation results align well with reality. Consequently, the simulation model using VISSIM was successfully calibrated and validated.

Table 2. Error Measurement of Average Vehicle Delay for Calibration Model

Approach	Average Vehicle Delay (sec/veh)		
	Simulated Results after Calibration	Observed Field Data	Error (%)
Northbound	122	115	6.09
Westbound	67	61	9.84
Southbound	76	71	7.04
Eastbound	29	21	3.81

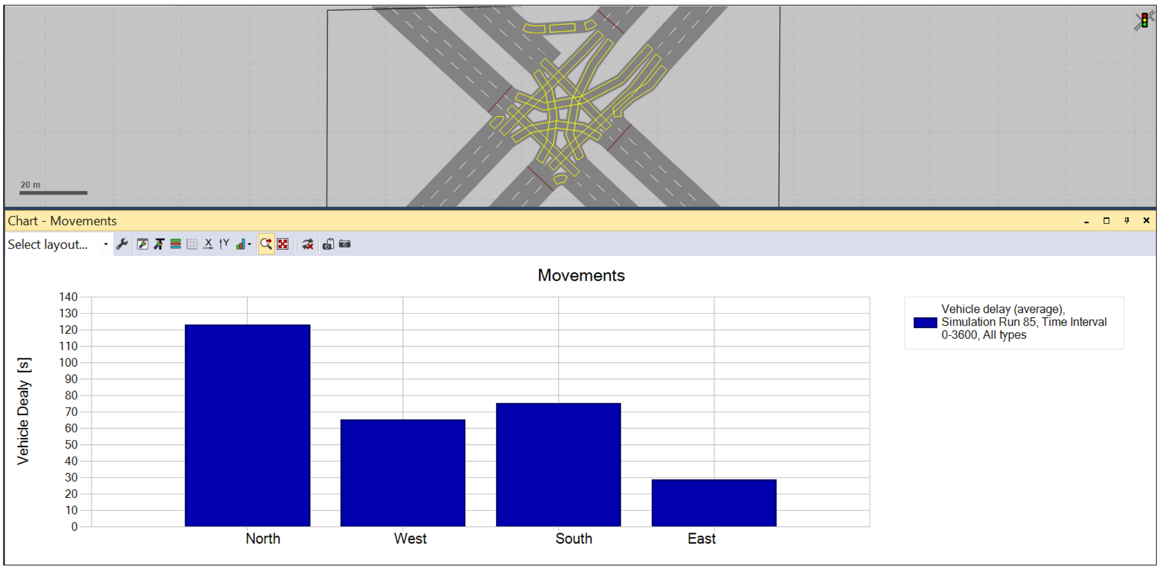


Figure 5. Vehicle Time Delay of Signalized Intersection for All Approaches

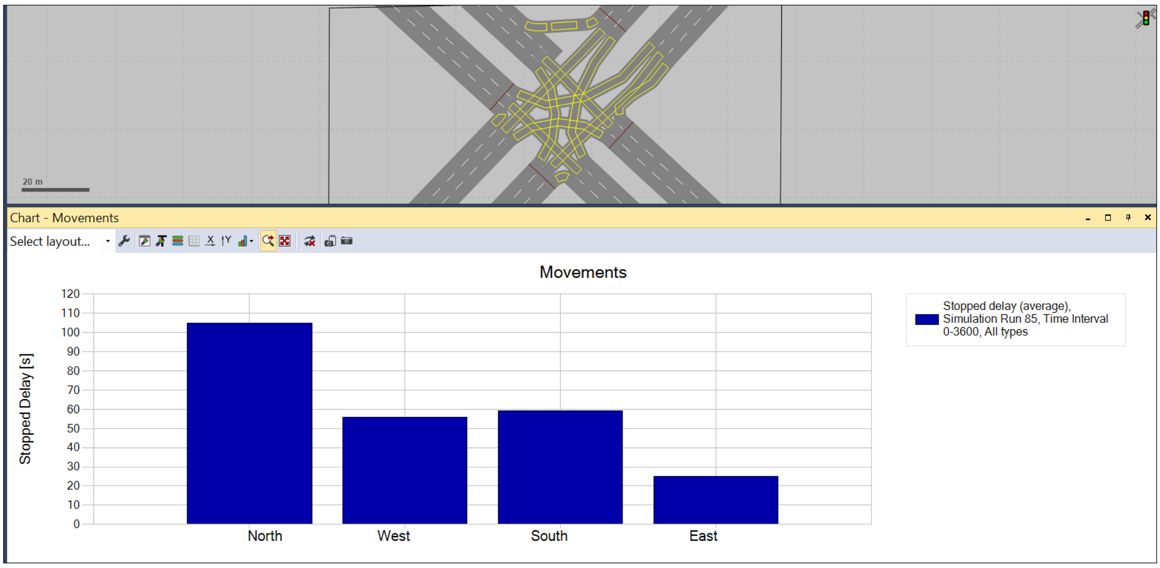


Figure 6. Stopped Delay of Signalized Intersection for All Approaches

Table 3. Error Measurement of Stopped Delay for Validation Model

Approach	Stopped Delay (sec/veh)		
	Simulated Results	Observed Field Data	Error (%)
Northbound	113	119	5.04
Westbound	56	51	9.80
Southbound	60	64	5.25
Eastbound	23	16	4.38

4. Results and Discussions

The simulation model for the physical layout of the signalized intersection was created in VISSIM for both actual and proposed scenarios, and the results were obtained from nodal analysis of the respective adopted cases. Average delay is a crucial indicator for assessing the traffic operation of signalized intersections, and these delay results were utilized to determine the actual model and assess the effectiveness of the proposed scenario.

Scenario 1: involved simulating the intersection with exclusive right-turn lanes for the north and west approaches, as shown in Figure 7. This model presents the creation of a four-approach intersection that starts with the VISSIM graphical user interface, which includes geometry layout, alignment, number of lanes, turn lanes, and stop bar using links and connectors. This was done to assess their effectiveness in addressing the impedance issues faced by through and left-turn movements from the north and east approaches. The simulation results showed reduced vehicle delay time and queue length for all approaches.

Scenario 2: involved redesigning the signal phase plan to further reduce vehicle delay and evaluate the optimum signal timing to achieve this objective. The left-turn phases for the south and north approaches of high traffic flow were separated at the present signalized intersection. The actual signal system had four phases, with a shared lane group (through, left, and right) for each approach, and was controlled by policemen. The VISSIM model applied the optimum cycle time of 95 seconds, which met the minimum average values for the selected intersection and is displayed in Figure 8. This includes the traffic signal controllers and signal heads, design phases, phase length, yellow and all red periods, cycle length, right turn on red, and maximum green. Figures 9 and 10 compare the actual model and scenarios 1 and 2 for vehicle delay and queue length results. It is evident from these Figures that the proposed scenarios could reduce the queue length and vehicle delay for the signalized intersection and result in efficient operational traffic conditions as depicted in Table 4. For a better level of service (LOS), the level of service was compared to a previous study. This study suggests a super street intersection to enhance traffic and improve the level of service. As observed, the LOS significantly improved for the north, south, east, and west approaches.

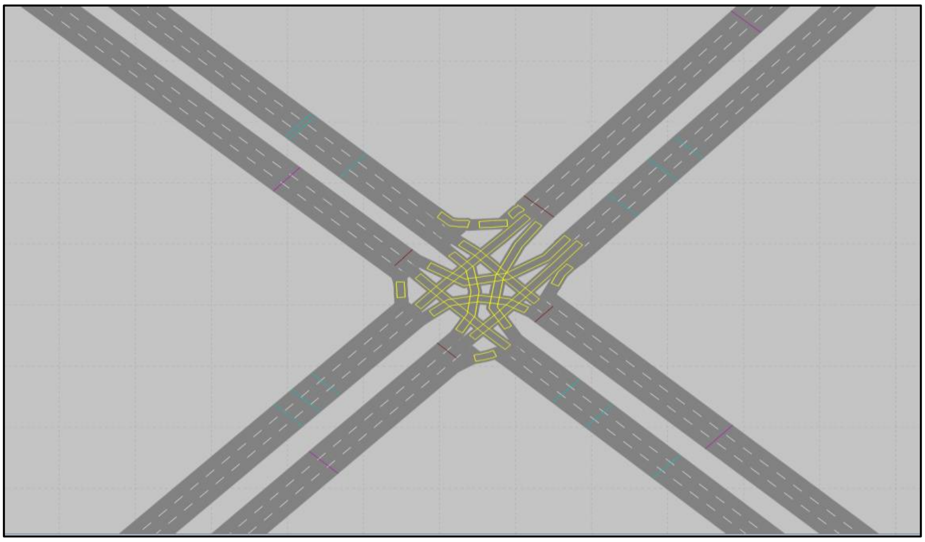


Figure 7. Scenario (1) the Simulated Intersection with Exclusive Right Turn

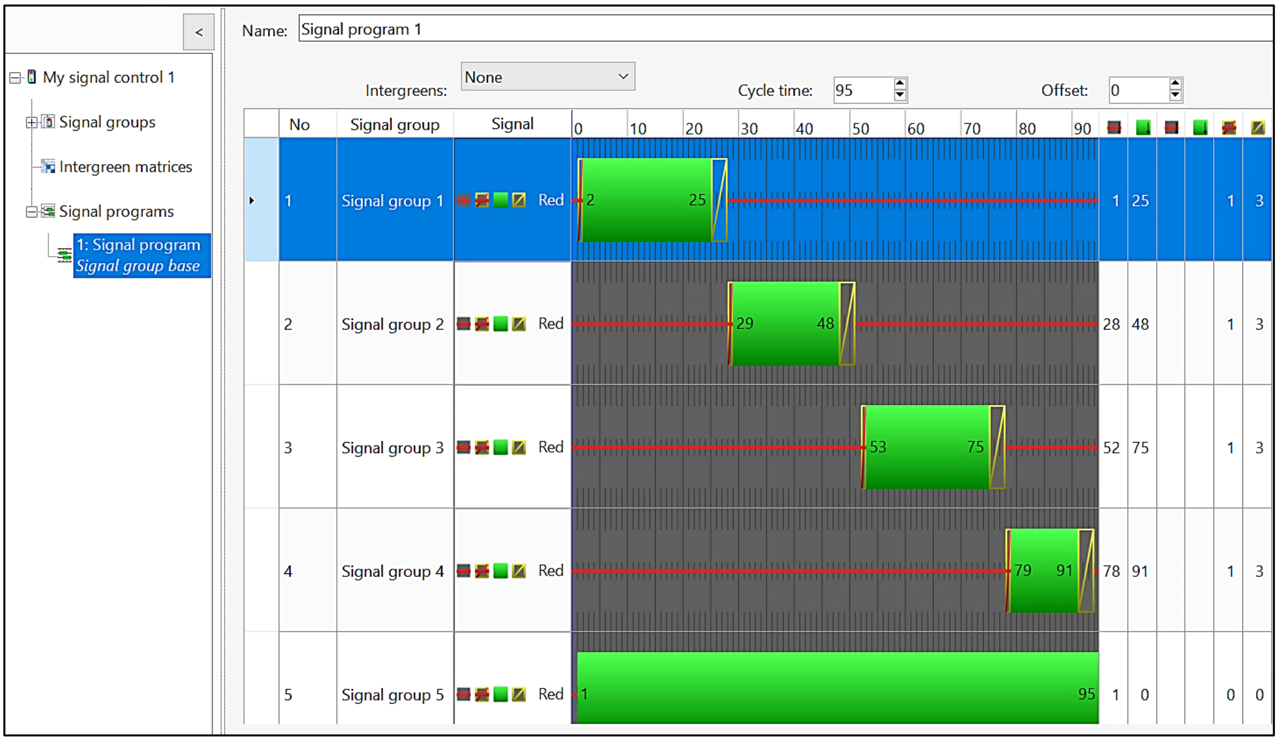


Figure 8. Signal Phase Plan in VISSIM simulation for Scenario (2)

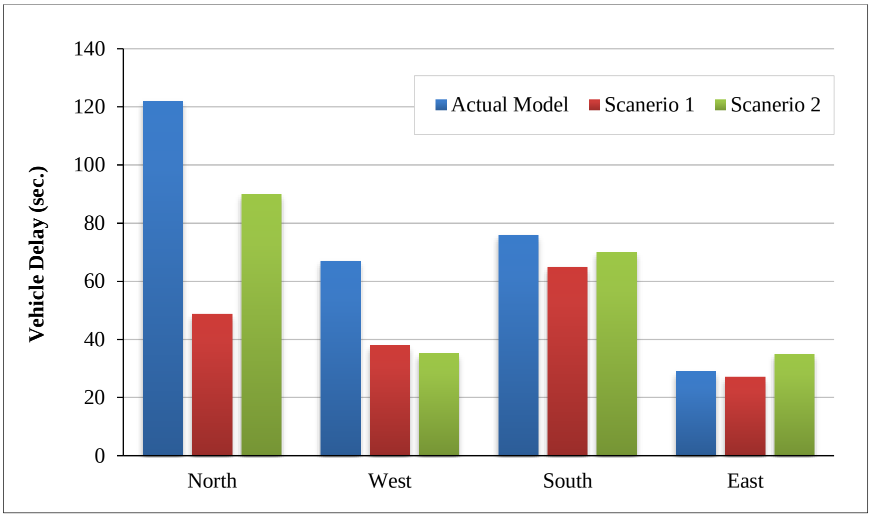


Figure 9. Vehicle Delay Results for Actual Model and Scenario (1) and (2)

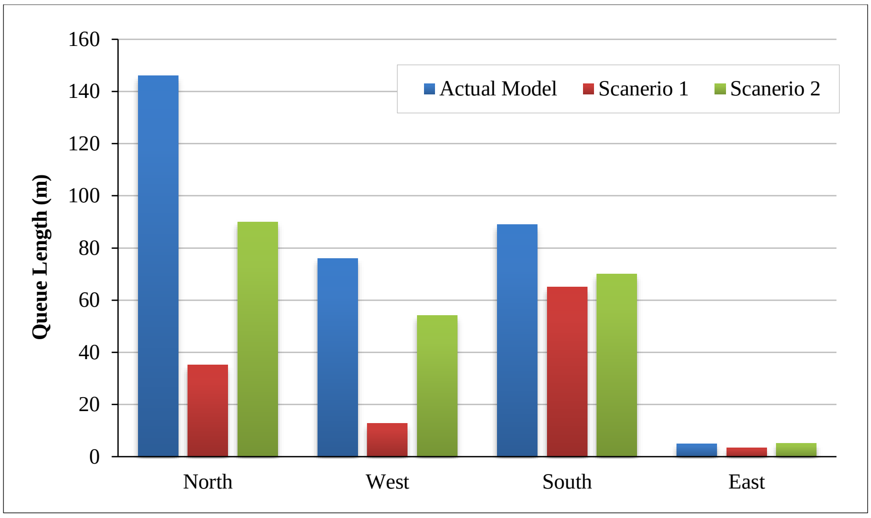


Figure 10. Queue Length Results for Actual Model and Scenario (1) and (2)

Table 4. Level of Service (LOS) for Actual Model and Scenario (1) and (2)

Approach	Level of Service (LOS)			
	Actual Model	**Scenario 1**	**Scenario 2**	**Alkaissi (2022) [20]**
Northbound	F	D	F	C
Westbound	E	D	C	B
Southbound	E	F	F	D
Eastbound	C	C	C	B

The provision of an exclusive right-turn lane, compared to the actual intersection design, results in significant improvement that serves as the foundation for quantifying the benefits of adopting this Scenario in the future. Both proposed Scenarios 1 and 2 show a reduction in delay under observed traffic conditions, with Scenario 1 demonstrating more efficiency in traffic operation at signalized intersections.

Scenario 1 proved to be effective in improving traffic operational conditions for the signalized intersection, with the induced exclusive right-turn lane resulting in a reduction in vehicle delay LOS from F to D for the north, west, and east approaches. Although the south approach only showed slight improvement with LOS changing from E to F, there was a notable reduction in queue length and vehicle delay by 25 to 50%, respectively. Figures 11 and 12 provide visual results for the VISSIM simulation of the actual model and the exclusive right-turn lane scenario, respectively. The potential impact of the exclusive right lane on reducing queue length is clear in Figure 12 compared to Figure 11. The visualization of the simulation model provides information about the policy decisions to make the required changes based on the obtained data. Hence, traffic can be efficiently managed to avoid recurrent congestion.

Figure 11. Visualization of VISSIM Simulation Actual Model for Al-Nakhala Intersection

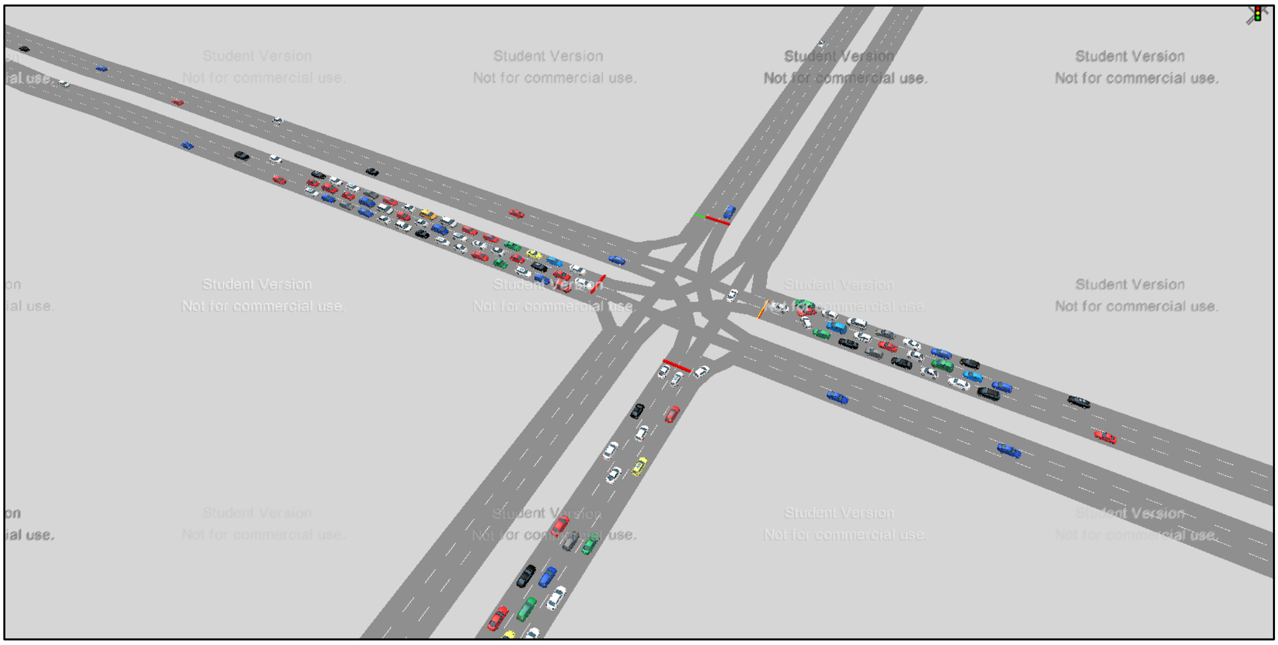


Figure 12. Visualization of VISSIM Simulation Model for Al-Nakhala Intersection with Exclusive Right–Turn

5. Conclusion

This study aimed to improve the traffic performance of the Al-Nakhala intersection in Baghdad, which was experiencing excessive delays and long queues. We utilized VISSIM simulation software to evaluate the traffic performance with an induced exclusive right-turn to achieve this. The simulation results indicated that the proposed solutions were effective in reducing delays and improving traffic operations at the intersection; generally, the simulation results for total delay were obtained from a post-calibration VISSIM model and were compared with observed field data. The percentage of error ranged from 3.81% to 9.84% for all approaches of the intersection model, which was below 10%. This indicated a good convergence between the observed field data and simulation delay results. Therefore, the VISSIM calibration model was considered to be completed. The simulation results showed that the proposed solution, which included an induced exclusive right-turn, was effective in reducing queue length and vehicle delay at the signalized intersection, leading to a more efficient traffic operation. The proposed solution, which included an induced exclusive right turn, resulted in a reduction in vehicle delay and improvement in LOS from F to D for the north, west, and east approaches. Although the south approach only showed a slight improvement with LOS changing from E to F, there was a notable reduction in queue length and vehicle delay by 25% to 50%, respectively.

5.1. Recommendations

- Continuous research should be conducted under various traffic conditions to identify effective solutions for addressing the traffic congestion issues at signalized intersections. Leveraging VISSIM simulation software as a part of the transportation planning model proves to be a valuable tool in facilitating well-informed decisions aims at enhancing the transportation system infrastructure.
- The application of intelligent transportation systems has become an urgent need to improve traffic operation at signalized intersections.
- The implementation of bus rapid transit (BRT) can be a solution to improve the quality of life for users in severely congested signalized intersections by providing signal priorities.

All of the aforementioned strategies have the potential to reduce fuel consumption and environmental pollution.

6. Declarations

6.1. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.2. Funding and Acknowledgements

The author would like to thank Mustansiriyah University, Baghdad, Iraq, for its support of this work.

6.3. Conflicts of Interest

The author declares no conflict of interest.

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