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Evaluating Traffic Delay at Urban Intersections: Field Measurements vs. VISSIM Modeling (Barzani Namr Ring Road, Erbil)

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ABSTRACT

Urban traffic congestion remains a pressing challenge in Erbil, particularly at signalized intersections where delays contribute to fuel consumption, emissions, and commuter frustration. This study presents a calibrated microsimulation model using PTV VISSIM to replicate field-measured control delays at a key intersection in Erbil. Field data were collected through video-based observations and analyzed to establish baseline performance. The simulation was calibrated using manual adjustments to driver behavior and signal timing parameters, constrained by the student version of the software. The model's accuracy was evaluated through statistical comparison with field data. Results showed a strong correlation (R = 0.938) and a high coefficient of determination (R^2 = 0.879), indicating that nearly 88% of the variation in simulated delay could be explained by observed conditions. Error metrics further supported the model's reliability, with a root mean square error (RMSE) of 7.31 seconds per vehicle, a mean absolute error (MAE) of 5.92 seconds, and GEH statistics consistently below 2, well within accepted thresholds for traffic modeling. While the study was limited to a single intersection due to software constraints, the findings offer practical insights for traffic engineers and policymakers. Recommendations include adopting adaptive signal control systems and integrating intelligent transportation technologies to improve intersection performance. Future research should expand the model to multiple intersections, incorporate real-time data, and explore environmental impacts. This study provides a localized, data-driven foundation for improving urban mobility in Erbil through simulation-based planning.

1. Introduction

Intersections are critical components of urban road networks, playing a vital role in managing traffic flow and ensuring efficient transportation. However, intersections often become bottlenecks, especially during peak hours, due to high traffic

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volumes and complex turning movements. The intersections on the Barzani Namr Ring Road are such junctions, experiencing significant congestion and delays.

The majority of research on traffic signals focuses on estimating the delays that result from the implementation of a signal control system at both individual intersections and a series of intersections. The main indicators of performance used to estimate fuel consumption and emissions, assess the sufficiency of lanes, and determine the intersection level of service (LOS) are traffic delays and queues. Traffic engineers concentrate on achieving the shortest delay because many transport authorities have determined that an acceptable LOS is one of the fundamental requirements to be addressed in signal control design [1].

Multiple methods for estimating vehicle delays at signalized crossings have been widely employed, and delays estimated at these intersections have been thoroughly examined in the literature. However, there is evidence that research on the delay estimation technique is still ongoing. This can be the result of taking into account a number of factors that could influence the delays. For instance, according to [2], the total delay can be roughly estimated by multiplying the stopped delay by a factor of 1.3. Instead of being a constant value, this element should be changeable [3-5].

The shift from stopped delay [2] to control delay [6-7] as the major factor for LOS measurement at signalized intersections also illustrates the ongoing progress by integrating the results of recent studies.

[8] demonstrated five different delay models for signalized intersections: the microscopic simulation delay model, the steady-state stochastic delay model, the time-dependent stochastic delay model, the shock wave delay model, and the deterministic queuing model.

In the context of signalized intersections, delay refers to the amount of time that a car or driver loses as a result of the signal's working as well as the traffic and geometry conditions at the intersection. In contrast, delay in the context of [7] is defined as the discrepancy between the actual travel time and the reference travel time that would occur under ideal circumstances, which include no traffic control, no geometric delay, no incidents, and no other cars on the road.

The control delay (total delay) can be categorized into acceleration, stopped delay, and deceleration delay. While overall delay better indicates the effectiveness of traffic signal operation, stopped delay is simpler to measure [3]. Transportation experts generally classify stopped delay as the delay that occurs when a vehicle is completely fixed, whereas deceleration and acceleration delay are the terms used to describe the delays caused by accelerating and decelerating vehicles, respectively.

According to [4], Figure 1 presents several elements of vehicle delay at signalized intersections, including control delay utilized in the HCM. While control delay only contained stopped delay in previous iterations, it now includes initial deceleration delay, queue move-up time, halted delay, and final acceleration delay [7].

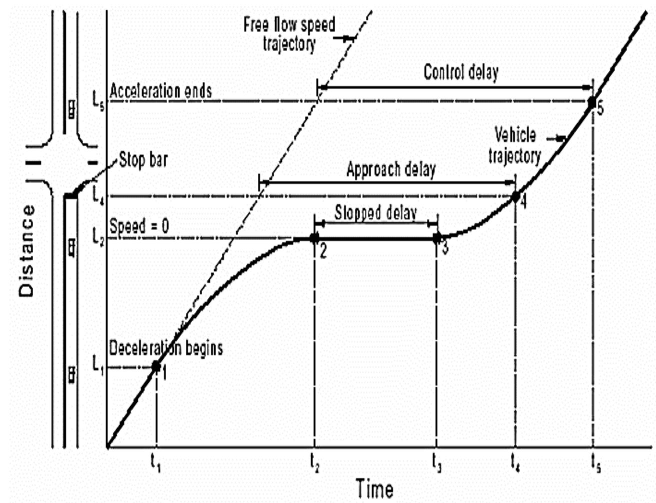

Figure 1. delay terms at a signalized intersection

Geometric delay is the name given to this kind of delay. According to [9], geometric delay is the amount of time lost as a result of intersection geometry. For turning movements, geometric delays could be significant. The sum of a vehicle's control and geometric delays is its total delay.

The operation of a signalized intersection is typically characterized in terms of effective signal intervals rather than actual intervals in delay estimate models, as illustrated in Figure 2, to account for the additional delays caused by driver reaction time and vehicle acceleration limits. By splitting the signal cycle into effective periods of stopped and moving traffic, within which constant traffic characteristics can be assumed, delay calculations are usually carried out rather than explicitly taking into account green, yellow, and amber intervals and attempting to model variable departure rates [10]. Driver reaction time at the start of the green interval and vehicle accelerations are thus assumed to determine how much the actual and effective timings differ.

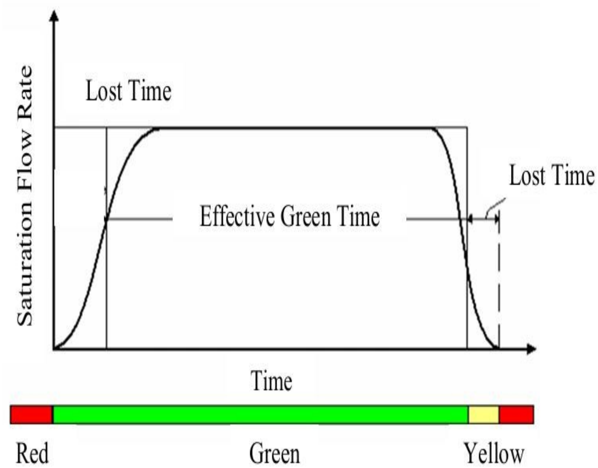

Figure 2. saturation flow diagram

Introducing VISSIM is a microscopic, time-step, and behavior-based simulation software developed by PTV Group (formerly PTV Planung Transport Verkehr AG) for modeling multimodal traffic operations. It is widely used in transportation engineering and planning to simulate and analyze traffic flow, pedestrian movement, and public transportation systems. VISSIM employs a stochastic, discrete, and time-step-based approach to model the movement of individual vehicles, cyclists, and pedestrians, making it a powerful tool for evaluating complex traffic scenarios [11].
VISSIM operates at a microscopic level, meaning it simulates the movement of individual vehicles and pedestrians based on car-following, lane-changing, and gap-acceptance models. This allows for detailed analysis of traffic behavior, including driver-vehicle interactions and the impact of traffic control measures [12].
Plus, the software supports the simulation of various transportation modes, including private vehicles, public transport (buses, trams, and trains), cyclists, and pedestrians. This multimodal capability makes it suitable for evaluating integrated transportation systems and their interactions.
Additionally, VISSIM provides advanced 2D and 3D visualization tools for analyzing simulation results. It also includes a comprehensive set of performance measures, such as travel time, delay, queue length, and level of service (LOS), to evaluate the effectiveness of transportation systems [12].

This study develops a validated microsimulation framework for delay estimation at signalized intersections in Erbil, Iraq, incorporating locally calibrated driving behavior parameters to address the limitations of conventional analytical models in aggressive driving environments.

2. Methodology

2.1. Site Selection and Description

Barzani Namr Ring Road, a vital thoroughfare in Erbil, Iraq, serves as the research site. The inner 30-meter ring road, or Barzani Namr Street, runs through the center of Erbil and encircles the city's old Citadel.
It connects important residential, commercial, and institutional districts and is a major traffic corridor that is essential for both commuters and business vehicles. The route is a good place to study traffic performance indicators like delay because of the heavy traffic volumes it experiences, especially during peak hours, as this is a critical period. Pedestrian activity, motorcycle volumes, and informal traffic behaviors were not explicitly modeled in this study due to their minimal presence within the selected corridor. Field observations and video recordings confirmed that such elements had negligible influence on overall traffic performance during the data collection period. Additionally, all recordings were conducted under stable weather conditions, with no rainfall or environmental disruptions observed. As such, weather-related impacts on driver behavior and traffic flow were considered insignificant for the scope of this analysis.
Based on their strategic positions, traffic significance, and representation of typical intersection designs in the area, eight signalized crossroads along Barzani Namr Ring Road were chosen for this study, as shown in Figure 3. The intersections that were chosen are:
A. Newroz Intersection: All approaches are busy, making this intersection a four-legged signalized one with heavy traffic coming from all sides.
B. Zaza Intersection: Unlike the other selected sites, this one has a signalized three-legged intersection, which makes it unique.
C. Shekhi Choli Intersection: This is a signalized four-legged intersection that is found within the center of a high-traffic area.
D. Media Intersection: This is a four-legged signalized intersection that is located close to media and commercially important areas.

E. Gal Intersection: A four-legged signalized intersection with significant traffic, both pedestrian and vehicular.
F. Shahidan Intersection: This is a four-legged signalized intersection that has an important connection function to the surrounding neighborhoods.
G. Khairullah Abdulkarim Intersection: A four-legged signalized intersection, with considerable traffic volume during the peak period.
H. Kurd and Arab Intersection: A four-legged signalized intersection situated in a highly congested urban area.
For the purpose of ensuring a thorough investigation of traffic performance, these crossings were selected to represent a variety of traffic circumstances and geometric configurations. The majority of intersections along the Barzani Namr Ring Road are four-legged and signalized, with the exception of Zaza.

2.2. Data Collection

The first step for traffic data collection is video recording, which is done by using 3 camera types (Sony a7mark4, Sony a7mark 3, and Canon mark4), which are recorded at morning and evening peak hours for more than one hour. Used to determine traffic volume, volume of vehicles in queue, cycle time, green time, yellow time, and all red time for each of the approaches of the intersections under study.
2.2.1. Geometric data collection
Primary dimensional data were obtained from the Traffic Engineering Department's authoritative design specifications and as-built documentation, as available in Table 1.
2.2.2. Signal data collection
Measuring cycle length, green time, yellow time, and all red time was given by the Erbil Directorate of Traffic, and double checked by video recordings; all the details are in Table 2.

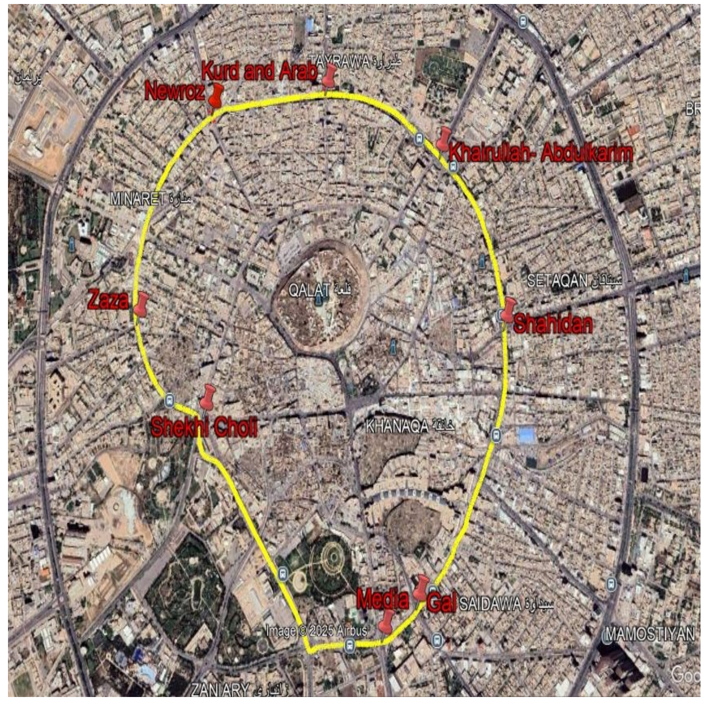

Figure 3. satellite image showing the Barzani Namr ring road and the eight intersections under study

2.2.3. Traffic Volume Data
Manual count was used very precisely cycle by cycle by replaying the video recording many times by multiple independent observers, ensuring cross-verification and minimizing the potential for human error, to determine volume of the approaches, indicating peak 15 minutes for each approaches of intersections, plus all the vehicles in the queue on the longest line is determined cycle by cycle, shown in Table 3.

2.4. Control delay

[13] indicated that control delay is a current measure of effectiveness (moe) for signalized and STOP-controlled intersections, it is best defined as time-in-queue delay plus time losses due to deceleration from and acceleration to ambient speed. According to HCM, the control delay can be calculated according to the equations below:

$$d = TQ + (FVS * CF) \quad (1)$$

$$TQ = \left(Is * \frac{\Sigma Viq}{Vtot}\right) * 0.9 \quad (2)$$

$$FVS = \frac{\Sigma vstop}{vtot} \quad (3)$$

$$Vslc = \Sigma \mathrm{Vstop}/(\mathrm{NC} * \mathrm{NL}) \quad (4)$$

CF will be obtained from Table 4.

Table 1. Geometric data of the eight intersections under study

Intersection	Approach	Width (meter)	No. of Lanes
Kurd and Arab	North	11.8	3
	East	10.4	3
	South	11.8	3
	West	10.4	3
Newroz	North	12	4
	East	16	4
	South	19	5
	West	10.5	3
Zaza	North	11	3
	South	11	3
	West	9	2
Shekhi Choli	North	7.5	2
	East	15	4
	South	19.5	5
Media	North	10.5	3
	East	13	4
	South	21	5
	West	16.5	4
Gal	North	7.5	2
	East	10.5	3
	South	9	2
	West	9	3
Shahidan	North	12.5	3
	East	10.4	3
	South	11	3
	West	8.5	2
Khairullah-Abdulkarim	North	19	6
	East	11.5	3
	South	15	5
	West	11.5	3

2.5. VISSIM Simulation Software

To accurately assess delays at the eight intersections along Barzani Namr Ring Road, a microscopic traffic simulation model was developed using PTV VISSIM, a robust traffic simulation software widely utilized for analyzing traffic operations under real-world conditions. The modeling process involved several critical steps to ensure the simulation closely replicated existing field conditions.

2.5.1. Geometric Representation

The geometric layout of each intersection was meticulously drawn in VISSIM to mirror real-world configurations, including lane assignments, turning bays, medians, and pedestrian crossings. Satellite imagery and site surveys were referenced to ensure dimensional accuracy, accounting for lane widths, curvature radii, and approach angles. This step was crucial in capturing the actual traffic flow dynamics and potential bottlenecks, as shown in Figure 4.

2.5.2. Traffic Volume and Movement Distribution

Vehicle input volumes were obtained from the video recordings, reflecting peak and off-peak traffic conditions. These volumes were entered into VISSIM as origin-destination matrices, with turning movement percentages (left, right, and through movements) assigned based on field observations and traffic count data. Heavy vehicle composition and pedestrian flows were also incorporated to enhance simulation realism.

2.5.3. Traffic Signal Timing and Control

Fixed-time traffic signal plans, as provided by the Erbil Directorate of Transportation, were implemented in VISSIM to replicate the existing signal phasing and timing at each intersection. Cycle lengths, green splits, amber, and all-red intervals were precisely defined to match real-world operations. Signal groups and detector logic were configured to ensure proper coordination and minimize phase conflicts.

2.5.4. Calibration and Validation

As a German-developed microsimulation software, PTV VISSIM incorporates default driving behavior parameters that reflect traffic conditions in Germany, which differ significantly from the aggressive driving patterns observed in Erbil, Kurdistan. Consequently, comprehensive calibration of the model's behavioral parameters, including car-following, lane-changing, and acceleration/deceleration patterns, was essential to ensure accurate representation of local traffic dynamics. The calibration process followed a rigorous trial-and-error methodology, requiring an extensive iterative adjustment to align simulated vehicle movements with real-world observations. This systematic approach ensured that the model reliably replicated Erbil's unique driving behaviors, enhancing the validity of traffic performance assessments. To ensure model reliability, validation was conducted using data from a separate intersection not included in the calibration phase. The accuracy of the simulation was evaluated using the Average Absolute Error (AAE) metric. Optimal values of parameters are defined by minimizing the absolute error between calibrated and field delay [14]. Acceptable and satisfactory model fidelity is when (AAE) falls significantly below the 15% maximum threshold according to [15]. Table 5 indicates the default values and calibrated values of VISSIM parameters.

Table 2. Signal timing of all the approaches of the eight Intersections Under Study

Intersections	Direction	Cycle length (seconds)	Green Time (Second)	Yellow (Second)	All Red (Second)
Kurd and Arab	North	232	45	4	4
	East		50	4	4
	South		40	4	4
	West		65	4	4
Newroz	North	162	30	4	4
	East		20	4	4
	South		45	4	4
	West		35	4	4
Zaza	North	104	30	4	4
	South		25	4	4
	West		30	4	4
Shekhi Choli	North	189	60	4	4
	East		45	4	4
	South		60	4	4
Media	North	219	30	4	4
	East		40	4	4
	South		67	4	4
	West		50	4	4
Gal	North	189	25	4	4
	East		50	4	4
	South		35	4	4
	West		47	4	4
Shahidan	North	212	55	4	4
	East		50	4	4
	South		40	4	4
	West		35	4	4
Khairulah - Abdulkarim	North	217	60	4	4
	East		50	4	4
	South		40	4	4
	West		35	4	4

Table 3. Volume data of all the approaches of the eight intersections under study

Intersections	Approach	Morning Peak (veh/hr)	Evening Peak (veh/hr)
Kurd and Arab	North	410	559
	East	625	710
	South	276	445
	West	598	715
Newroz	North	617	932
	East	764	1063
	South	799	1421
	West	496	789
Zaza	North	760	1049
	South	451	626
	West	119	258
Shekhi Choli	North	598	796
	East	888	1085
	South	964	1242
Media	North	643	912
	East	367	654
	South	854	1611
	West	792	1733
Gal	North	178	370
	East	569	681
	South	398	508
	West	458	570
Shahidan	North	854	977
	East	403	588
	South	628	794
	West	310	492
Khairullah-Abdulkarim	North	634	971
	East	598	751
	South	700	970
	West	526	663

Table 4. Acceleration and deceleration correction factor, CF

Free-Flow Speed	≤ 7 Vehicles	8-19 Vehicles	20-30 Vehicles
≤37 mi/h	5	2	-1
> 37-45 mi/h	7	4	2
> 45 mi/h	9	7	5

Table 5. Default and calibrated values of the VISSIM software

No.	Parameter PTV VISSIM	Default Values	Calibrated Values
1	Following		
	Look-ahead distance	250 meter	(80 meter max.-5 meter min.)
	Look back distance	150 meter	(40 meter max.-5 meter min.)
2	Car following model: Wiedemann 99		
	CC0 (Standstill distance)	1.5 meter	0.7 meter
	CC1 (Gap time distribution)	2: 0.9 seconds	1:0.5 second
	CC2 ('Following' distance oscillation)	4 meter	4 meter
	CC3 (Threshold for entering 'following')	-8	-8
	CC4 (Negative speed difference)	-0.35	-0.5
	CC5 (Positive speed difference)	0.35	0.5
	CC6 (Distance dependence of oscillation)	11.44	0.3
	CC7 (Oscillation acceleration)	0.25	1.2
	CC8 (Acceleration from standstill)	3.5	1.2
	CC9 (Acceleration at 80 km/h)	1.5	0.8
3	Lane change		
	General behaviour	Free lane selection	Free lane selection
	Waiting time before diffusion	60 second	60 second
	Min. clearance (front/rear)	0.5 meter	0.5 meter
4	Lateral		
	Desired position at free flow	Middle of the lane	Any
	Overtake on the left.	Not checked	Checked
	Overtake on the right.	Not checked	Checked
	Min. lateral distance at 50 km/h	1 meter	0.5 meter
	Min. lateral distance at 0 km/h	0.2 meter	0.5 meter
5	Signal control		
	Behaviour at the amber signal	Continous check	Continous check
	Behaviour at the red/amber signal	Go (same as green)	Stop (same as red)

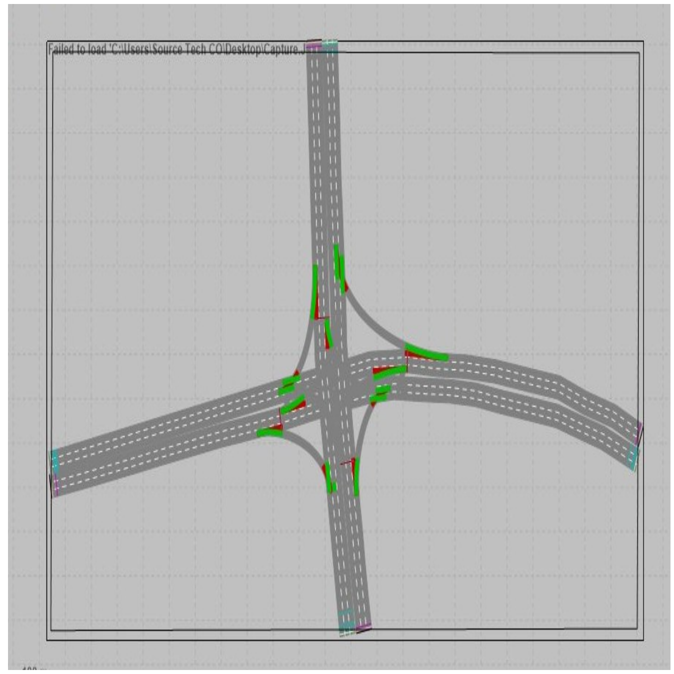

Figure 4. typical modelling by VISSIM software for Kurd and Arab intersection, showing the geometry and number of lanes

The present study employed the student edition of PTV VISSIM v21, which includes specific limitations regarding network capacity and available simulation functionalities. In particular, the software restricts modeling to a maximum of 1,500 vehicles and 12 links, and does not permit the integration of external signal controllers or the use of Component Object Model (COM) scripting. As a result, the analysis was confined to a single intersection rather than a more extensive network. Despite these constraints, the primary objective of calibrating and validating the VISSIM model for traffic conditions in Erbil was effectively achieved. The findings remain reliable within the defined scope and offer a solid basis for future research utilizing the full-featured version of the software.

3. Results and Discussion

This section presents the findings of a comprehensive traffic performance analysis conducted at eight signalized intersections along Barzani Namr Ring Road during peak hour, which is in the evening (pm). The research employed two distinct yet complementary methods to calculate control delay at the studied intersections. Following established transportation engineering practice, the Highway Capacity Manual (HCM) methodology was applied as it is more compatible with VISSIM simulation software, specifically using Equation 1, to derive theoretical delay values based on field-collected traffic parameters. These manual calculations considered critical factors, including traffic volumes, signal timing configurations, and saturation flow rates observed during peak periods.

In parallel, microscopic traffic simulation using VISSIM software generated delay estimates in the default case and the calibrated case. The simulation model incorporated detailed adjustments to accurately reflect local driver behavior patterns and traffic flow characteristics. As visually demonstrated in the comparative analysis chart, the delay values obtained from both methods showed remarkable consistency, with VISSIM outputs closely matching the HCM-based calculations, as is obvious in Table 6.

Table 6. Delay observations of the eight intersections on the Barzani Namr ring road

Intersections	Intersection Field Control Delay (sec/veh)	VISSIM Intersection Delay in Default Case (sec/veh)	VISSIM Intersection Delay in Calibrated Case (sec/veh)
Kurd and Arab	91.64	28.14	86.88
Newroz	77.2	42.48	75.44
Zaza	20.59	11.02	30
Shekhi Choli	82.95	41.66	85.13
Media	74.4	41.43	77.66
Gal	69.76	38.26	60.73
Shahidan	85.34	45.09	82.84
Khairullah Abdulkarim	75.37	77.93	89.85

The observed variation in control delay across intersections is a product of multiple interacting factors. High delay locations are typically characterized by elevated traffic volumes, inefficient signal timing, and geometric constraints, while low delay intersections benefit from coordinated signal plans, favorable geometry, and lower demand. These findings underscore the importance of context-specific calibration and highlight the need for targeted interventions such as signal optimization, geometric redesign, and adaptive control strategies to improve intersection performance in Erbil. The observed AAE is 11.91% demonstrates acceptable and satisfactory model fidelity, falling significantly below the 15% maximum threshold according to [15].

3.1. Regression Analysis of Delay Correlation

A linear regression analysis was conducted to examine the relationship between field-measured control delay and VISSIM-simulated delay across eight intersections. Tables 7 and 8 show the details of the regression analysis. The relationship between the field-measured control delay and the calibrated VISSIM-simulated delay was examined using linear regression analysis. The resulting correlation coefficient (R = 0.938) indicates a very strong positive association, meaning that as the delay observed in the field increases, the delay predicted by the simulation also increases in a closely aligned manner. The coefficient of determination (R^2 = 0.879) reveals that approximately 87.9% of the variation in the simulated delay can be directly explained by the field data. This high value confirms that the simulation model is well-tuned to reflect real-world traffic conditions.

The regression model was statistically significant ($p < 0.001$), which means there is less than a 0.1% chance that the observed relationship occurred randomly. This strengthens confidence in the validity of the model. The slope of the regression line (0.846) suggests that for every one-second increase in field-measured delay, the simulation predicts an increase of approximately 0.85 seconds. This slightly lower-than-one slope implies that the model tends to underestimate delay at higher field values, though the difference is modest. The intercept value (12.54 seconds) represents the baseline delay predicted by VISSIM when the field delay is zero. This reflects inherent simulation assumptions, such as vehicle acceleration, deceleration, and minimum signal delay, even under ideal traffic conditions.

Residual analysis was conducted to assess the accuracy of individual predictions. The residuals—differences between actual simulated delays and those predicted by the regression model—ranged from -10.81 to +13.57 seconds, with standardized residuals between -1.57 and +1.97. These values fall within acceptable statistical limits, indicating that no extreme outliers were present and that the model's predictions are consistently close to observed values.

Additionally, the percentile distribution of VISSIM delay values showed a realistic spread, ranging from 30 seconds at the lower end to nearly 90 seconds at the upper end. This distribution aligns with typical peak-hour traffic conditions in urban environments and confirms that the model captures a plausible range of intersection delays.

Taken together, these results demonstrate that the calibrated VISSIM model is both statistically sound and practically reliable for simulating intersection performance in Erbil. It provides a strong foundation for future traffic analysis and decision-making, especially when more advanced simulation features or broader network coverage are introduced.

Table 7. Regression analysis outputs for the eight intersections under study

Regression Statistics	
Multiple R	0.937798771
R Square	0.879466535
Adjusted R Square	0.859377624
Standard Error	7.426170316
Observations	8
Significance F	0.000573922
Intercept	12.54266334
Intersection Field Control Delay (sec/veh)	0.845714497

Table 8. Residual outputs

Intersections	Predicted Residuals	Standard Residuals
1	-3.163939826	-0.460189499
2	-2.391822493	-0.347886387
3	0.044075168	0.006410656
4	2.435319151	0.3542129
5	2.196178098	0.319430253
6	-10.80970664	-1.572252874
7	-1.875938497	-0.272851965
8	13.56583504	1.973126917

3.2 Model Validation Metrics: GEH, RMSE, and MAE

Table 9 presents the error metrics used to evaluate the accuracy of the calibrated VISSIM model against field-measured control delays across eight intersections. The absolute and squared errors quantify the deviation between simulated and observed values, while the GEH statistic, commonly used in traffic modeling, assesses the goodness-of-fit for each location. The results show that all GEH values fall well below the accepted threshold of 5, with an average of 0.77, indicating a strong alignment between simulation and reality. The overall RMSE of 7.31 sec/veh and MAE of 5.92 sec/veh further confirm the reliability of the model. These metrics collectively validate the effectiveness of the calibration process and support the model's suitability for traffic performance analysis in Erbil. The GEH statistic was calculated for each intersection using the following formula:

$$GEH = \sqrt{\frac{2\times(S-F)^2}{S+F}} \quad (5)$$

A GEH value below 5 is generally considered acceptable in traffic modeling, with values below 2 indicating a strong fit.

Table 9. Performance Assessment of VISSIM Calibration: GEH, RMSE, and MAE Metrics

Metric	Value
RMSE (Root Mean Square Error)	7.31 sec/veh
MAE (Mean Absolute Error)	5.92 sec/veh
Average GEH Statistic	0.77

The calibration and validation outcomes of the present study, highlighted by a strong correlation coefficient (R = 0.938), a high coefficient of determination (R^2 = 0.879), and low error metrics (RMSE = 7.31 sec/veh, MAE = 5.92 sec/veh, average GEH = 0.77), demonstrate a robust alignment between simulated and field-measured delays. These results are consistent with, and in some cases exceed, the calibration standards reported in regional microsimulation research.

In a recent study conducted in Al-Madinah City, Saudi Arabia, [16] calibrated a VISSIM model using traffic volume and travel speed, and validated it against average travel time. Their model achieved GEH values consistently below 5, confirming a strong fit between observed and simulated traffic flow. The study emphasized the importance of calibrating driver behavior parameters such as standstill distance and headway time to improve simulation precision. Compared to their findings, the present study's GEH average of 0.77 indicates an even tighter fit, particularly in delay estimation, which was not the primary focus of the Al-Madinah study.

Similarly, [15] conducted a calibration and validation study in Sohag City, Egypt, focusing on control delay at signalized intersections. Their methodology relied on field data collection and VISSIM simulation, reporting R^2 values above 0.85 and RMSE values ranging between 6 and 9 seconds per vehicle. The current study's R^2 of 0.879 and RMSE of 7.31 sec/veh align closely with these benchmarks, reinforcing the validity of the calibration approach used for Erbil's traffic conditions.

In the Iraqi context, a study by [17] in Baghdad calibrated VISSIM using field data from congested urban corridors. Their model achieved R^2 values of 0.81 and average GEH statistics of 1.2 across multiple intersections. While their calibration focused on heterogeneous traffic flow and lane discipline challenges, the present study's lower GEH average and higher R^2 suggest a more refined calibration, likely due to the focused scope on a single intersection and the use of repeated video-based data extraction.

Furthermore, [18] explored calibration techniques using neural network applications for roundabout modeling in the Middle East. Although the study did not report GEH or RMSE directly, it emphasized the importance of multi-source data validation and iterative calibration cycles. The current study's use of multiple reviewers and repeated video analysis aligns with these best practices, ensuring reliability despite software limitations.

4. Conclusion

This study successfully calibrated and validated a microsimulation model using the student version of PTV VISSIM 21 to replicate field-measured control delays at a signalized intersection in Erbil. The regression analysis yielded a strong correlation (R = 0.938) and a high coefficient of determination (R^2 = 0.879), while error metrics such as RMSE (7.31 sec/veh), MAE (5.92 sec/veh), and GEH statistics (average 0.77) confirmed the model's reliability and robustness within the defined scope. These results demonstrate that, despite software limitations, the calibrated model provides a credible representation of local traffic conditions and offers a solid foundation for operational analysis.

However, the scope of the study was constrained by the technical restrictions of the student version of VISSIM, which limited network size, vehicle volume, and excluded advanced features such as COM scripting and external signal controller integration. These constraints necessitated a focus on a single intersection rather than a broader network, which may limit the generalizability of the findings. This limitation has been acknowledged and should be addressed in future studies through the use of full-featured simulation platforms and expanded network modeling.

From a practical standpoint, the findings offer actionable insights for traffic engineers and policymakers in Erbil. The calibrated model can be used to evaluate signal timing strategies, assess intersection performance, and support data-driven decision-making. It is recommended that traffic authorities consider implementing adaptive signal control systems to respond dynamically to fluctuating traffic demand and explore the integration of Intelligent Transportation Systems (ITS) to enhance coordination and reduce delay. These technologies, when supported by calibrated simulation models, can significantly improve urban mobility and reduce environmental impacts.

Future research should extend the analysis to multiple intersections and corridors, incorporating real-time traffic data, vehicle emissions, and fuel consumption metrics. A clear roadmap includes: (1) upgrading to full VISSIM capabilities to enable COM-based signal logic and network-wide coordination; (2) integrating field data from multiple peak periods to improve temporal accuracy; and (3) evaluating the impact of ITS deployment scenarios using simulation-based performance indicators. Additionally, comparative studies across different urban zones in Erbil would help identify systemic inefficiencies and prioritize infrastructure investments.

In conclusion, while the current study provides a rigorous and localized calibration framework, its broader applicability depends on overcoming software constraints and expanding the analytical scope. Nonetheless, the results contribute meaningfully to the advancement of traffic modeling practices in Erbil and offer a foundation for future policy-oriented research and implementation.

Nomenclature

d	Total control delay (seconds/vehicle)
TQ	Average time-in-queue per vehicle (seconds/vehicle)
CF	Correction factor for acceleration, deceleration delay
	Fraction of vehicles stopping.
FVS	Sum of vehicles in the queue counts
ΣViq	(vehicle).
Is	Interval between vehicle-in-queue
	counts (seconds).
$Vtot$	Total number of vehicles arriving
	during the survey period (vehicles).
ΣVstop	Total count of stopping vehicles
Nc	(vehicles).
	Number of cycles included in the
NL	survey.
	Number of lanes in the survey lane
	group.
GEH	Geoffrey E. Havers
S	Simulated value
F	Field-measured value

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Conflicts of Interest

The authors declare no conflict of interest.

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