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RESEARCH ARTICLE Open Access

Enhancing Traffic Flow Efficiency Towards Sustainability: A Case Study of Kasnazan Arterial Road

Nishtman Abdulkhaleq Ali [1], and Botan Majeed Al-Hadad [2]

[1] Department of Highway Engineering, Technical Engineering College, Erbil Polytechnic University, Erbil, Iraq.
[2] Department of Road Construction, Technology College, Erbil Polytechnic University, Erbil, Iraq.

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** Communicated by: Assoc. Prof. Dr. Thamir M. Ahmed*
**Email address:*
Nishtman.ali@epu.edu.iq
* Corresponding Author

Abstract: Urban traffic congestion is a pressing issue in rapidly growing cities like Erbil, exacerbated by population growth, increased vehicle ownership, and inadequate infrastructure. This study evaluates traffic conditions on the Kasnazan arterial road (known as Erbil-Koya Road) using field data and VISSIM microsimulation. The analysis focused on peak-hour traffic, geometric road design, and Level of Service (LOS) metrics, revealing severe congestion (LOS F) with extensive delays, high emissions, and inefficient traffic flow due to blocked lanes, illegal parking, unsuitable speed bumps, and excessive access points. Four improvement scenarios were simulated: lane expansion, ramp implementation, driver behavior adjustments, and access point optimization. Results demonstrated that lane expansion and ramp installations significantly enhanced traffic flow, reducing delays by up to 93% and lowering CO emissions by 63%, while improving LOS to D or C. Driver behavior modifications and access point management also yielded moderate improvements.
The study underscores the need for integrated solutions combining infrastructure upgrades, behavioral interventions, and sustainable transport policies. Recommendations include unblocking and expanding lanes, replacing U-turns with roundabouts, and promoting public transit to alleviate congestion and reduce environmental impacts. These measures aim to enhance traffic efficiency, support economic growth, and improve urban sustainability in Erbil.

Keywords: *Traffic Congestion; LOS; Driver Behavior; Flow Efficiency; Sustainability.*

1. Introduction

Urban traffic congestion is a growing challenge in many cities worldwide, driven by rapid population growth, increasing vehicle ownership, and insufficient infrastructure development. This issue not only affects travel efficiency and safety but also contributes to environmental concerns such as air pollution and higher emissions. Traffic flow inefficiency and congestion constitute emergent phenomena stemming from the intricate interaction of infrastructural factors and road-user behavior. Key systemic contributors include suboptimal types of roads, road users, community culture, traffic signal timing, excessive access point density, insufficient lane capacity, and disruptive maneuvers such as U-turns, incident-related blockages, and driver behaviors, including random lane changes and illegal parking, which collectively degrade traffic stream stability. Addressing these challenges requires effective transportation planning.

Improving road capacity and traffic flow efficiency is critical for addressing urban congestion worldwide; upgrading roads is essential to accommodate increasing vehicle volumes, particularly in densely populated urban areas. These strategies aim to reduce congestion, increase vehicle speed, and improve overall transportation safety and reliability in urban environments[1].

Erbil's rapid urbanization and economic expansion have worsened traffic problems[2]—the challenges of managing urban growth and its impact on transportation in Erbil. Therefore, effective transportation planning and management are essential to accommodate this growth, support economic activity, and maintain the livability of these urban centers[3].

"Level of Service (LOS) is a crucial metric for assessing transportation system performance, indicating traffic flow conditions. Traffic flow conditions are qualitatively measured by LOS, which ranges from freely moving traffic (LOS A) to extremely crowded conditions (LOS F)" [4]. LOS A signifies the highest level with free-flowing traffic. Other levels progressively degrade through the intermediate levels (LOS B, C, D, and E), with each stage representing a further decline in flow quality. Finally, LOS F represents the worst conditions, characterized by a near traffic jam..

In addition to the immediate concerns of congestion and delay, there are growing concerns about the sustainability of the current transportation system, "sustainable development as meeting present needs without compromising future generations' ability to meet theirs," achieved through harmonizing economic, environmental, and social elements [5], The study emphasizes the importance of sustainable urban planning for Kasnazan arterial road, emphasizing public participation and regional planning for holistic development and cultural preservation.

In addition, heavy traffic volumes contribute to increased fuel consumption, elevated levels of greenhouse gas emissions, and diminished air quality[6]. These environmental impacts pose a threat to the long-term health and well-being of the region's inhabitants and contradict the goals of sustainable urban development.

The Kasnazan arterial road, a vital transit link, is heavily used for trade, social, industrial, and agricultural transport. This road link serves as a major transportation corridor connecting the densely populated areas of Sulaymaniyah and Raparin. However, rapid growth in Koya and Erbil has increased the load on this infrastructure, leading to traffic congestion, longer travel times, and reduced road safety. This has a negative impact on locals' quality of life and economic growth. This growth has resulted in increased demand for transportation infrastructure, placing further pressure on the existing road network.

The study analyzed traffic congestion on the Kasnazan arterial road using field data and VISSIM microsimulation. It considered peak-hour traffic volumes, vehicle composition, LOS, road geometric design, and illegal encroachments.

2. Literature Review

Strategies to increase the capacity of roads and the efficiency of traffic flow have been the subject of several studies conducted internationally. The inadequate development of roadway capacity and traffic flow efficiency is influenced by multiple factors, such as heavy vehicles significantly impacting traffic operations[7, 8], due to their slower speeds and larger space occupancy. Network density, volume, and speed also play a crucial role, as highly connected networks may experience increased congestion if not properly managed[9]. Additionally, lane-changing behavior and speed variations contribute to flow disruptions, reducing overall roadway efficiency[10, 11].

On-street parking[12] occupies travel lanes and increases conflicts between moving and parked vehicles. Road geometry is another critical factor, with lane width, the number of lanes, and the acceleration/deceleration lanes influencing traffic performance[13, 14]. Horizontal and vertical curves can also restrict visibility and speed consistency, leading to bottlenecks[15, 16]. Moreover, roadside infrastructure and traffic calming measures, while improving safety, can sometimes reduce capacity if not optimally designed[17-22]. Lastly, high access point density increases vehicular conflicts, particularly at intersections and driveways[23, 24].

Another key challenge in addressing these issues is the lack of detailed traffic data collection, which hinders accurate analysis and targeted interventions. Comprehensive data is essential for understanding traffic patterns, identifying bottlenecks, and implementing effective solutions to enhance roadway capacity and flow efficiency. In this context, traffic microsimulation has emerged as a valuable tool for analyzing and improving road networks according to delay, travel time, flow, capacity, and volume by software such as AIMSUN[25-27], HCS[28, 29], VISSIM[30-33]

VISSIM has been established as one of the most reliable microsimulation tools due to its ability to model drivers' behavior. The accuracy of VISSIM microsimulation models hinges critically on proper calibration and validation. A systematic calibration approach, incorporating driving behavior parameters, desired speed distributions, and vehicle characteristics[34], VISSIM's microscopic simulation capabilities allow for the modeling of individual vehicle movements, providing insights into traffic flow dynamics[35].

A significant research gap exists in the integration of real-world traffic data into microsimulation tools such as VISSIM, particularly under mixed traffic conditions. Current studies frequently neglect the complex interplay between road geometry, driver behavior, on-street parking, speed-calming measures, lane configurations, and turning movements, leading to insufficiently accurate models. Addressing this gap is critical for enhancing the reliability of traffic simulations, which can inform better urban planning and traffic management strategies by incorporating these to improve network capacity and operational efficiency, ultimately contributing to more sustainable transportation systems.

2.1 Aim and Objectives

This study aims to evaluate and enhance the operational efficiency of the Kasnazan arterial road utilizing the LOS approach by identifying congestion hotspots and improvements through microsimulation modeling. The specific objectives are:-

1. To analyze the existing traffic flow characteristics.
2. To find the level of services for the Kasnazan arterial road in both directions, from Erbil to the Koya sub-district (called Koya-Erbil Road direction) and from the Koya to Erbil direction (called Koya-Erbil Road direction).
3. To test multiple improvement scenarios, including lane addition, change in access points, removing on-street parking, etc.
4. To recommend optimal solutions based on performance metrics, including travel time, delay, level of service, queue length, and emissions.
5. Use VISSIM as a microsimulation tool to model the existing traffic and geometric road conditions and to process the proposed scenarios.
6. To compare the Level of Service calculated using HCM 2010 with the results obtained from traffic simulation in PTV VISSIM.

3. Methodology

3.1 Study Area Selection

This research focuses on the Kasnazan arterial road, a 1 km segment connecting Erbil city to Koya sub-district, a major arterial route with high traffic volumes, aiming to assess and improve traffic operations shown in Fig.1.

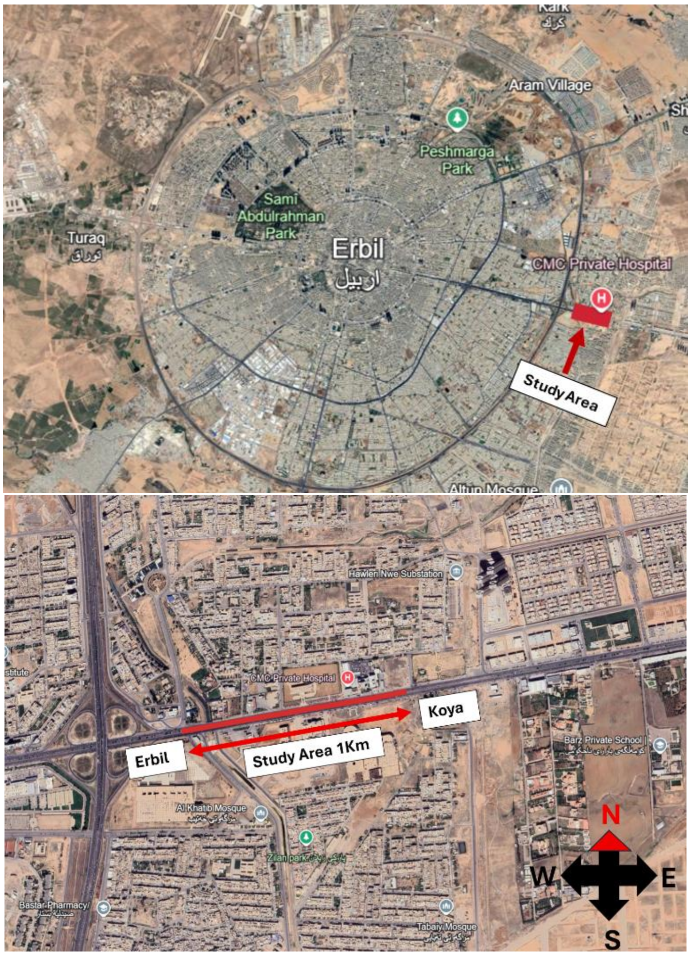

Figure 1:Kasnazan Arterial Road Study Area.

3.2 Data Collection

3.2.1 Geometric Data Collection

A site visit was conducted to collect geometric data, which was utilized with manual measurement techniques with precision surveying equipment to ensure accuracy, as presented in Table 1.

Table 1:Geometric Data of Kasnazan Arterial Road

Directions	No. of lane	Lane width[m]	Gutter width [m]	Shoulder [m]	sidewalk width [m]	Number of Bumps	Number of access lines	Access Point Density	Median [m]	Number of U-Turns	Section [m]
Erbil–Koya	4	3.5	0.7	2.8	8.5	0	10	44	8	1	1000
Koya–Erbil	3	3.5	0.7	3.45	3	1	16	31	8	1	1000

3.2.2 Traffic Data Collection

Traffic data were collected through video processing to ensure comprehensive and reliable data extraction.

1. Camera Setup: A camera was installed at a strategic location to record traffic movements along both directions (Erbil-Koya and Koya-Erbil) as presented in Fig. 2. The process included:

Figure 2: Camera Installation and View Angle**.**

2. Recording Duration:

   A comprehensive video recording schedule was implemented over four consecutive days (Thursday-Sunday), including two working days (Thursday, Sunday) and two weekend days (Friday, Saturday), to capture varying traffic patterns. On the first day, 14 hours of continuous recording (06:00 AM–08:00 PM) were conducted to identify peak hours, while the following three days focused on two-hour sessions during morning (07:00–09:00 AM) and evening peaks (04:00–06:00 PM). Extracted traffic parameters included traffic volume (vehicles/15 min), vehicle speed (km/h), turning percentages at U-turns, and vehicle classification (passenger cars, buses, trucks, motorcycles, etc.).

3.3 Data Processing

Video processing for the recorded footage was analyzed using VTM (Video Traffic Monitoring). However, manual verification of extracted data was manually cross-checked to ensure accuracy and eliminate errors. Table 2. Classifies vehicle traffic into five distinct types (passenger cars, small trucks, large trucks, buses, and motorbikes) during peak periods for both the Erbil-Koya and Koya-Erbil directions of the Kasnazan arterial road.

3.4 Traffic Simulation

The PTV VISSIM 2025 (SP 05) Thesis License, along with the PTV manual, was employed for microsimulation modeling to simulate existing traffic conditions by inputting geometric and traffic data into VISSIM. The model was calibrated using observed traffic flow, speed, human behavior, and delays, and its accuracy was verified by comparing simulated outcomes with real-world data. Statistical methods ensured the reliability of the results, while performance measures such as level of service (LOS), delay, queue length, fuel consumption, and emission gases were analyzed based on HCM2010 guidelines for multilane highways. Therefore, LOS was calculated manually with reference to HCM 2010, which relies on the following equations: free flow speed (FFS) is estimated by Equation (1):

Table 2: Analyzed traffic data for Kasnazan Arterial Road

Peak period	Direction	Peak hour time	Volume [veh/hr]	U-Turn Volume %	PC %	Small truck %	Large truck %	Bus %	Motorbike %	Peak Direction
Thursday Morning	Erbil → Koya	7:30-8:30	3,086	14	86.5	3.5	2	4	4	Koya → Erbil
	Koya → Erbil	7:30-8:30	4,469	10	91	2.5	1.5	2	3	Koya → Erbil
Sunday Evening	Erbil → Koya	5:00-6:00	4,700	8	89	3	2	1	5	Erbil → Koya
	Koya → Erbil	5:00-6:00	3,527	16	88	4	2	2	4	Erbil → Koya

(1) $$FFS = BFFS - fLW - fLC - fM - fA$$

"*Where: BFFS = base FFS for multilane highway segment (mi/h); FFS = FFS of basic freeway segment (mi/h). fLW = adjustment for lane width, from Exhibit 14-8 (mi/h). fLC = adjustment for TLC, from Exhibit 14-9 (mi/h).fM = adjustment for median type, from Exhibit 14-10 (mi/h); and fA = adjustment for access point density, from Exhibit 14-11 (mi/h)*" [4]. Equation (2) was applied to determine the demand flow rate under equivalent base conditions:

(2) $$vp = \frac{V}{PHF \times N \times f_{hv} \times f_p}$$

"*Where: vp = demand flow rate under equivalent base conditions (pc/h/ln); V = demand volume under prevailing conditions (veh/h); PHF = peak hour factor; N = number of lanes (one direction); fHV = adjustment factor for presence of heavy vehicles in traffic stream, from Equation 14-4; and fp = adjustment factor for atypical driver populations*" [4]. The heavy-vehicle adjustment factor f_{HV} is computed by Equation (3);

(3) $$f_{HV} = \frac{1}{1 + P_T(E_{T-1}) + P_R(E_{R-1})}$$

"*Where: PT = proportion of trucks and buses in traffic stream, PR = proportion of RVs in traffic stream, ET = passenger-car equivalent (PCE) of one truck or bus in traffic stream, and ER = PCE of one RV in traffic stream.*"[4]. To find LOS manually, HCM2010 considers three main criteria: density, speed, and flow rate, as their relation is presented below:

(4) $$D = \frac{vp}{S}$$

"*Where: D = density (pc/mi/ln), and S = mean speed of traffic stream (mi/h)*" [4]. Table 3 presents the results of the Kasnazan Arterial Road performance evaluation for both directions (Erbil-Koya and Koya-Erbil) as a multilane road. This is manually determined using the methods described in the HCM (2010).

Table 3: Kasnazan Arterial Road performance evaluation (Manual calculation)

Time Period	BFFS [km/h]	FFS [km/h]	F_{HV}	*Vp* [*pc/h/ln*]	S [km/h]	D [pc/km/ln]	LOS
Thursday—Morning (07:30-08:30) Koya-Erbi (3 Lane)	80	59.5	0.97	1600	58	45	F
Sunday – Evening (05:00-06:00) Erbil-Koya (4 lane)	80	55.5	0.97	1262	55.5	37	E
Sunday – Evening (05:00-06:00) Erbil-Koya (*3 lane)	80	55.5	0.97	1683	53.4	51	F

Note: * (The 4th lane of the Erbil-Koya Road is assumed blocked due to on-street parking for Vissim simulation comparison)

This methodology ensures a systematic approach to evaluating the Kasnazan Arterial Road's performance and developing data-driven solutions for traffic improvement.

4. Findings and Discussion

The speed analysis for the Kasnazan Arterial Road was conducted during two time periods: morning (7:30-8:30) and evening (5:00-6:00), as presented in Table 4. The data revealed significant variations in vehicle speeds across lanes and directions, influenced by lane blockages, parking, access points, bumps, and U-turns.

Table 4: Average Speed analysis of Kasnazan Arterial Road (km/h)

Vehicle type	Directions	Thursday morning peak hour				Sunday- Evening peak hour			
		1st lane	2nd lane	3rd lane	U-Turn	1st lane	2nd lane	3rd lane	U-Turn
PC	Erbil-Koya	56	50	42	23	56	50	42	23
	Koya-Erbil	63	52	49	23	63	52	49	23
Small truck	Erbil-Koya	52	46	38	19	52	46	38	19
	Koya-Erbil	42	34	25	19	42	34	25	19
Large truck	Erbil-Koya	-*	40	37	-*	-*	40	37	-*
	Koya-Erbil	-*	29	22	-*	-*	29	22	-*
Bus	Erbil-Koya	-**	41	38	18	-**	41	38	18
	Koya-Erbil	37	31	23	18	37	31	23	18
Motor	Erbil-Koya	85	79	76	36	85	79	76	36
	Koya-Erbil	65	43	44	36	65	43	44	36

Note:* no large truck ,** no bus

The Erbil-Koya direction of the Kasnazan Arterial Road comprises four lanes, but the 4th lane (adjacent to the shoulder) is effectively blocked due to parking activities. The shoulder is occupied by car sellers, and the 4th lane is used for parking, forcing vehicles to merge into the third lane, which subsequently pushes traffic into the 2nd lane. This disruption creates congestion and reduces flow efficiency. The Koya-Erbil direction of the Kasnazan arterial road has three lanes, with parking on the shoulder and a speed bump at the midpoint of the selected segment of the study area. Table 5 presents the existing road conditions during Thursday morning and Sunday evening peak hours, highlighting severe congestion and inefficiency. These results underscore the critical need for infrastructure improvements to alleviate congestion, reduce environmental impact, and enhance traffic flow efficiency. PTV VISSIM uses the Bosch Emission Model, which leverages Bosch's cloud-based Environmentally Sensitive Traffic Management (ESTM) to calculate emissions and fuel consumption by analyzing per-second trajectory data (speed, acceleration, gradient, and emission class). VISSIM sends this data to Bosch's cloud, which returns detailed emissions (e.g., nitrogen oxides, carbon monoxide, volatile organic compounds) for visualization and analysis, enabling precise, vehicle-specific pollution assessments. The model dynamically computes emissions based on traffic conditions, offering high accuracy but requiring an internet connection.

Table 5: Exiting condition performance by VISSIM for the Kasnazan Arterial Road

	Thursday-Morning Peak Hour		**Sunday- Evening Peak Hour**	
Direction	**Koya-Erbil**	**Erbil-Koya**	**Koya-Erbil**	**Erbil-Koya**
average QLEN [m]	40.7	81.3	68.6	71.7
QLEN MAX [m]	358.5	311.9	432.6	311.9
LOS	F	F	F	F
Average VEH. DELAY [s]	91.8	291.1	137.7	253.6
average STOP DELAY[s]	10.4	108.8	26.1	128
STOPS [stopped vehicle/non-stopped vehicle]	2.4	19	5.6	13.7
Carbon monoxide [g]	7435.7	12305.1	8629	14008.6
Nitrogen Oxides [g]	1446.7	2394.1	1678.9	2725.6
Volatile organic compounds [g]	1723.3	2851.8	1999.8	3246.6
Fuel Consumption [L]	402.6	666.3	467.2	758.5

Given these deficient performance metrics, Fig.3 shows the existing condition of the road and four alternative scenarios to identify potential improvements in traffic flow, reduce delays, and minimize environmental impact. These scenarios were tested to determine the most effective solution for upgrading the road network, which are the following:

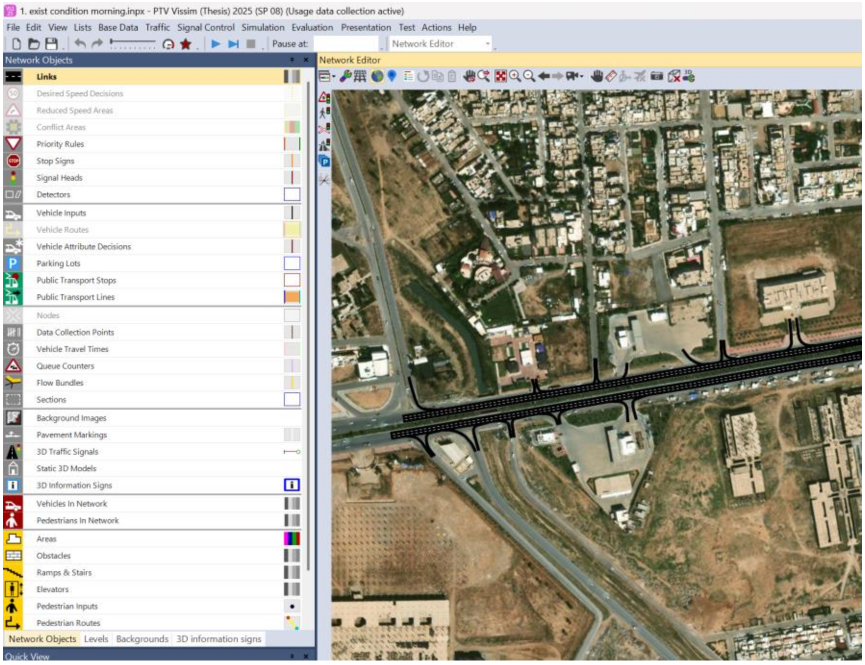

Figure 3: The Existing Road condition of the Kasnazan arterial road (shows direction, access points, medians, and the U-turn)

1. The first scenario involves reinstating the fourth blocked lane on the Erbil-Koya route while adding an additional lane to the Koya-Erbil direction, thereby expanding it from a three-lane to a four-lane roadway. Fig.4. illustrates the performance evaluation of this scenario, demonstrating its effectiveness in reducing congestion and emissions. This scenario significantly improves traffic flow during both morning and evening peak hours. In the morning, queue lengths decreased by 28% (Koya-Erbil) and 99% (Erbil-Koya), with LOS improving to LOS_D in both directions and delays dropping by up to 91%, with CO emissions decreasing by 6% (Koya-Erbil) and 63% (Erbil-Koya). Similarly, the evening peak shows reductions in queues (77% Koya-Erbil, 58% Erbil-Koya), delays (76% and 81%), and emissions (38% and 37%), with LOS improving to LOS_D and LOS_E, respectively.

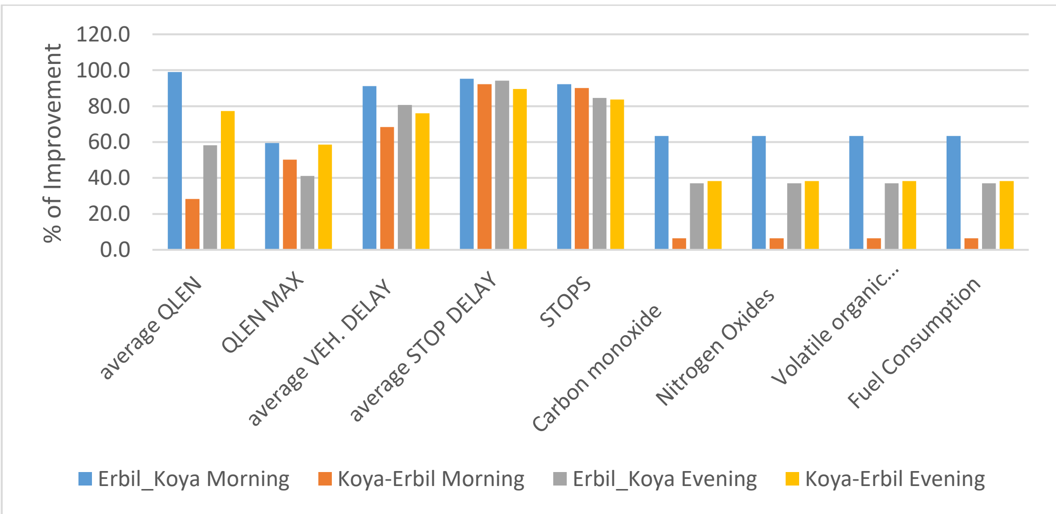

Figure 4: The effect of reinstating a blocked lane and adding an extra lane.

2. The Ramp Scenario is the second scenario, which involves removing bumps and replacing U-turns with ramp turns. Demonstrates significant improvements in traffic conditions, particularly

for the Erbil-Koya route, as evaluated based on performance metrics, as shown in Fig.5, which achieves LOS_D (Koya-Erbil) and LOS_C (Erbil-Koya) in the morning. Queue lengths are drastically reduced by 99.5% (Koya-Erbil) and 99.9% (Erbil-Koya) compared to the existing scenario, while delays decrease by 63% (Koya-Erbil) and 93% (Erbil-Koya). Emissions and fuel consumption also show moderate reductions, with CO emissions dropping by 9% (Koya-Erbil) and 48% (Erbil-Koya). In the evening, ramps further enhance traffic flow for both directions to LOS D, reducing queue lengths by 95% (Koya-Erbil) and 99.6% (Erbil-Koya) and cutting delays by 81% (Koya-Erbil) and 88% (Erbil-Koya), alongside decreases in emissions by 19% (Koya-Erbil) and 43% (Erbil-Koya).

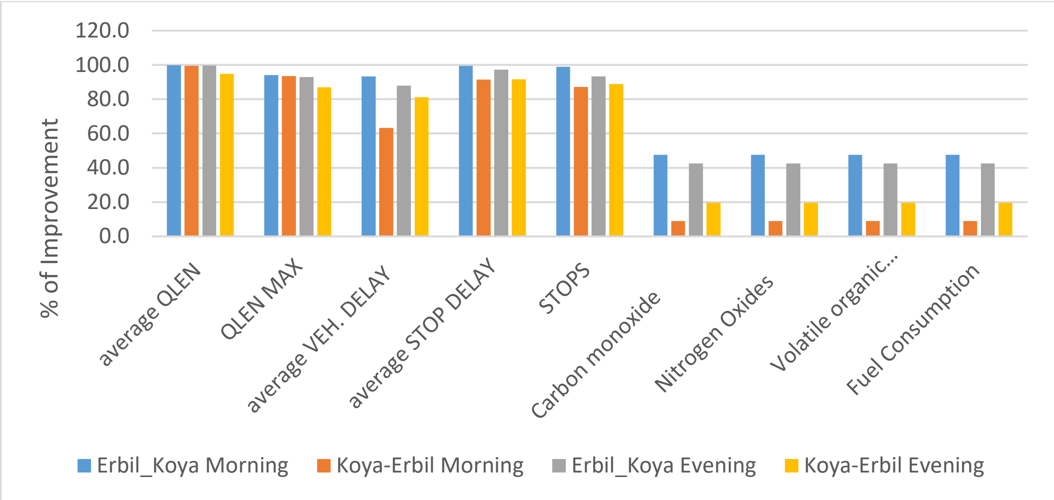

Figure 5: The Scenario of Replacing the Existing U-Turn with a Ramp

3. Adjusting driver behavior by (enhancing the 5s duration of 5% probability for driver's error to 0%) and activating safe stop distance mode, the evaluation of the third scenario presented in Fig.6. In the morning, modifying driver behavior leads to a significant reduction in queue lengths by 56% (Koya-Erbil) and 31% (Erbil-Koya), yet both directions remain at LOS_F, indicating persistent congestion. Delays show an improvement of 22% for Koya-Erbil, higher by 43% for Erbil-Koya. Emissions and fuel consumption exhibit minor fluctuations of 3% (Koya-Erbil) and decrease by 24% (Erbil-Koya). Similarly, in the evening scenario, adjusting driver behavior results in an 82% reduction in queue lengths for Koya-Erbil but no change for Erbil-Koya. Delays decreased by 27% (Koya-Erbil) but improved by 67% (Erbil-Koya). Emissions dropped by 28% for Koya-Erbil and by 19% for Erbil-Koya. These findings suggest that while driver behavior adjustments can enhance certain performance metrics, their effectiveness varies significantly depending on the time of day and traffic direction, underscoring the need for targeted interventions.

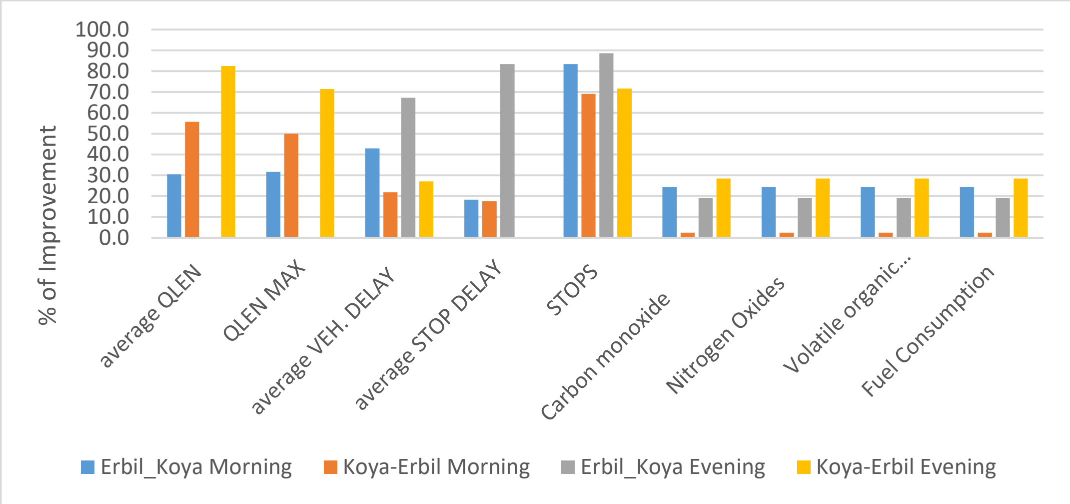

Figure 6: Performance of deducing the driver behavior error scenario.

4. The fourth scenario involves the implementation of acceleration and deceleration lanes for both travel directions to mitigate the adverse effects of access points on traffic flow and capacity, as illustrated in Fig.7. During morning peak hours, this optimization yields significant improvements for the Koya-Erbil direction, obtaining the level of service (LOS) of D with a 99.5% reduction in queue length, while the Erbil-Koya direction shows moderate enhancements, achieving E with an 82% decrease in queue length. Additionally, delays were reduced by 66% (Koya-Erbil) and 83% (Erbil-Koya), alongside notable declines in CO emissions of 26% and 42%, respectively. In the evening peak, the benefits are even more pronounced, with LOS D and LOS E obtained for Koya-Erbil and Erbil-Koya, respectively, with queue lengths diminishing by 99.6% in both directions, delays decreasing by 76% (Koya-Erbil) and 81% (Erbil-Koya), and emissions dropping by 25% and 46%. These results demonstrate that integrating acceleration and deceleration lanes effectively enhances traffic efficiency, reduces environmental impact, and improves overall roadway performance.

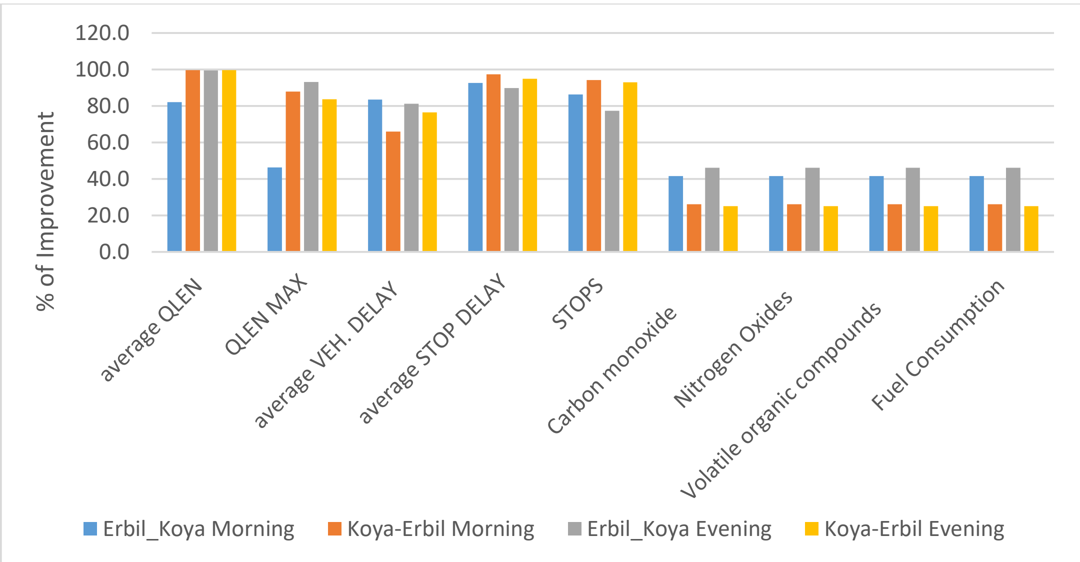

Figure 7: Adding acceleration and deceleration performance.

5. Conclusion

This study evaluates the traffic congestion on the Kasnazan arterial road (known as Erbil-Koya Road), using field data and VISSIM microsimulation. The analysis reveals severe congestion, with both directions operating at Level of Service (LOS) F during peak hours, characterized by excessive delays, long queue lengths, and high emissions. Key contributing factors included illegal parking, blocked lanes, inadequate road geometry, including the location and geometry of the existing U-turn, and a high density of access points. These issues not only impaired traffic flow efficiency but also exacerbated environmental problems, such as increased fuel consumption and greenhouse gas emissions.

The analysis of the Kasnazan arterial road during morning (7:30-8:30) and evening (5:00-6:00) peak hours reveals significant traffic challenges. The existing scenario consistently shows the worst performance, with Level of Service (LOS) F, long queues, high delays, and elevated emissions and fuel consumption. Implementing a 4-lane road (Scenario 1) or a ramp (Scenario 2) improves traffic flow, reducing delays and emissions, and upgrading the flow efficiency to LOS to D and C, respectively. Expanding the road to four lanes or adding ramps would significantly enhance traffic conditions, reduce delays, and lower emissions.

The findings underscore the importance of integrated transportation planning that combines infrastructure upgrades with behavioral and operational improvements, while existing infrastructure is inadequate for current traffic demands. Applying these integrated solutions—such as lane expansion, the replacement of U-turns with ramps, and the addition of dedicated acceleration and deceleration lanes—to Koya's road network presents a direct pathway to achieving significant sustainability objectives. These infrastructural interventions, coupled with the promotion of efficient driving behaviors, optimize traffic flow, which substantially decreases vehicle fuel consumption. This reduction in fossil fuel use directly translates into lower emissions of CO_2 and other harmful greenhouse gases and pollutants.

In short, these improvements boost public health through cleaner air and strengthen the economy by reducing fuel and medical expenses. Therefore, executing this strategy is vital for a more efficient and sustainable transport system.

A comparison of the Level of Service (LOS) results between HCM manual calculations and Vissim software for the Koya-Erbil and Erbil-Koya directions reveals notable differences. For the Koya-Erbil direction (Thursday morning), both methods yielded LOS F, indicating consistent congestion levels. However, for the Erbil-Koya direction (Sunday evening), HCM produced LOS E, while Vissim resulted in LOS F. This discrepancy arises primarily from two factors: first, Vissim simulated the scenario with three lanes due to assumed on-street parking blockage, whereas HCM calculations initially considered four lanes. When HCM was adjusted to three lanes, it also produced LOS F, aligning with Vissim. Second, Vissim utilized real field speed data, while HCM relied on speed equations, introducing minor variations. Despite these differences, the results were closely aligned, validating the reliability of Vissim's output.

The study recommends prioritizing lane additions and ramp implementations, as these scenarios delivered the most substantial benefits in terms of congestion relief, environmental sustainability, and overall traffic efficiency. Future research could explore the combined effects of these interventions and their long-term impacts on pavement conditions with cost analysis.

Based on the findings of this study, the following recommendations are proposed by simulation in PTV VISSIM to improve traffic flow on the Kasnazan arterial road. Key measures include expanding capacity by adding a fourth lane in each direction and enforcing anti-parking rules. The existing U-turn should be replaced with an interchange ramp to remove speed bumps and reduce delays. These efforts should be supported by promoting disciplined driving through awareness campaigns.

PTV VISSIM is a comprehensive traffic simulation tool that allows engineers to accurately evaluate the performance of existing road networks and test various optimization strategies in a virtual environment prior to real-world implementation. It facilitates the precise identification of congested and problematic areas by simulating complex behaviors such as lane-changing, car-following dynamics, and vehicle headways. The software incorporates probabilistic elements to account for drivers' errors and variations in driving style, enhancing its realism. Furthermore, it provides detailed environmental analyses, measuring emissions and fuel consumption under different traffic conditions to assess the impact of scenarios on travel time, pollution, and overall sustainability.

Authors Contribution

Nishtman Abdulkhaliq Ali (1): Collected the data, conducted the analysis, and prepared the manuscript.

Botan Majeed Ahmad (2): Supervised the research and contributed to the critical review and revision of the manuscript.

Conflict of Interest

The authors have no conflicts of interest to declare.

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