ISSN: 2524-1354 (Online), ISSN: 2519-7851 (Print)
Africa Habitat Review Journal
Volume 21 Issue 2 (May - August 2026)
http://uonjournals.uonbi.ac.ke/ojs/index.php/ahr

Evaluating Intelligent Traffic Management and Intersection Performance at Ring Road Kileleshwa/Riverside Drive, Nairobi

***Tabitha Wambui Kariuki, Simpson Nyambane Osano, John Francis Gichaga and Brian Oketch Jobita**
https://orcid.org/0009-0009-0259-7553

Received on 7th April, 2026; Received in revised form 19th May, 2026; Accepted on 11th June, 2026.

Abstract
This study evaluates the impact of Intelligent Traffic Management Systems (ITMS) on the operational performance of the Ring Road Kileleshwa/Riverside Drive intersection in Nairobi City, Kenya. Despite increasing deployment of ITMS in African cities, microsimulation-based evaluations of their operational effectiveness remain limited. Using AIMSUN microsimulation software, four traffic control scenarios were modelled and analysed: unsignalized priority control, fixed-time signals, optimized fixed-time signals, and vehicle-actuated signals. Performance was assessed using throughput, volume-to-capacity ratio, delay, queue length, and Level of Service (LOS). Results indicate that all scenarios experienced severe congestion, although operational performance varied across approaches. Vehicle-actuated control increased throughput but worsened delays due to unoptimized base timing, while the optimized fixed-time plan achieved the most balanced operational performance. The findings demonstrate that signal optimization alone cannot resolve physical capacity constraints and must be complemented by geometric improvements. The study contributes a replicable microsimulation framework for evaluating ITMS effectiveness in African urban intersections.

Keywords: Adaptive traffic control, AIMSUN, microsimulation, signal optimization, urban mobility, level of service, queue length, traffic flow, Nairobi

INTRODUCTION

Urban traffic congestion has intensified in many cities globally, including Nairobi, due to increasing vehicle ownership and limited road capacity. Congestion is characterized by reduced travel speeds, longer travel times, and increased operational inefficiencies, particularly at intersections which constitute critical bottlenecks within urban road networks (An et al., 2022; Githinji & Asuna, 2020). The resulting delays generate substantial economic, social, and environmental costs, especially in rapidly urbanizing cities within developing countries (Aboud et al., 2024; Ahmida et al., 2023).

Conventional congestion mitigation measures such as road expansion and grade-separated infrastructure require substantial financial investment and land acquisition, making them difficult to implement sustainably in many African cities (Pokhrel et al., 2023). Consequently, transport authorities are increasingly adopting Intelligent Traffic Management Systems (ITMS) to improve traffic operations through adaptive and data-driven traffic control approaches (Vijayaraghavan & Rian Leevinson, 2020).

In Nairobi, ITMS have been deployed at several intersections, including the Ring Road Kileleshwa/Riverside Drive intersection under the Kenya Urban Roads Authority's Nairobi Western Ring Road project. Despite this deployment, the intersection continues to experience severe congestion and frequent manual traffic control during peak periods, raising concerns regarding the operational effectiveness of the system.

Although ITMS deployment is increasing across African cities, rigorous microsimulation-based

**Corresponding author:*
***Tabitha Wambui Kariuki** Engineer, Kenya Roads Board*
Email: tabbykariuki2012@gmail.com

evaluations of their operational performance within local traffic conditions remain limited. Unlike previous studies focusing primarily on analytical modelling, this study applies calibrated microsimulation to evaluate multiple ITMS operational scenarios within Nairobi's traffic environment. The Ring Road Kileleshwa/Riverside Drive intersection was selected because of its strategic role in linking major residential and commercial areas within Nairobi and its inclusion in Nairobi's ITMS pilot corridor.

This study therefore evaluates the impact of intelligent traffic management on the operational performance of the Ring Road Kileleshwa/Riverside Drive intersection in Nairobi City, Kenya, focusing on traffic flow, capacity, delay, queue length, and Level of Service under different traffic control scenarios.

THEORY

The literature reviewed is organized into three thematic categories: (i) ITMS definitions and technologies; (ii) intersection performance evaluation methods; and (iii) simulation tools and their application in performance assessment.

Vijayaraghavan & Rian Leevinson (2020) define Intelligent Traffic Management System (ITMS) as a combination of networks and systems for optimal road user commuting experience. Theoretically, ITMS is grounded in systems optimization and feedback control theory, whereby real-time sensor data drives dynamic adjustment of signal parameters to minimize network-wide delay and maximize throughput (Agrahari et al., 2024; Nellore & Hancke, 2016). The evolution of ITMS encompasses various technologies including adaptive signal control systems (ASCS), real-time traffic monitoring sensors, Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication technologies, artificial intelligence algorithms, and predictive analytics (Nematichari et al., 2022).

Operational performance of intersections is an assessment of an intersection's efficiency in facilitating the movement of vehicles, pedestrians, and other transportation modes while minimizing delays and maximizing system effectiveness (Hameed & Ahmed, 2019). Researchers have identified key performance metrics used to assess intersection operational performance including queue length, average delay, Level of Service (LOS), traffic flow, emissions, and Volume-to-Capacity ratio (Ahmida et al., 2023; Ashqer et al., 2024; Pokhrel et al., 2023; Tilahun Fetene, 2025; Yimer, 2021). Various approaches can be employed to evaluate intersection operational performance, including analytical methods, simulation, and field studies (Tilahun Fetene, 2025).

Researchers have applied these methods to assess the operational performance of signalized and unsignalized intersections. Pokhrel et al. (2023) assessed the performance of a T-junction (Jay Nepal intersection) in Kathmandu, Nepal using SIDRA Intersection software based on average delay, queue length, and LOS indicators. The study established that adjusting cycle lengths and optimizing left-turning movements improved LOS while reducing delay and queue length.

Hong et al. (2017) used SIDRA and AIMSUN to evaluate the performance of a roundabout in Adelaide, Australia based on queue length, speed of travel, delay, and LOS. The findings showed that maximum queue length and speeds were comparable between the models while delay and LOS values were slightly higher in SIDRA than in AIMSUN. This divergence is methodologically significant as it suggests that SIDRA's analytical approach tends to produce more conservative delay and LOS estimates compared to the stochastic simulation in AIMSUN. The implication is that model selection can influence conclusions regarding intersection performance and the resulting policy interventions. For complex traffic environments, microscopic simulation tools such as AIMSUN may therefore offer greater representational fidelity.

Ahmida et al. (2023) used SIDRA software to assess the performance of four junctions in Al-Beyda city, Libya. The study concluded that improving traffic signal coordination and timing results in decreased delay, enhanced LOS, and increased traffic flow. These findings reinforce evidence that signal timing optimization improves operational performance across different traffic and geographic contexts. However, both the Ahmida et al. (2023) and Pokhrel et al. (2023) studies relied solely on SIDRA and did not validate simulation outputs against field-observed traffic data.

To evaluate these operational indicators, researchers increasingly rely on traffic simulation techniques capable of replicating real-world traffic behaviour under varying traffic control conditions. Traffic simulation models are broadly categorized into macroscopic, microscopic, and mesoscopic types. Macroscopic simulations analyze traffic flow using aggregate parameters such as volume, speed, and density, making them suitable for evaluating regional transport plans. Microscopic simulations, based on car-following, lane-changing, gap-acceptance, and route choice theories, simulate individual vehicle behavior to provide detailed network analyses. Mesoscopic models integrate features of both macroscopic and microscopic approaches, capturing platoon behavior for accurate travel time estimation. Overall, traffic simulation models enable precise evaluation of transportation network performance before and after road improvement interventions (Rahimi et al., 2021). This study adopted a microscopic simulation model using AIMSUN software.

Despite global advancements in Intelligent Traffic Management Systems, many countries continue to face challenges such as inadequate technical knowledge, lack of synchronization among systems, absence of a master plan, and financial limitations which impair the efficiency of deployed systems. Evaluating the effectiveness of these systems is therefore necessary to ensure that the technologies applied are appropriate for local traffic conditions (Makino et al., 2018).

There remains a significant gap in evaluating the applicability and operational impact of ITMS within Nairobi City's traffic context. Unlike previous studies that primarily relied on analytical modelling approaches, this study applies calibrated microsimulation to evaluate multiple ITMS operational scenarios within Nairobi's urban traffic environment. The study therefore undertakes a systematic evaluation of the impact of intelligent traffic management on the operational performance of the Ring Road Kileleshwa/ Riverside Drive intersection in Nairobi City, Kenya, offering insights into the effectiveness of ITMS and guiding future transportation planning and policy interventions.

Conceptual Framework

Figure 1 presents the conceptual framework guiding this study by illustrating the relationship between Intelligent Traffic Management interventions and intersection operational performance indicators. The independent

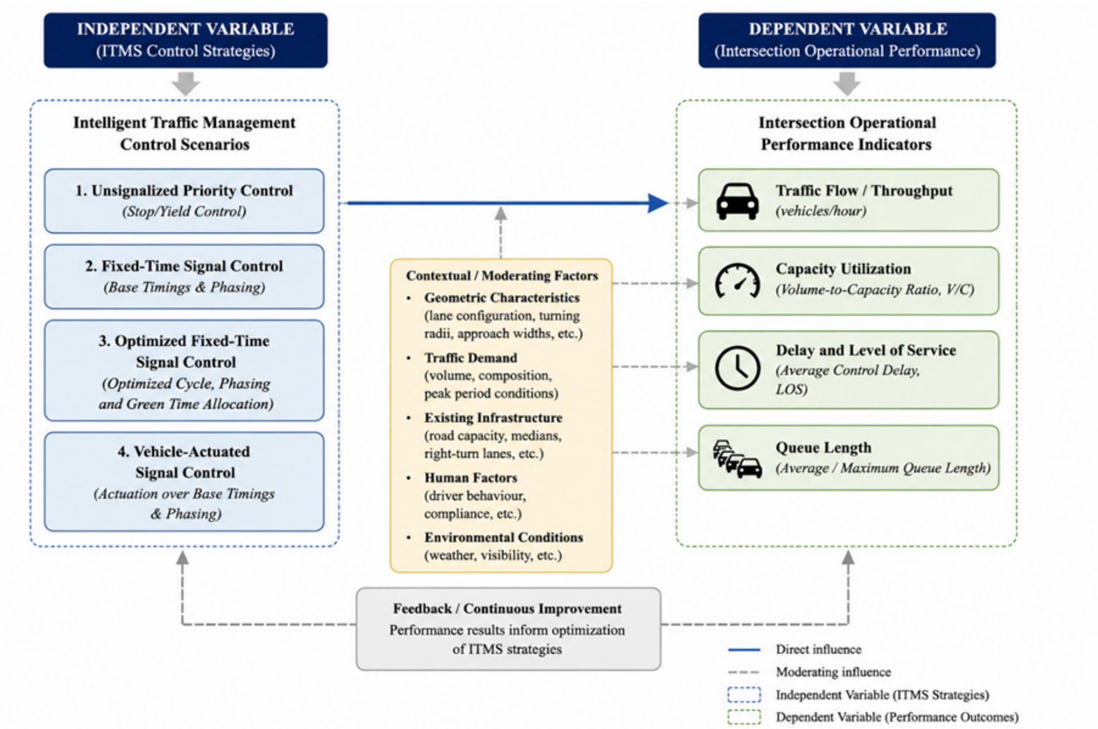

FIGURE 1
Conceptual framework for intersection operational performance evaluation
Source: Author, 2026

variables comprise the different traffic control scenarios including unsignalized priority control, fixed-time signal control, optimized fixed-time signal control, and vehicle-actuated signal control. These interventions influence the dependent variables namely traffic throughput, volume-to-capacity ratio, average delay, queue length, and Level of Service (LOS), which collectively measure intersection operational performance.

The framework assumes that variations in traffic signal control strategies directly influence traffic flow characteristics and operational efficiency at the intersection. However, the relationship between intelligent traffic management and operational performance is also affected by existing geometric and capacity conditions at the intersection. The conceptual framework therefore supports evaluation of how different intelligent traffic management approaches affect operational performance under Nairobi's urban traffic conditions.

RESEARCH METHODS

This study combines literature review with empirical analysis specific to the Ring Road Kileleshwa/Riverside Drive intersection. **Figure 2** presents the methodological flow followed in conducting the study.

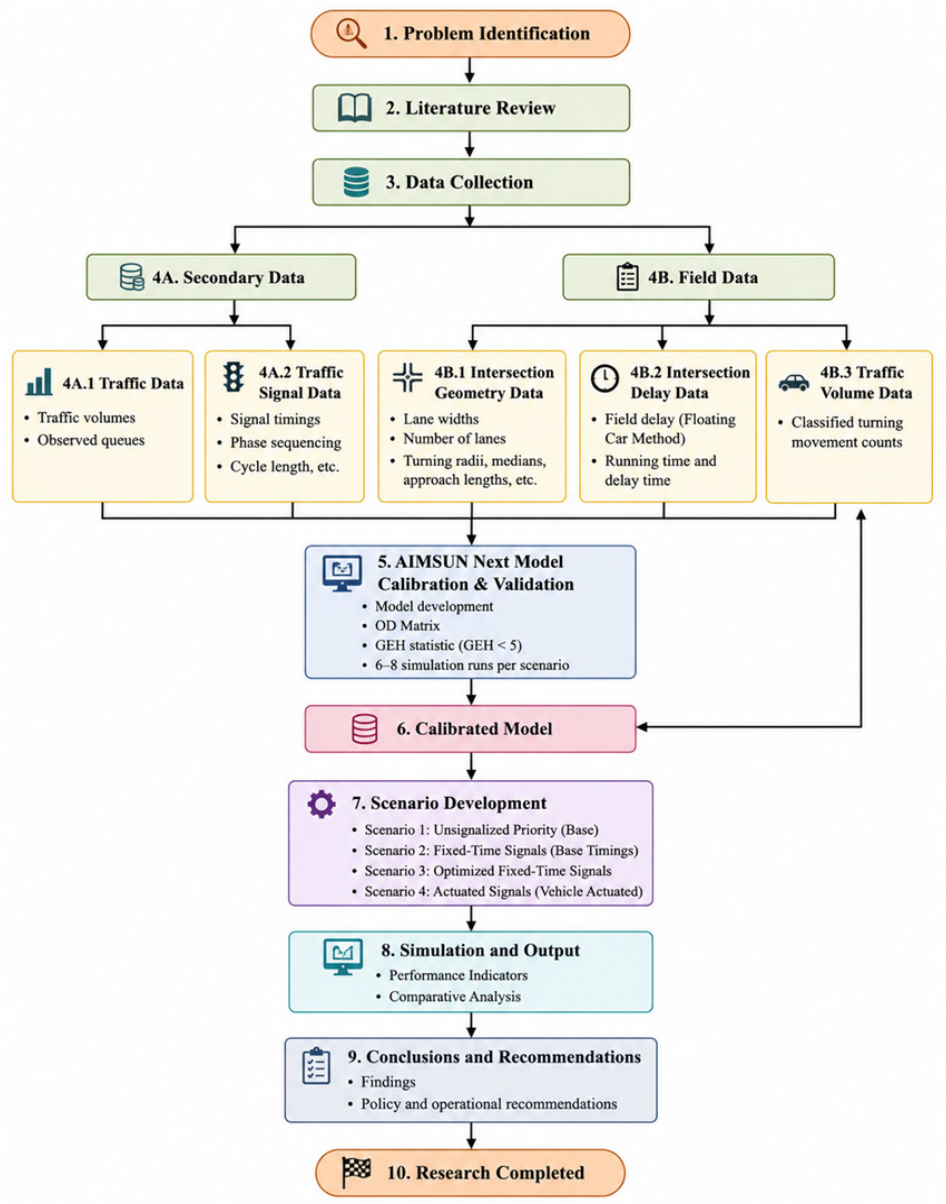

FIGURE 2
Research methodology flow chart
Source: Author, 2026

Study Location Description

The Ring Road Kileleshwa/Riverside Drive intersection in Nairobi City, Kenya, serves as a major connection point between residential and commercial areas. It is a four-leg cross intersection whose approaches are Ring Road Kileleshwa (Northbound), Ring Road Westlands (Southbound), Riverside Drive West (Eastbound), and Riverside Drive East (Westbound). Ring Road Westlands, Riverside Drive West, and Riverside Drive East are two-way, two-lane roads. In contrast, the Ring Road Kileleshwa approach is a dual carriageway with two lanes in each direction. All four approaches have an additional lane at the junction to accommodate right-turning vehicles.

The intersection is one of seven junctions under the Kenya Urban Roads Authority's (KURA) Nairobi Western Ring Road ITMS pilot project. **Figure 3** illustrates the location of the Ring Road Kileleshwa/Riverside Drive intersection within Kenya and Nairobi County.

Figure 4 presents a satellite image of the study intersection showing the geometric layout and surrounding road network.

Data Collection

The study collected traffic volume data, intersection geometric layout data, traffic signal data, and field delay data. Twenty-four-hour traffic volume data was obtained from Kenya Urban Roads Authority's (KURA) Vehicle Video Detectors installed at the intersection. In addition, manual traffic counts were undertaken over three (3) days using video recording, classifying vehicles by turning direction (left turn, through, and right turn) for each approach.

Data was collected during the AM (06:00–10:00 hrs), interpeak (12:00–14:00 hrs), and PM (16:00–18:00 hrs) periods. These periods were selected because they represent the highest traffic demand within the 24-hour cycle, as confirmed by the KURA volume data, and therefore reflect the most critical conditions for evaluating intersection performance.

Vehicles were classified into five categories: Motorcycle/Tuktuk, Saloon Cars/Large Cars/4-Wheel Drives/Jeeps/Pick-ups/Vans, Matatus/Small Buses/Large Buses, Light/Medium Trucks, and Heavy/Articulated/Draw-back Trucks (3–7 Axles).

The geometry of the intersection was measured on site capturing lane widths, number of lanes, approach lengths, turning radii, medians, shoulder widths, and the overall intersection layout. These measurements were verified against Google Earth satellite imagery and organized into schematic drawings and tables for input into AIMSUN

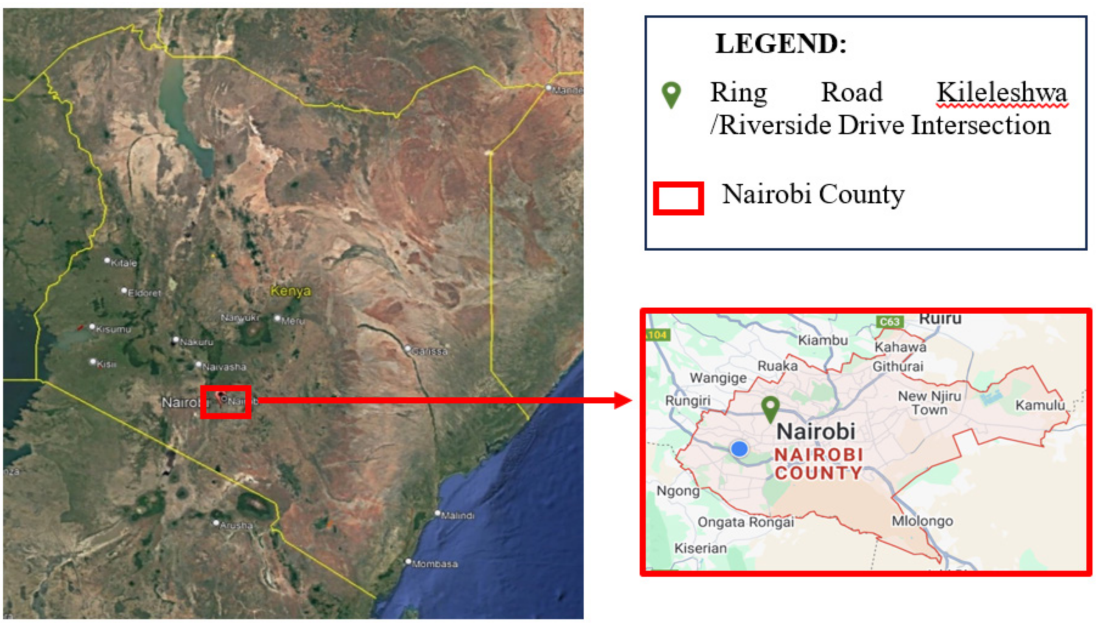

FIGURE 3
Location of Ring Road Kileleshwa/Riverside Drive intersection in Kenya and Nairobi County
Source: Google Maps, 2026

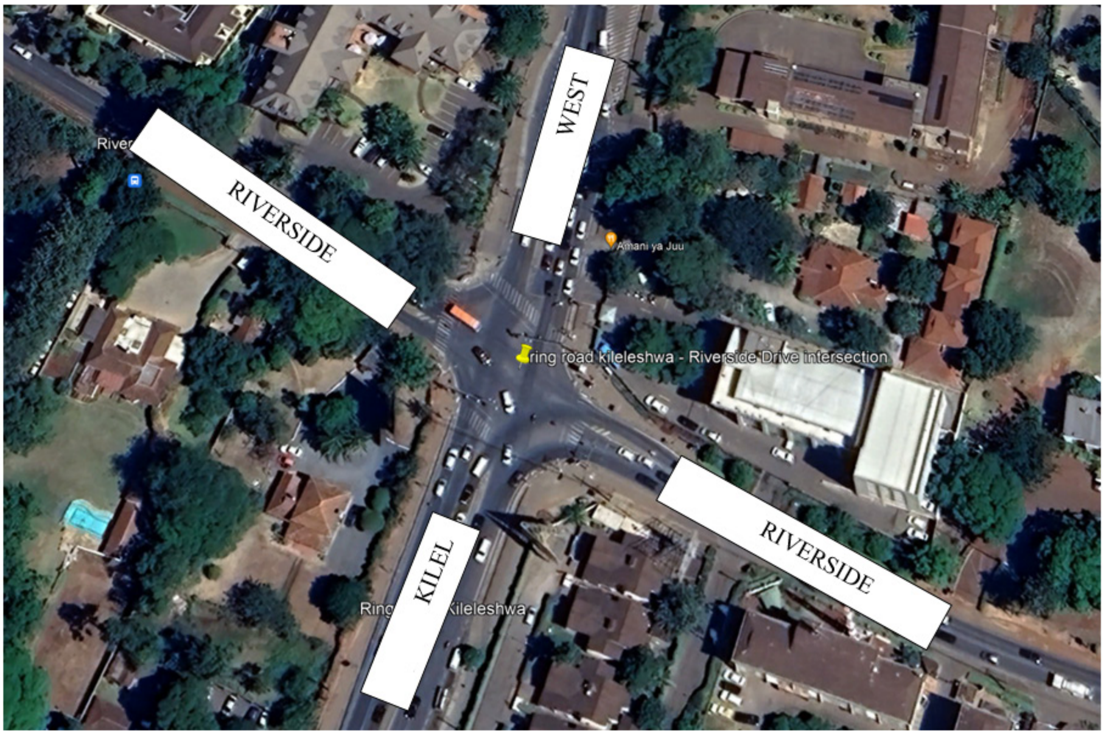

FIGURE 4
Satellite image of the Ring Road Kileleshwa/Riverside Drive intersection
Source: Google Maps, 2026

simulation software.

Traffic signal control data was obtained from KURA for model calibration. The data included cycle length, phase sequencing, minimum and maximum green times, amber time, and red time for a typical day.

Field delays were measured using the floating car method in which a test vehicle was driven along each approach during morning and evening peak periods while maintaining pace with the surrounding traffic flow. Travel times were recorded and separated into running time and delay time. Average delays per vehicle were then calculated from multiple runs and used to calibrate and validate the simulation model.

Regarding data collection ethics, all traffic counts were conducted from public vantage points observing vehicular movements without collecting personal data. In addition, institutional permission to access KURA traffic signal and volume data was obtained prior to the study.

AIMSUN Modelling Framework
The model was developed using AIMSUN Next, a traffic microsimulation software that models individual vehicle behaviour using established car-following and lane-changing algorithms based on the Gipps model (Casas et al., 2010; Lu et al., 2017). The software integrates microscopic, mesoscopic, and macroscopic simulation within a single platform and has been widely validated for predicting traffic performance indicators (Aimsun, 2024; Chaudhry & Ranjitkar, 2009; Hong et al., 2017; Rahimi et al., 2021).

The intersection geometry was coded within a scaled Google Earth window to accurately represent the physical layout of the intersection. The study used an Origin-Destination (OD) Matrix based on field survey data to represent traffic demand.

Calibration was performed by comparing the modelled flows and observed flows for each link and turning movement using the GEH statistic, a standard measure of fit in traffic modelling where a value below 5 indicates acceptable accuracy (Aimsun, 2024). All links and turning movements achieved a GEH value below 5, confirming that the model was well calibrated. Between six and eight simulation runs were conducted for each scenario, and the mean results were used in the analysis.

Modelled Scenarios

Four scenarios were modelled and analysed to evaluate the operational performance of the intersection under different traffic control conditions.

i) *Scenario 1 (Base Scenario):*
This scenario represented operations at the intersection under stop/yield priority control.

ii) *Scenario 2 (Fixed-Time Signals Scenario):*
This scenario represented operations under fixed-time signal control using the base timings and phasing currently configured at the intersection.

iii) *Scenario 3 (Optimized Fixed-Time Signals Scenario):*
This scenario represented operations under optimized fixed-time signal control. The optimization measures applied included reducing the cycle time from 155 seconds to 140 seconds, reducing the number of phases from five to four, increasing the number of movements per phase by allowing left-turning traffic, and redistributing green time from the northbound approach to the westbound and eastbound approaches.

v) *Scenario 4 (Actuated Signals Scenario):*
This scenario applied vehicle-responsive actuation over the base timings and phasing plan used in Scenario 2. It represented the operational condition of the ITMS at the time of conducting the study.

RESULTS

Traffic Demand and Composition

The traffic demand characteristics of the intersection were evaluated using 24-hour traffic volume and composition data collected across all approaches. **Figure 5** presents the hourly traffic variation by approach.

The intersection experiences high traffic movement between 08:00 and 19:00 hours, with the morning peak occurring between 09:00–10:00 hours and the evening peak between 17:00–19:00 hours. Ring Road Kileleshwa and Riverside Drive East recorded the highest traffic volumes, while Riverside Drive West consistently recorded the lowest volumes. Vehicle composition across the approaches is illustrated in **Figure 6**.

Cars (saloon cars, SUVs, and pick-ups) constituted more than 60% of traffic on all approaches, while motorcycles and tuktuks accounted for between 22% and 33% of vehicles. Matatus, buses, and trucks constituted a relatively small proportion of the traffic stream, reflecting the predominantly residential and commercial land use surrounding the intersection. Overall, the intersection experiences sustained peak-hour demand

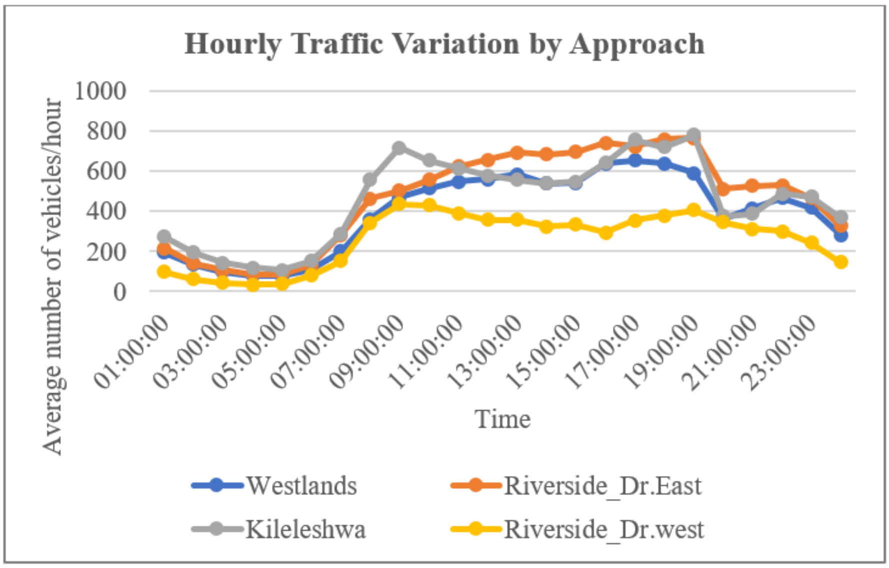

FIGURE 5
Hourly traffic variation by approach
Source: Author, 2026

dominated by private vehicles and intermediate public transport modes.

Intersection Configuration

The intersection geometry and lane configuration were modelled in AIMSUN as illustrated in **Figure 7**. The same geometric configuration was applied across all simulation scenarios.

Intersection Operational Performance

Intersection operational performance was evaluated using traffic throughput, volume-to-capacity ratio, delay, queue length, and Level of Service (LOS). The LOS assessment adopted the Highway Capacity Manual (HCM) 2016 criteria for signalized and unsignalized intersections as summarized in **Table 1**.

Tables 2 to 5 summarize the operational performance of the intersection under the four modelled traffic control scenarios.

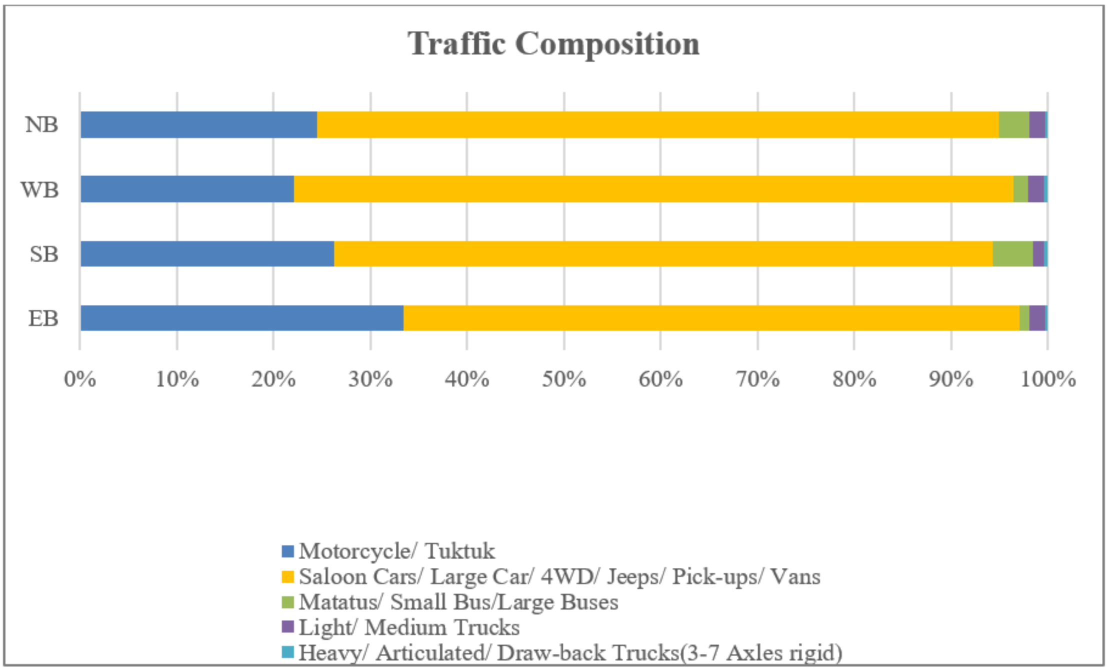

FIGURE 6
Traffic composition per approach
Source: Author, 2026

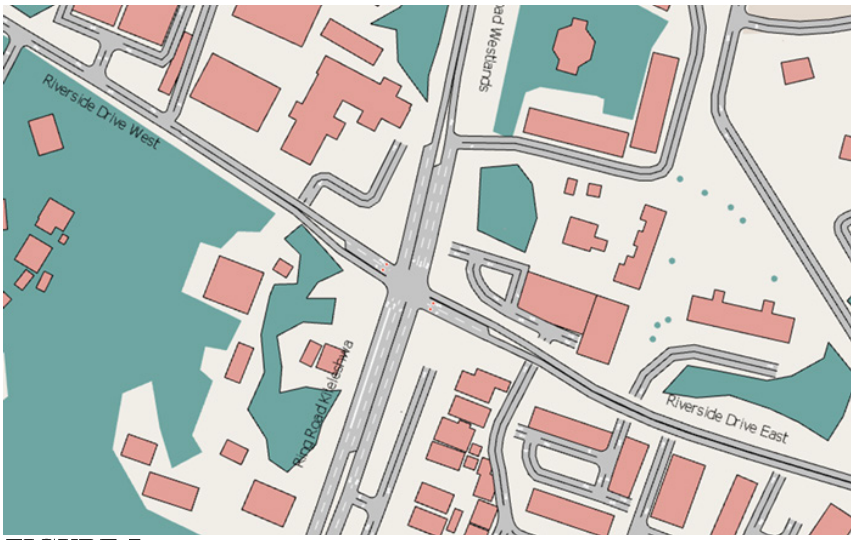

FIGURE 7
Intersection configuration
Source: AIMSUN Model, 2026

TABLE 1
Level of service criteria

LOS	Signalized Intersection (Average Control Delay - sec/veh)	Two-Way Stop Controlled (TWSC) Intersection (Unsignalized) (Average Control Delay - sec/veh)	Description	LOS by Volume to Capacity Ratio	
				≤ 1	>1
A	≤ 10	≤ 10	Free flow conditions	A	F
B	> 10 - 20	> 10 - 15	Stable flow, slight delays	B	F
C	> 20 - 35	> 15 - 25	Stable flow, acceptable delays	C	F
D	> 35 - 55	> 25 - 35	Approaching unstable flow	D	F
E	> 55 - 80	> 35 - 50	Unstable flow, significant delays	E	F
F	> 80	> 50	Forced flow, extreme delays	F	F

Source: Transportation Research Board (2016), Volume 3, Exhibit 19-8 & 20-2

TABLE 2
Operational performance under stop/yield control

Approach	Volume (veh/hour)	V/C	Queue (veh)	Delay (sec)	LOS
Ring Road Kileleshwa (NB)	1,314	0.82	0	1	A
Riverside Drive West (EB)	315	0.45	17	225	F
Ring Road Westlands (SB)	996	1.25	0	1	A
Riverside Drive East (WB)	488	0.70	32	247	F
OVERALL	**3,113**	**0.82**	**32**	**67**	**F**

Source: Author (2026)

TABLE 3
Operational performance under fixed-time signal control

Approach	Volume (veh/hour)	V/C	Queue (veh)	Delay (sec)	LOS
Ring Road Kileleshwa (NB)	1,342	0.84	5	50	D
Riverside Drive West (EB)	353	0.50	17	243	F
Ring Road Westlands (SB)	951	1.19	22	196	F
Riverside Drive East (WB)	518	0.74	30	306	F
OVERALL	**3,164**	**0.83**	**30**	**155**	**F**

Source: Author (2026)

TABLE 4
Operational performance under optimized fixed-time signal control

Approach	Volume (veh/hour)	V/C	Queue (veh)	Delay (sec)	LOS
Ring Road Kileleshwa (NB)	1,536	0.96	12	89	F
Riverside Drive West (EB)	366	0.52	16	187	F
Ring Road Westlands (SB)	912	1.14	21	174	F
Riverside Drive East (WB)	636	0.91	25	203	F
OVERALL	**3,450**	**0.91**	**25**	**145**	**F**

Source: Author (2026)

TABLE 5
Operational performance under vehicle-actuated signal control

Approach	Volume (veh/hour)	V/C	Queue (veh)	Delay (sec)	LOS
Ring Road Kileleshwa (NB)	1,614	1.01	19	89	F
Riverside Drive West (EB)	385	0.55	18	248	F
Ring Road Westlands (SB)	1,032	1.29	22	193	F
Riverside Drive East (WB)	612	0.87	27	236	F
OVERALL	**3,643**	**0.96**	**27**	**190**	**F**

Source: Author (2026)

Scenario 1: Stop/Yield Priority Control
Under the stop/yield control scenario, the major road approaches (Ring Road Kileleshwa and Ring Road Westlands) experienced negligible delays and operated at LOS A due to priority allocation. In contrast, the minor road approaches (Riverside Drive West and Riverside Drive East) experienced severe congestion characterized by high delays and long queues, resulting in LOS F conditions.

Although the intersection-wide V/C ratio remained below 1.0, Ring Road Westlands exceeded capacity, indicating localized oversaturation despite acceptable aggregate intersection performance.

Overall, the unsignalized scenario favoured major-road traffic movement at the expense of the minor approaches.

Scenario 2: Fixed-Time Signal Control
Implementation of fixed-time signal control redistributed delays across all approaches. Compared with Scenario 1, signalization improved operational equity but increased overall intersection delay. Ring Road Kileleshwa operated at LOS D, while the remaining approaches operated at LOS F.

Ring Road Westlands consistently exceeded capacity across scenarios, indicating that signal control alone could not resolve the existing physical capacity deficit. The fixed-time signal plan also generated long queues on the Riverside Drive approaches, suggesting inadequate green time allocation for these movements. Overall, the base fixed-time signal plan improved traffic distribution but failed to eliminate oversaturation and excessive delays.

Scenario 3: Optimized Fixed-Time Signal Control
Compared with Scenario 2, the optimized fixed-time signal plan improved traffic throughput while reducing queue lengths and average delays on several approaches. Although all approaches continued operating at LOS F, the optimized scenario achieved more balanced operational performance across the intersection.

The optimized timing strategy redistributed green time more effectively and reduced peak queue accumulation, particularly on Riverside Drive East and Riverside Drive West. However, Ring Road Westlands remained oversaturated, demonstrating that signal optimization alone cannot compensate for inadequate physical capacity.

Overall, the optimized fixed-time scenario achieved the most balanced operational performance among the signalized control strategies.

Scenario 4: Vehicle-Actuated Signal Control
Vehicle-actuated signal control achieved the highest traffic throughput among all scenarios. However, compared with the optimized fixed-time scenario, actuated control increased average delays and queue lengths across several approaches.

The actuated strategy amplified congestion on already oversaturated approaches because vehicle-responsive control was applied over an unoptimized base timing plan. Ring Road Westlands remained the most congested approach, while the overall intersection continued operating at LOS F.

Overall, vehicle-actuated control improved throughput but worsened operational efficiency due to inadequate base signal timing and persistent geometric constraints.

Summary of Operational Performance

Table 6 summarizes the comparative operational performance of the four modelled scenarios.

Overall, all four scenarios resulted in LOS F conditions at the intersection, indicating persistent congestion and operational inefficiency. However, the optimized fixed-time signal scenario achieved the most balanced operational performance by improving throughput while moderating delay and queue accumulation. The findings further demonstrate that signal optimization alone cannot eliminate congestion where physical capacity constraints persist.

DISCUSSION

Traffic Throughput

Traffic throughput was analysed to evaluate the effectiveness of the different traffic control strategies in processing traffic demand across the intersection approaches. **Figure 8** presents the traffic throughput per approach under the four modelled scenarios.

The throughput results identify Ring Road Kileleshwa as the highest-volume approach and Riverside Drive West as the lowest-volume approach across all scenarios. Compared with the unsignalized condition, signalized control generally improved throughput across most approaches. However, Ring Road Westlands, which remained the most capacity-deficient approach, did not achieve proportional throughput gains from signalization relative to the other approaches. This finding suggests that signal optimisation alone cannot compensate for insufficient physical capacity where traffic

TABLE 6
Summary of operational performance by scenario

Scenario	Throughput Performance	Delay Performance	Queue Performance	Overall Outcome
Stop/Yield Control	Moderate	Severe on minor roads	Concentrated on minor roads	Unequal traffic distribution
Fixed-Time Signals	Improved distribution	Increased overall delay	Long queues across approaches	Poor operational efficiency
Optimized Fixed-Time Signals	Improved throughput	Reduced relative delay	More balanced queues	Best overall balance
Vehicle-Actuated Signals	Highest throughput	Highest delays	Increased queues	Throughput gains with inefficiency

Source: Author (2026)

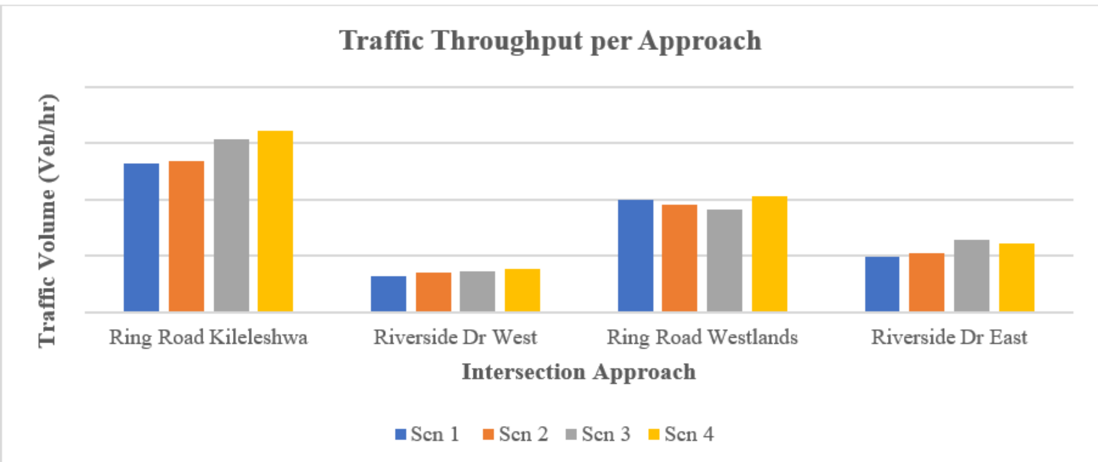

FIGURE 8
Traffic throughput per approach
Source: Author, 2026

demand exceeds available infrastructure.

Intersection-wide throughput performance across the four scenarios is illustrated in **Figure 9**.

Compared with the unsignalized scenario, intersection-wide throughput increased progressively under the signalized control strategies. Fixed-time signals achieved marginal throughput improvement, while the optimized and actuated signal strategies produced substantially higher throughput gains. The actuated signal scenario recorded the highest intersection-wide throughput, reflecting the responsiveness of vehicle-actuated control to fluctuating traffic demand conditions. The variation in throughput between the traffic control strategies is summarized in **Table 7**.

Compared with the unsignalized baseline, fixed-time signalization improved throughput on most approaches except Ring Road Westlands. Similarly, the optimized fixed-time plan improved throughput relative to the base fixed-time scenario across most approaches, while vehicle-actuated control generated the highest throughput gains overall. These findings are consistent with previous studies demonstrating that signal optimization and adaptive signal control improve operational efficiency and traffic progression at congested intersections (Ahmida et al., 2023; Pokhrel et al., 2023; Reddy et al., 2023). However, the unequal distribution of throughput gains across the approaches indicates that operational improvements are constrained by existing geometric and capacity limitations. Approaches already operating near or beyond capacity benefit less from signal optimization than those with available residual capacity. From a policy perspective, these findings suggest that throughput maximization strategies should be accompanied by targeted geometric improvements at bottleneck approaches to achieve sustainable operational gains. Overall, signal optimization

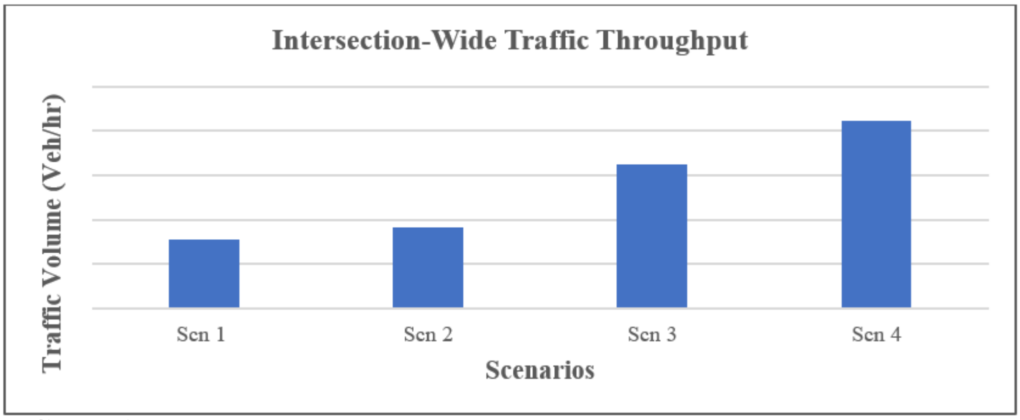

FIGURE 9
Intersection-wide traffic throughput
Source: Author (2026)

TABLE 7
Variation in traffic throughput by control scenario

Approach	Fixed Time vs Unsignalized (%)	Actuated vs Fixed Time (%)	Optimized vs Fixed Time (%)
Ring Road Kileleshwa	2.1	20.3	14.5
Riverside Drive West	12.1	9.1	3.7
Ring Road Westlands	-4.5	8.5	-4.1
Riverside Drive East	6.1	18.1	22.8
Intersection-Wide	1.6	15.1	9.0

Source: Author (2026)

improved throughput performance but did not eliminate localized oversaturation.

Volume to Capacity Ratio

The volume-to-capacity (V/C) ratio was analysed to assess the extent of congestion and capacity utilization under each traffic control scenario. **Figure 10** presents the V/C ratios across the four intersection approaches.

Ring Road Westlands consistently recorded the highest V/C ratios and exceeded the capacity threshold under all scenarios, confirming the existence of a persistent physical capacity deficit. Compared with the other approaches, Riverside Drive West maintained relatively low V/C ratios throughout the analysis, indicating comparatively lower congestion pressure.

Ring Road Kileleshwa operated close to the oversaturation threshold and exceeded capacity under the actuated signal scenario. This suggests that increased throughput under vehicle-actuated control was accompanied by intensified congestion pressure on already heavily utilized approaches. Intersection-wide V/C ratios are presented in **Figure 11**.

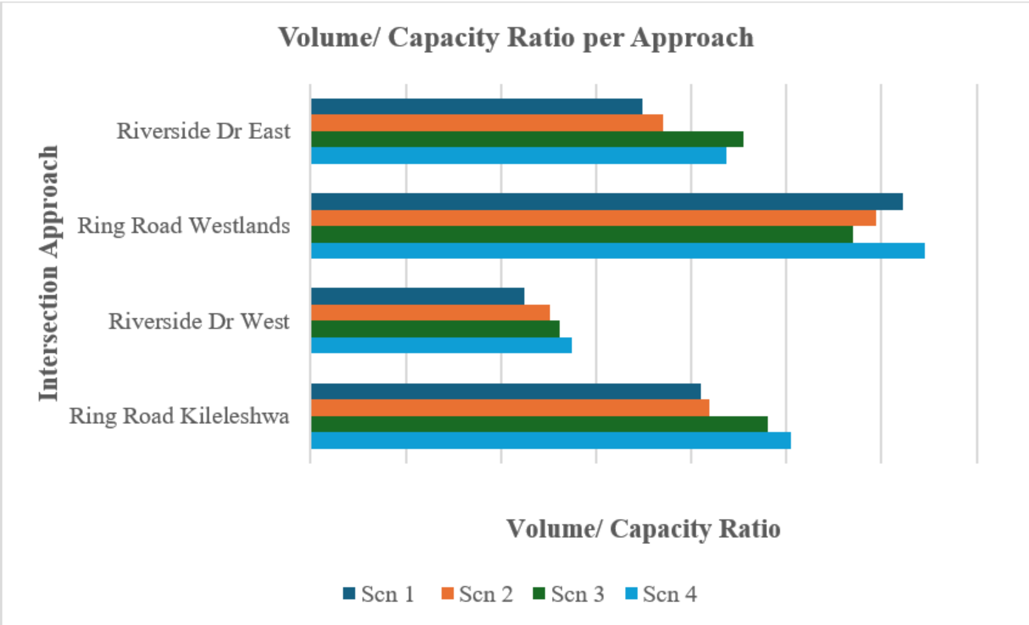

FIGURE 10
Volume-to-capacity ratio per approach
Source: Author (2026)

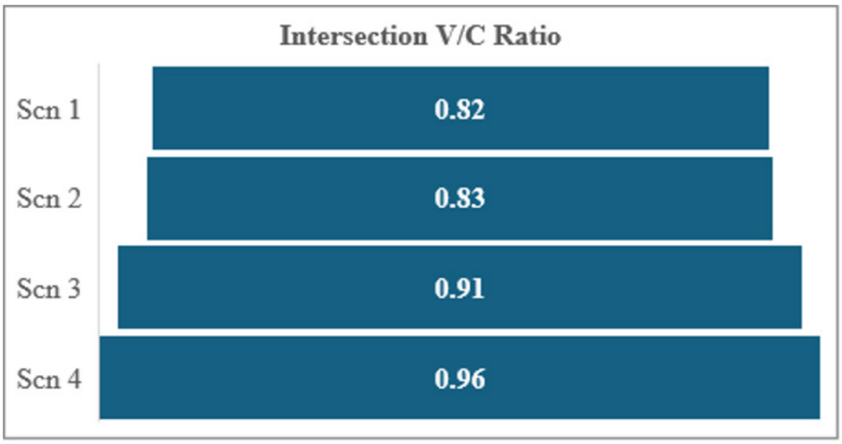

FIGURE 11
Intersection-wide volume-to-capacity ratio
Source: Author (2026)

Although the overall intersection-wide V/C ratio remained below 1.0 across all scenarios, this aggregate measure masked localized oversaturation on Ring Road Westlands and Ring Road Kileleshwa. This divergence between intersection-wide and approach-level performance demonstrates that aggregate operational indicators may obscure critical bottlenecks within individual approaches.

These findings align with observations by Hailesilassie (2024), Tilahun Fetene (2025), and Ahmida et al. (2023), who established that geometric constraints remain a major limitation to operational efficiency even under optimized signal control conditions. The findings further reinforce the argument that intelligent traffic management systems should complement, rather than substitute, physical infrastructure improvements.

Overall, the V/C analysis demonstrates that signal optimization improved traffic distribution but could not fully resolve the underlying capacity deficiencies at the intersection.

Delay and Level of Service

Average delay and Level of Service (LOS) were evaluated to assess the operational efficiency of the intersection under the different traffic control scenarios. **Figure 12** compares the average approach delay across the four modelled scenarios.

Under the unsignalized scenario, the major-road approaches experienced negligible delays due to right-of-way priority allocation, while the Riverside Drive approaches experienced severe delays exceeding 200 seconds. This imbalance demonstrates the operational inequity associated with priority-controlled intersections where dominant approaches operate efficiently at the expense of minor approaches.

Compared with the unsignalized scenario, the introduction of fixed-time signals redistributed delays across all approaches but increased overall intersection delay. This indicates that the base signal timing plan allocated insufficient green time to the Riverside Drive movements and introduced additional stopping delays on previously uninterrupted approaches. Intersection-wide delay performance is illustrated in **Figure 13**.

Compared with the fixed-time scenario, the optimized fixed-time strategy reduced intersection-wide delay and achieved a narrower distribution of delays across the approaches. This indicates a more balanced allocation of operational efficiency within the intersection. In contrast, the actuated signal scenario produced the highest overall delays, confirming that vehicle-responsive control operating over an unoptimized base plan amplified congestion rather than alleviating it. The corresponding LOS classifications for each scenario are summarized in **Table 8**.

All four scenarios resulted in an overall intersection LOS F, indicating severe congestion and unstable traffic flow conditions. However, substantial

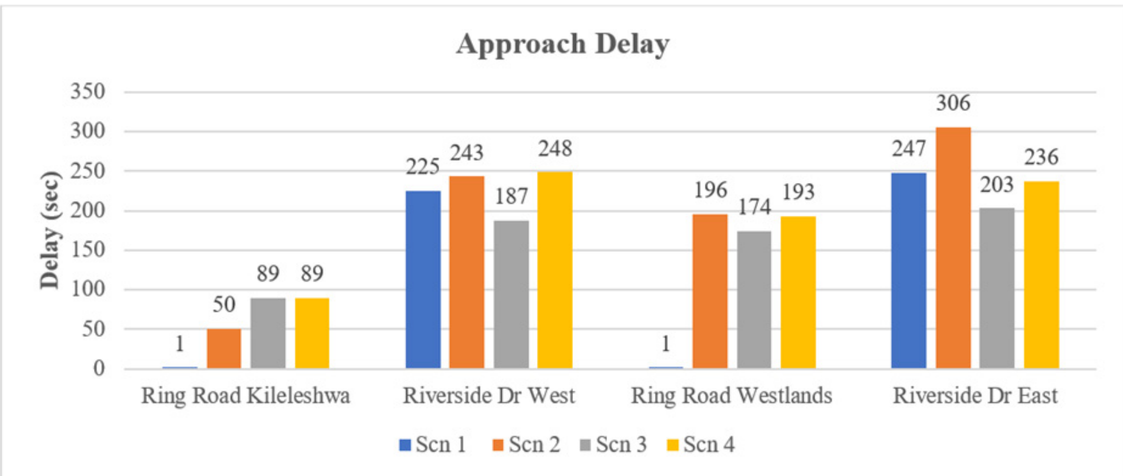

FIGURE 12
Average delay per approach
Source: Author (2026)

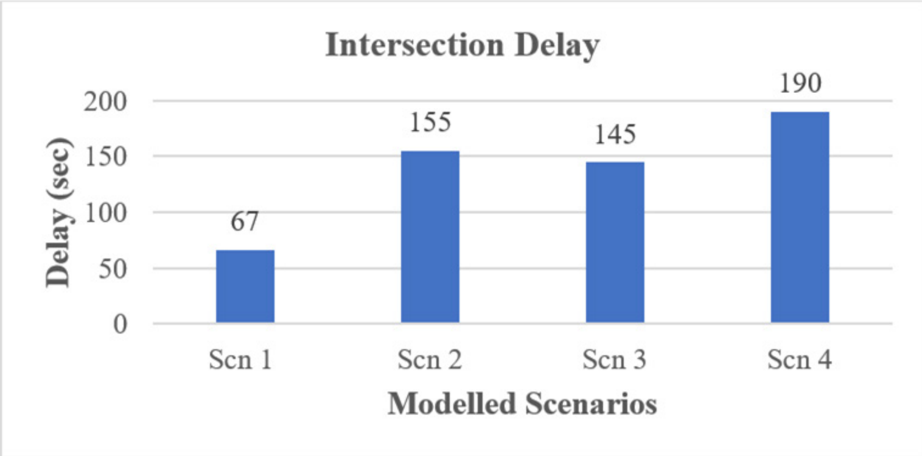

FIGURE 13
Intersection-wide delay
Source: Author (2026)

TABLE 8
Level of service by scenario and approach

Approach	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Ring Road Kileleshwa	A	D	F	F
Riverside Drive West	F	F	F	F
Ring Road Westlands	A	F	F	F
Riverside Drive East	F	F	F	F
OVERALL	F	F	F	F

Source: Author (2026)

differences existed within the LOS F classification. Although Scenarios 3 and 4 both recorded LOS F, the optimized fixed-time scenario achieved lower delays than the actuated signal scenario, demonstrating that LOS categories alone may not adequately distinguish operational quality within highly congested conditions.

These findings corroborate studies by Pokhrel et al. (2023), Ahmida et al. (2023), and Tilahun Fetene (2025), which established that optimized signal timing improves delay performance and operational balance at congested intersections. However, the results contradict findings by Syla & Lala (2026), who reported substantial delay reductions under actuated signal control. The difference may be attributed to the implementation of vehicle-responsive control over an unoptimized base timing plan within the current study.

Overall, the delay and LOS analysis demonstrates that optimized signal timing improved operational balance, although severe congestion persisted due to underlying capacity limitations.

Queue Length

Queue length was analysed to assess the spatial extent of congestion and the operational impact of each traffic control strategy. **Figure 14** presents the average queue lengths per approach across the four modelled scenarios.

Under the unsignalized condition, queues were concentrated primarily on the minor-road approaches while the major-road approaches remained largely uninterrupted. Compared with the unsignalized condition, fixed-time signalization redistributed queues across all approaches but maintained significant queue accumulation on the Riverside Drive approaches, indicating insufficient green time allocation.

Compared with the fixed-time signal scenario, the optimized fixed-time strategy reduced queue

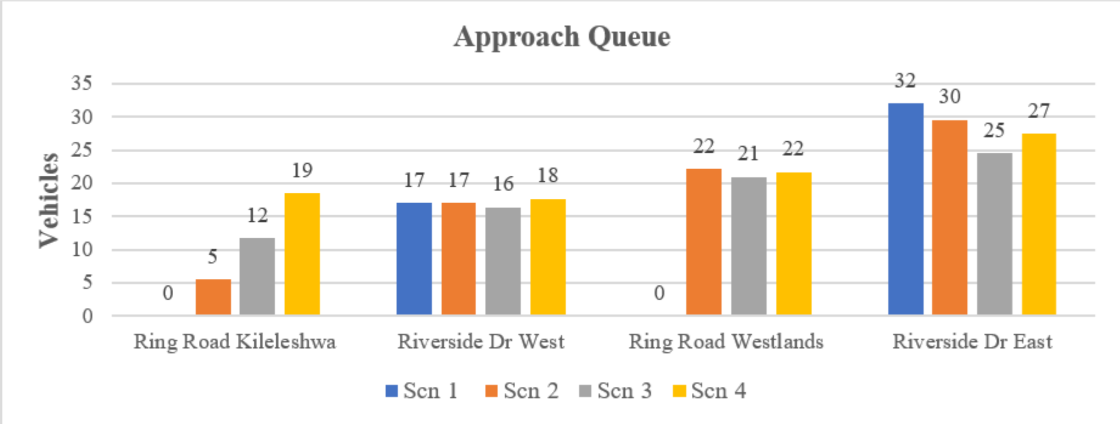

FIGURE 14
Queue length per approach
Source: Author (2026)

accumulation and achieved a more balanced queue distribution across the approaches. The shorter cycle length and improved green time allocation contributed to reduced congestion spillback on the most heavily affected approaches.

In contrast, vehicle-actuated control generated the highest queue lengths among the signalized scenarios. This finding indicates that responsive signal actuation operating over an unoptimized base timing framework intensified congestion on approaches experiencing high traffic demand.

These findings align closely with studies conducted in Addis Ababa, Bahir Dar, and Al-Beyda, where researchers established that signal optimization alone cannot sustain operational improvements without complementary geometric capacity enhancements (Ahmida et al., 2023; Hailesilassie, 2024; Tilahun Fetene, 2025).

Theoretically, the findings contribute to the broader discourse on technology-led urban mobility governance within the Global South. Increasing evidence from African cities suggests the existence of a “technology-infrastructure gap,” where intelligent traffic systems are deployed within road networks that remain physically constrained. The findings therefore emphasize that ITMS should be implemented as part of integrated transportation improvement strategies combining signal optimization with geometric and corridor-level infrastructure interventions.

Overall, the queue length analysis demonstrates that optimized fixed-time control achieved the most balanced queue distribution, although persistent congestion remained on the capacity-deficient approaches.

CONCLUSION

This study evaluated the impact of Intelligent Traffic Management Systems (ITMS) on the operational performance of the Ring Road Kileleshwa/Riverside Drive intersection in Nairobi City, Kenya using AIMSUN microsimulation modelling. The findings demonstrate that the ITMS, as currently configured, does not achieve substantial operational improvement at the intersection. All four modelled scenarios operated at an overall Level of Service (LOS) F, indicating persistent congestion, excessive delays, and unstable traffic flow conditions.

Despite the overall underperformance, signalized control improved traffic throughput distribution compared with the unsignalized priority-control scenario. Consistent with findings by Hailesilassie (2024) and Ranjitkar et al. (2014), signalization enhanced operational equity by redistributing traffic movement across the intersection approaches. However, the operational benefits varied significantly across the different signal control strategies.

Vehicle-actuated control achieved the highest traffic throughput, recording a 17% increase relative to the unsignalized scenario. This finding aligns with studies by Reddy et al. (2023) and Syla & Lala (2026), which established that actuated signals generally outperform fixed-time control under variable traffic demand conditions. However, unlike previous findings reporting substantial reductions in queue length and delay under actuated control, the current study found that vehicle-actuated operation increased delays and queue accumulation. This outcome is attributed to implementation of vehicle-responsive control over an unoptimized base timing plan, which amplified rather than corrected existing operational inefficiencies (Vijayaraghavan & Rian Leevinson, 2020).

The optimized fixed-time signal scenario achieved the most balanced operational performance among the signalized control strategies. Compared with the base fixed-time plan, optimization improved throughput while reducing delays and queue accumulation across several approaches. These findings corroborate studies by Ahmida et al. (2023), Pokhrel et al. (2023), and Tilahun Fetene (2025), which established that signal timing optimization enhances intersection operational efficiency through improved green time allocation and phase coordination.

Nevertheless, the analysis demonstrated that signal optimization alone cannot resolve the intersection's underlying physical capacity limitations. Ring Road Westlands consistently exceeded capacity across all scenarios, while substantial residual queues persisted throughout the intersection. Similar observations have been reported by Hailesilassie (2024) and Korea Expressway Corporation et al. (2018), who concluded that intelligent traffic management systems are most effective when implemented alongside geometric and infrastructure improvements.

The findings therefore demonstrate that ITMS should not be treated as a substitute for physical road capacity expansion, but rather as a complementary operational management tool. Sustainable operational improvement at the Ring Road Kileleshwa/Riverside Drive intersection requires integrated intervention combining signal optimization, geometric enhancement, and corridor-level traffic management strategies.

This study contributes a replicable microsimulation framework for evaluating ITMS operational performance under multiple traffic control scenarios within African urban traffic environments. The framework offers practical value for transport authorities undertaking performance-based evaluation of intelligent traffic management interventions prior to implementation or during operational monitoring.

RECOMMENDATIONS

The following recommendations are proposed to enhance the operational performance of the Ring Road Kileleshwa/Riverside Drive intersection and improve the effectiveness of the existing Intelligent Traffic Management System.

Short-Term Operational Recommendations

Continuous Signal Optimization

The optimized fixed-time signal plan evaluated in this study achieved the most balanced operational performance among all signalized scenarios. The optimized timing plan should therefore be adopted as the operational baseline during peak periods, with periodic review and recalibration to accommodate changing traffic demand patterns and traffic composition over time.

Optimization of the Actuated Signal Base Plan

The existing detector infrastructure and vehicle-actuated capabilities should be retained due to their demonstrated throughput advantages. However, actuated control should be implemented over an optimized timing and phasing framework rather than the existing base plan. This would improve responsiveness to fluctuating traffic demand while minimizing excessive delays and queue accumulation.

Routine Operational Monitoring and Maintenance

Regular operational audits and maintenance of detectors, controllers, and communication infrastructure should be undertaken to ensure reliable real-time vehicle detection and signal responsiveness. Continuous monitoring would also support identification of operational deficiencies requiring recalibration or adjustment.

Medium- to Long-Term Strategic Recommendations

Geometric Capacity Improvements

Geometric improvements should be prioritized at the most capacity-deficient approaches, particularly Ring Road Westlands. Recommended interventions include additional through lanes, extended right-turn storage lanes, channelization for left-turning traffic, and improved lane allocation and approach widening. These improvements are necessary because signal optimization alone cannot eliminate congestion where traffic demand exceeds physical capacity.

Corridor-Level Traffic Management

Intersection-level optimization should be integrated within broader corridor-level traffic management strategies along the Nairobi Western Ring Road corridor. Coordinated signal timing between adjacent intersections would improve progression and reduce spillback effects between junctions.

Demand Management Strategies

Long-term congestion mitigation should incorporate travel demand management strategies including promotion of public transport, staggered working hours, dissemination of real-time traffic information, and enhancement of non-motorized transport infrastructure. These interventions would reduce peak-period traffic pressure and complement operational improvements at the intersection.

Expansion of Advanced ITMS Capabilities

Future upgrades to the ITMS should explore more advanced intelligent transportation functionalities including adaptive corridor-wide signal coordination, emergency vehicle prioritization, predictive traffic analytics, and integration with connected vehicle technologies. These capabilities may further improve operational efficiency under complex and dynamic urban traffic conditions.

CITED REFERENCES

Aboud, G. M., Khaled, T. T., Ezzat, E. N., Jashami, H., & Shukri, Z. A. (2024). Assessment of signalized intersection: A case study in Baghdad City by using SIDRA software. *Journal of Engineering and Sustainable Development*, 28(2), 178–189. https://doi.org/10.31272/jeasd.28.2.3

Agrahari, A., Dhabu, M. M., Deshpande, P. S., Tiwari, A., Baig, M. A., & Sawarkar, A. D. (2024). Artificial intelligence-based adaptive traffic signal control system: A comprehensive review. *Electronics,* 13(19), 3875. https://doi.org/10.3390/electronics13193875

Ahmida, W., Mohamed, A., Fadiel, A., & Abu-Lebdeh, T. (2023). Performance evaluation and improvement of main road intersections in Al-Bayda City using SIDRA software. *American Journal of Engineering and Applied Sciences,* 16(1), 23–28. https://doi.org/10.3844/ajeassp.2023.23.28

Aimsun. (2024). *Aimsun Next users manual 24.0.2.* Retrieved from website: https://docs.aimsun.com/next/24.0.2/

An, H. K., Awais Javeed, M., Bae, G., Zubair, N., Metwally, A. S. M., Bocchetta, P., Na, F., & Javed, M. S. (2022). Optimized intersection signal timing: An intelligent approach-based study for sustainable models. *Sustainability,* 14(18), 11422. https://doi.org/10.3390/su141811422

Ashqer, M. I., Ashqar, H. I., Elhenawy, M., Almannaa, M., Aljamal, M. A., Rakha, H. A., & Bikdash, M. (2024). Evaluating a signalized intersection performance using unmanned aerial data. *Transportation Letters,* 16(5), 452–460. https://doi.org/10.1080/19427867.2023.2204249

Casas, J., Ferrer, J. L., Garcia, D., Perarnau, J., & Torday, A. (2010). Traffic simulation with Aimsun. In J. Barceló (Ed.), *Fundamentals of traffic simulation* (Vol. 145, pp. 173–232). Springer. https://doi.org/10.1007/978-1-4419-6142-6_5

Chaudhry, M. S., & Ranjitkar, P. (2009). Capacity analysis of signalised intersection using micro-simulation. *32nd Australasian Transport Research Forum*, Auckland, New Zealand.

Githinji, H., & Asuna, M. (2020). Sustainable transportation: Use of intelligent transport systems. *27th IEK International Conference.* Retrieved from website: https://iekenya.org/27thIEKConference/27thIEKConferencePapers/Sustainable%20Transportations%20Use%20of%20Intelligent%20Transport%20Systems.pdf

Google Maps. (2025). *Ring Road Kileleshwa/Riverside Drive intersection, Nairobi, Kenya* [Satellite imagery]. Google LLC. Retrieved from website: https://www.google.com/maps

Hailesilassie, B. (2024). *Assessment of operational performance of separate road intersection and traffic control system: Case study at Addis Abobe*

Bole-Micheal. Ethiopian Civil Service University. Retrieved from website: https://doi.org/10.2139/ssrn.5197362

Hameed, U., & Ahmed, H. U. (2019). Operational performance analysis of signalized intersections: A case study of Lahore. *1st Conference on Sustainability in Civil Engineering,* Capital University of Science and Technology, Islamabad, Pakistan.

Hong, K. A., Wen, L. Y., & Branko, S. (2017). Dual signal roundabout evaluation in Adelaide using SIDRA and AIMSUN. *Road & Transport* Research: *A Journal of Australian and New Zealand Research and Practice,* 26(2), 36–49.

Korea Expressway Corporation, Cheil Engineering, & Seoul Urban Solutions Agency. (2018). *Support for implementing intelligent traffic systems in Nairobi Metropolitan Region, Kenya: Final report*. Korea Eximbank; Ministry of Economy and Finance.

Lu, X.-Y., Kan, X., Shladover, S. E., Wei, D., & Ferlis, R. A. (2017). An enhanced microscopic traffic simulation model for application to connected automated vehicles. *Transportation Research Board 96th Annual Meeting.*

Makino, H., Tamada, K., Sakai, K., & Kamijo, S. (2018). Solutions for urban traffic issues by ITS technologies. *IATSS Research,* 42(2), 49–60. https://doi.org/10.1016/j.iatssr.2018.05.003

Nellore, K., & Hancke, G. (2016). A survey on urban traffic management system using wireless sensor networks. *Sensors,* 16(2), 157. https://doi.org/10.3390/s16020157

Nematichari, A., Pechlivanoglou, T., & Papagelis, M. (2022). Evaluating and forecasting the operational performance of road intersections. *Proceedings of the 30th International Conference on Advances in Geographic Information Systems,* 1–12. https://doi.org/10.1145/3557915.3560965

Pokhrel, A., Basnyat, D. S., Tiwari, H., Poudel, R., Luitel, S., & Dhungel, S. (2023). Performance assessment of a signalized intersection: A case study of Jay Nepal intersection. *5th International Conference on Engineering and Technology (KEC Conference 2023)*, Dhapakhel, Lalitpur.

Rahimi, A. M., Dulebenets, M. A., & Mazaheri, A. (2021). Evaluation of microsimulation models for roadway segments with different functional classifications in Northern Iran. *Infrastructures*, 6(3), 46. https://doi.org/10.3390/infrastructures6030046

Ranjitkar, P., Shahin, A., & Shirwali, F. (2014). Evaluating operational performance of intersections using SIDRA. *The Open Transportation Journal,* 8(1), 50–61. https://doi.org/10.2174/1874447801408010050

Reddy, R., Almeida, L., Gaitán, M. G., Santos, P. M., & Tovar, E. (2023). Synchronous management of mixed traffic at signalized intersections toward sustainable road transportation. *IEEE Access,* 11, 64928–64940. https://doi.org/10.1109/ACCESS.2023.3288691

Syla, V., & Lala, A. (2026). Microsimulation-based evaluation of fixed-time and vehicle-actuated traffic signal control strategies using PTV Vissim in an urban corridor. *Informatica*, 50(5). https://doi.org/10.31449/inf.v50i5.10459

Tilahun Fetene, A. (2025). Evaluating the performance of signalized intersection using SIDRA software: A case study in Bahir Dar City, Ethiopia. *Put i Saobraćaj,* 71(1), 1–8. https://doi.org/10.31075/PIS.71.01.01

Transportation Research Board. (2016). *Highway capacity manual: A guide for multimodal mobility analysis* (6th ed., Vol. 3). Transportation Research Board, National Academies of Sciences, Engineering, and Medicine.

Vijayaraghavan, V., & Rian Leevinson, J. (2020). Intelligent traffic management systems for next generation IoV in smart city scenario. In Z. Mahmood (Ed.), *Connected vehicles in the Internet of Things* (pp. 123–141). Springer. https://doi.org/10.1007/978-3-030-36167-9_6

Yimer, H. M. (2021). Comparative study of operational performance between roundabout and signalized intersection using SIDRA software: A case study of Addis Ababa City. *International Journal for Research in Applied Science and* Engineering Technology, 9(11), 1593–1602. https://doi.org/10.22214/ijraset.2021.39059