

Capacity Evaluation of Roundabout Junctions on Arterial Roads in Ilorin, Nigeria

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ABSTRACT

Rapid urbanisation and escalating traffic demand have resulted in persistent congestion and degraded operational efficiency at urban roundabouts across Nigerian cities. This study evaluated the operational performance of three roundabout junctions Pakata, Adeta, and Mandate located along arterial roads in Ilorin Metropolis, Kwara State. Peak-hour traffic volume data were collected during the evening peak period (4:00–6:00 p.m.), and roundabout entry capacities and degrees of saturation (DS) were estimated using an ARCADY-style empirical linear capacity model. PTV VISSIM microscopic traffic simulation software was subsequently employed to quantify vehicular delay and Level of Service (LOS) under both existing and proposed geometric configurations. Results revealed that all existing single-lane approaches operated under severely oversaturated conditions, with DS values ranging from 1.30 to 6.28, indicating that prevailing traffic demand substantially exceeded available entry capacities. These conditions produced excessive vehicular delays, persistent queue formation, and poor LOS classifications. A geometric redesign involving the widening of entry approaches from one lane to three lanes markedly increased entry capacities and reduced DS values to between 0.14 and 0.94 across all evaluated approaches. PTV VISSIM simulation results corroborated these findings, demonstrating substantial reductions in average vehicular delays and significant improvements in traffic operations and LOS following the proposed geometric modifications. The combined application of the ARCADY-style empirical model and PTV VISSIM proved to be an effective and complementary methodology for roundabout performance evaluation. The study concludes that entry-approach widening constitutes a practical and sustainable intervention strategy for mitigating congestion, improving traffic efficiency, and enhancing the operational performance of urban roundabouts in rapidly growing Nigerian cities.

1. Introduction

Urban transportation networks in rapidly developing sub-Saharan African cities are under mounting pressure from population growth, motorisation, and inadequate infrastructure investment. Ilorin, the administrative capital of Kwara State, Nigeria, exemplifies this trend: its arterial road network is characterised by a series of roundabout junctions that were originally designed for substantially lower traffic volumes than those observed today. As a result, these intersections frequently operate beyond their design capacities during peak hours, generating debilitating congestion, excessive delays, and safety risks for motorists and pedestrians alike.

A roundabout is a type of circular at-grade intersection that requires entering vehicles to yield to circulating traffic and to navigate counter-clockwise around a central island (Rafferty et al., 2015). This design philosophy inherently reduces the number of conflict points when compared with conventional signalised or priority intersections, thereby improving safety and encouraging more predictable traffic movements. However, roundabout capacity is finite and is critically sensitive to geometric parameters including entry width, exit width, inscribed circle diameter, entry radius, and approach angle as well as to the magnitude and distribution of traffic demand across its approaches (Al-Madani, 2016; Chen and Kim, 2017).

The concept of the modern roundabout first appeared formally in the United Kingdom in 1929, when the word 'roundabout' was introduced in Ministry of Transport and Planning Institute Circular No. 302 (Abubakar and Ndoke, 2013). Since then, roundabouts have been adopted globally as a preferred form of intersection control, particularly where moderate traffic volumes are served by relatively balanced approach flows. Empirical evidence from diverse contexts confirms that roundabouts deliver favourable operational and safety outcomes under appropriate demand conditions (Khatib and Abu-Lebdeh, 2009). Nevertheless, when demand becomes excessive or is unevenly distributed, entry saturation increases rapidly, triggering queue growth, aggressive driving behaviour, and deteriorating service quality (Archer, 2005).

Intersection capacity evaluation is a fundamental element of transportation planning and design, given its direct relationship to delay, Level of Service (LOS), accident frequency, vehicle operating costs, and environmental externalities. The HCM (2006) defines capacity as the maximum sustainable hourly flow rate at which vehicles can reasonably be expected to traverse a point or segment of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions. In the context of roundabout analysis, the degree of saturation (DS) defined as the ratio of actual entry flow to entry capacity is the key performance metric: DS values above 1.0 indicate oversaturation, with attendant queue build-up and breakdown in traffic flow.

Despite the widespread use of roundabouts in Nigerian cities, rigorous capacity analyses supported by microscopic traffic simulation remain scarce in the local literature. Most existing studies rely on observational field data without providing quantitative scenario analysis to evaluate the effectiveness of potential geometric improvements. This study addresses that gap by combining an ARCADY-style empirical capacity model with PTV VISSIM microscopic simulation to assess existing performance deficiencies at three major roundabouts in Ilorin and to quantify the potential operational benefits of entry-approach widening.

1.1 Study Objectives

The specific objectives of this study are to: (i) collect peak-hour traffic volume and geometric data at Pakata, Adeta, and Mandate roundabouts in Ilorin Metropolis; (ii) estimate entry capacities and degrees of saturation for all approaches using an ARCADY-style empirical model; (iii) simulate existing traffic operations using PTV VISSIM to quantify vehicular delay and LOS; (iv) evaluate the operational impact of a proposed three-lane entry-approach widening scenario; and (v) provide evidence-based recommendations for traffic management practitioners and urban planners in Nigerian cities.

2. Literature Review

2.1 Roundabout Capacity Models

Roundabout capacity analysis has evolved considerably over the past five decades. Early gap-acceptance models which estimated entry capacity as a function of critical and follow-up headways were progressively supplanted by empirically calibrated regression-based models following the seminal work of Kimber (1980) at the UK Transport Research Laboratory (TRL). The TRL model, which forms the basis of the ARCADY methodology, expresses entry capacity as a linear function of the circulating flow, with coefficients derived from geometric parameters such as entry width, flare length, inscribed circle diameter, entry angle, and entry radius. This approach has been validated across numerous international contexts and is widely regarded as robust for single-lane roundabouts under prevailing demand conditions (Highway Capacity Manual, 2006).

Subsequent international adaptations of the TRL model have been developed to account for regional driver behaviour, vehicle fleet composition, and design standards. Al-Madani (2016) extended roundabout capacity research to Gulf region contexts, demonstrating that entry capacity relationships are sensitive to local geometric standards and mixed traffic characteristics. Chen and Kim (2017) investigated capacity-flow interactions at multi-lane roundabouts, highlighting the non-linear relationship between entry volume, circulating flow, and approach geometry under high-demand conditions. In sub-Saharan Africa, Abubakar and Ndoke (2013) compared the operational performance of small and large central island rotaries in Minna, Nigeria, establishing that inscribed circle diameter is a key determinant of capacity in the Nigerian context.

2.2 Microscopic Traffic Simulation

Microscopic traffic simulation tools enable analysts to model individual vehicle movements, interactions, and decision-making processes within a virtual representation of a road network. PTV VISSIM, developed by PTV Group (Germany), is among the most widely applied commercial microsimulation platforms globally, offering detailed modelling of car-following, lane-changing, gap-acceptance, and yielding behaviour at complex intersections including roundabouts (Archer, 2005). The software computes key performance metrics including average delay, queue length, throughput, and LOS for each network element under user-specified demand scenarios and geometric configurations.

The complementarity of empirical capacity models and microsimulation is well documented in the literature. Empirical models provide rapid, formula-based estimates that are suitable for preliminary screening, whereas microsimulation enables detailed evaluation of dynamic traffic phenomena and sensitivity testing of alternative geometric or operational configurations (Khatib and Abu-Lebdeh, 2009). This combined methodological approach is therefore particularly well suited to applied engineering studies in data-constrained environments, where detailed calibration data for stochastic models may be unavailable.

2.3 Level of Service Criteria

Level of Service (LOS) is a qualitative performance descriptor that categorises the quality of traffic service experienced by road users. For unsignalised intersections — including roundabouts — the HCM (2006) defines LOS on the basis of average control delay per vehicle, ranging from LOS A (delay ≤ 10 s/veh; excellent, free-flow conditions) to LOS F (delay > 50 s/veh; breakdown, forced-flow conditions). LOS D (35–50 s/veh) is generally considered the acceptable threshold for urban intersection design in developing countries, acknowledging higher acceptable delay levels relative to the US context. Studies by Ishant and Pardeep (2015) confirm that delay-based LOS criteria provide a consistent and practical basis for comparing intersection performance across design scenarios.

3. Study area and data collection

3.1 Description of Study Area

This study focuses on three roundabout junctions situated along principal arterial roads in Ilorin, the capital city of Kwara State, Nigeria (Figure 1). Ilorin is located at approximately latitude 8.50°N and longitude 4.55°E in the North-Central geopolitical zone of Nigeria. The city has experienced rapid population growth over the past two decades, with an estimated urban population exceeding 900,000, generating commensurately high traffic demand on its arterial road network.

Pakata Roundabout is situated at coordinates $\text{N } 8^{\circ}49'4.93''$ and $\text{E } 4^{\circ}52'46.23''$, at a critical intersection connecting to the Oja Oba market axis. It serves six approach roads — Ita Ogumbo, Adeta, Okekere, Oke Apomu, Ita Ebo, and Sakere — and functions as a major commercial and vehicular hub in the city centre.

Adeta Roundabout is located at $\text{N } 8^{\circ}48'76.20''$ and $\text{E } 4^{\circ}51'70.22''$, serving as a vital junction connecting Al-Hikmah University Road, Oke Foma Road, Agbo Oba Road, Kuntu Road, and Pakata Road. Its proximity to a major tertiary institution generates high and temporally concentrated traffic flows.

Mandate Roundabout is situated at $\text{N } 8^{\circ}47'42.29''$ and $\text{E } 4^{\circ}50'28.16''$, linking Western Reservoir Road, Al-Hikmah University Road, Cails Road, and Gerewu Road. It serves as a critical node between Adeta Roundabout and the Geri Alimi commercial intersection and is characterised by intense commercial and socio-economic activity.

3.2 Geometric Survey

Physical measurements of the key geometric features of each roundabout were conducted using a calibrated linen tape. Measured parameters included inscribed circle diameter, entry width per approach, entry radius, entry angle, and circulatory carriageway width. Table 1 presents a consolidated summary of the geometric parameters recorded at all three roundabouts.

Table 1
Summary of Geometric Parameters for All Study Roundabouts

Roundabout	Approach Road	Entry Width (m)	Radius (m)	Circumference (m)	Diameter (m)
Pakata	Ita Ogumbo / Adeta / Okekere	2.4	7.14	42.5	14.28
Pakata	Oke Apomu / Sakere	2.0	7.14	42.5	14.28
Pakata	Ita Ebo	2.1	7.14	42.5	14.28
Adeta	Al-Hikmah University Rd	3.2	25.70	161.45	51.4
Adeta	Oke Foma Road	3.0	25.70	161.45	51.4
Adeta	Agbo Oba Road	2.2	25.70	161.45	51.4
Adeta	Kuntu Road	2.1	25.70	161.45	51.4
Adeta	Pakata Road	2.0	25.70	161.45	51.4
Mandate	Western Reservoir Road	3.1	6.75	47.45	13.49
Mandate	Al-Hikmah University Rd	3.2	6.75	47.45	13.49
Mandate	Cails Road	2.2	6.75	47.45	13.49
Mandate	Gerewu Road	2.0	6.75	47.45	13.49

3.3 Traffic Volume Survey

Peak-hour traffic counts were conducted manually at each roundabout during the evening peak period (4:00–6:00 p.m.) on representative weekday survey days. Trained enumerators stationed at each approach road recorded turning movement counts — including left-turn, right-turn, and through movements — at one-hour intervals. Vehicles were classified into relevant categories (motorcycles, cars, buses, trucks, and tricycles) and converted to passenger car units (PCUs) using the Nigerian standard PCU equivalency factors. The evening peak period was selected based on prior reconnaissance observations confirming consistently higher traffic volumes and longer queue durations during this window relative to the morning peak.

4. Methodology

4.1 ARCADY-Style Empirical Capacity Model

Entry capacity for each approach was estimated using the ARCADY-style linear empirical model, which expresses entry capacity (C) as a decreasing linear function of circulating flow (Q_c):

$$C = A - B \cdot Q_c$$

where C is the entry capacity (veh/h), Q_c is the circulating flow (veh/h), and A and B are empirically derived geometric coefficients that depend on the approach geometry (principally entry width, inscribed circle diameter, and entry radius). The model coefficients were calibrated to Nigerian

traffic conditions in line with guidance from Abubakar and Ndoke (2013) and the Highway Capacity Manual (2006). The degree of saturation (DS) for each approach was then computed as:

$$DS = Q / C$$

where Q is the total entry flow (veh/h). A DS value greater than 1.0 indicates oversaturation, implying that traffic demand exceeds available entry capacity. Capacity analyses were conducted for both the existing single-lane configuration and the proposed three-lane widening scenario for all approaches at the three roundabouts.

4.2 PTV VISSIM Microscopic Traffic Simulation

PTV VISSIM was used to build calibrated microsimulation models of each roundabout under existing geometric and demand conditions. The network geometry, lane configurations, entry widths, and circulating carriageway dimensions were coded according to measured field data. Observed peak-hour turning movement volumes were assigned as vehicle inputs. Wiedemann 74 car-following parameters were adopted for urban driving conditions, and priority rules and conflict areas were set according to the give-way requirements applicable at Nigerian roundabouts. Each simulation run covered a 60-minute peak-hour period, preceded by a 10-minute warm-up period to initialise network loading. Three simulation runs with different random seeds were conducted for each scenario, and results were averaged to reduce stochastic variability. Performance outputs — including average vehicular delay (s/veh) and LOS per approach — were extracted and compared between the existing and proposed scenarios.

4.3 Level of Service Classification

LOS classification was based on average control delay per vehicle (s/veh) according to the HCM (2006) criteria for roundabouts: LOS A (≤ 10 s/veh), LOS B (10–15 s/veh), LOS C (15–25 s/veh), LOS D (25–35 s/veh), LOS E (35–50 s/veh), and LOS F (> 50 s/veh or breakdown conditions). LOS D was adopted as the acceptable service threshold for the study area, consistent with the operational standards applied in comparable Nigerian transportation studies.

5. Results And Discussion

5.1 Capacity Analysis: Pakata Roundabout

Table 2 presents the capacity analysis results for all six approaches at Pakata Roundabout under the existing single-lane and proposed three-lane configurations. Under the existing geometry, all approaches recorded DS values substantially exceeding 1.0, ranging from 1.43 (Ita Ebo Road) to 5.90 (Ita Ogunbo Road), confirming that the roundabout operates under severe oversaturation during the peak hour. The Adeta Road approach, which benefits from relatively low circulating flow (126 veh/h), recorded the highest entry capacity among Pakata approaches (1,036 veh/h), yet its DS of 4.58 still reflects highly congested conditions with total entry flow reaching 4,738 veh/h. The Ita Ogunbo approach — burdened by the highest circulating flow (729 veh/h) recorded the lowest capacity (583 veh/h) and the highest DS (5.90), indicating near-total operational breakdown.

Following the proposed widening to three lanes, entry capacities increased by a factor of approximately 1.5 to 3.0 across all approaches, while DS values fell to a range of 0.51 (Adeta Road) to 0.94 (Oke Apomu Road), all below the critical threshold of 1.0. These results demonstrate that the proposed geometric intervention would restore stable, under-capacity operations at all approaches during the peak hour.

Table 2

Capacity Analysis Results — Pakata Roundabout (Existing 1-Lane vs. Proposed 3-Lane)

Approach	Qc (veh/h)	Q — 1 Lane (veh/h)	C — 1 Lane (veh/h)	DS (1- Lane)	Q — 3 Lane (veh/h)	C — 3 Lane (veh/h)	DS (3- Lane)
Adeta Road	126	4,738	1,036	4.58	1,579	3,107	0.51
Ita Ogunbo Rd	729	3,442	583	5.90	1,147	1,750	0.66
Okekere Road	227	2,197	960	2.29	732	2,879	0.25

Approach	Qc (veh/h)	Q — 1 Lane (veh/h)	C — 1 Lane (veh/h)	DS (1- Lane)	Q — 3 Lane (veh/h)	C — 3 Lane (veh/h)	DS (3- Lane)
Oke Apomu Rd	517	2,051	718	2.86	684	2,153	0.32
Ita Ebo Road	633	1,374	961	1.43	458	2,883	0.16
Sakere Road	298	1,600	875	1.83	533	2,626	0.20

5.2 Capacity Analysis: Adeta Roundabout

Table 3 summarises the capacity analysis results for Adeta Roundabout. The existing single-lane configuration yielded DS values ranging from 1.30 (Kuntu Road) to 6.28 (Al-Hikmah University Road), representing the highest degree of oversaturation observed across all three study roundabouts. Despite the comparatively large inscribed circle diameter of Adeta (51.4 m), which theoretically provides more circulatory storage capacity, the high approach volumes — particularly at Al-Hikmah University Road (total entry flow: approximately 6,177 veh/h) — drove the DS to critical levels. Entry capacities under the single-lane scenario ranged from 978 veh/h to 1,096 veh/h, far below the demand levels recorded.

The proposed three-lane widening reduced all DS values below 0.70, with the most dramatic improvement observed at Al-Hikmah University Road (DS reduced from 6.28 to 0.64) and Oke Foma Road (DS reduced from 5.85 to 0.65). Kuntu Road recorded the lowest post-widening DS of 0.14, indicating free-flow conditions. These results confirm that the three-lane configuration would effectively eliminate peak-hour oversaturation at Adeta Roundabout.

Table 3

Capacity Analysis Results — Adeta Roundabout (Existing 1-Lane vs. Proposed 3-Lane)

Approach	Qc (veh/h)	Q — 1 Lane (veh/h)	C — 1 Lane (veh/h)	DS (1- Lane)	Q — 3 Lane (veh/h)	C — 3 Lane (veh/h)	DS (3- Lane)
Al-Hikmah Univ. Rd	—	~6,177	~983	6.28	2,059	3,225	0.64
Oke Foma Road	101	~5,852	~1,000	5.85	2,059	3,163	0.65
Agbo Oba Road	171	1,471	1,002	1.47	490	3,005	0.16
Kuntu Road	203	1,275	978	1.30	425	2,933	0.14
Pakata Road	46	1,548	1,096	1.41	516	3,287	0.16

5.3 Capacity Analysis: Mandate Roundabout

Table 4 presents the results for Mandate Roundabout. The existing single-lane geometry produced DS values ranging from 1.50 (Gerewu Road) to 4.21 (Western Reservoir Road), with entry capacities constrained to between 555 veh/h and 941 veh/h. The Western Reservoir Road approach — characterised by both the highest circulating flow (767 veh/h) and the lowest entry capacity (555 veh/h) — recorded the worst operational performance. The small inscribed circle diameter of Mandate Roundabout (13.49 m) severely limits circulatory capacity and amplifies the sensitivity of individual approach capacities to circulating flow levels.

Under the three-lane widening scenario, DS values declined dramatically across all approaches, falling to a maximum of 0.47 (Western Reservoir Road) and a minimum of 0.17 (Gerewu Road and

Cails Road). Entry capacities increased to between 1,664 veh/h and 2,823 veh/h, well above peak-hour demand levels, confirming the effectiveness of the proposed intervention.

Table 4

Capacity Analysis Results — Mandate Roundabout (Existing 1-Lane vs. Proposed 3-Lane)

Approach	Qc (veh/h)	Q — 1 Lane (veh/h)	C — 1 Lane (veh/h)	DS (1- Lane)	Q — 3 Lane (veh/h)	C — 3 Lane (veh/h)	DS (3- Lane)
Western Reservoir Rd	767	2,334	555	4.21	778	1,664	0.47
Al-Hikmah Univ. Rd	445	1,943	796	2.44	648	2,398	0.27
Cails Road	252	1,478	941	1.57	493	2,823	0.17
Gerewu Road	252	1,408	941	1.50	469	2,823	0.17

5.4 PTV VISSIM Simulation Results: Vehicular Delay and Level of Service

Table 5 presents a consolidated summary of the average vehicular delay and LOS classification derived from PTV VISSIM simulations under both existing and proposed geometric conditions for all three roundabouts. Under the existing single-lane configuration, average delays at Pakata Roundabout ranged from approximately 85 s/veh (Ita Ebo Road) to over 310 s/veh (Ita Ogunbo Road), all corresponding to LOS F — the lowest possible service classification indicating operational breakdown. Similar conditions were observed at Adeta and Mandate roundabouts, where oversaturation produced unbounded queue growth and simulation instability consistent with real-world observations of protracted gridlock during peak hours.

Following the implementation of the three-lane widening scenario in the simulation models, average vehicular delays fell markedly across all approaches and roundabouts. At Pakata Roundabout, delays were reduced to a range of approximately 8–18 s/veh, corresponding to LOS A and LOS B classifications. At Adeta and Mandate roundabouts, post-widening delays similarly fell within the LOS A–C range, with no approach recording LOS D or worse. These simulation outcomes corroborate the capacity model results and confirm that the proposed geometric modification would eliminate operational breakdown, substantially reduce delay, and restore acceptable levels of service at all three roundabouts.

Table 5

PTV VISSIM Simulation Results — Average Delay and LOS Before and After Widening

Roundabout	Approach	Existing Delay (s/veh)	Existing LOS	Proposed Delay (s/veh)	Proposed LOS
Pakata	Adeta Road	>180	F	~12	B
Pakata	Ita Ogunbo Road	>310	F	~18	B
Pakata	Okekere Road	>120	F	~10	A
Pakata	Ita Ebo Road	~85	F	~8	A
Adeta	Al-Hikmah Univ. Rd	>350	F	~20	C

Roundabout	Approach	Existing Delay (s/veh)	Existing LOS	Proposed Delay (s/veh)	Proposed LOS
Adeta	Oke Foma Road	>300	F	~20	C
Adeta	Agbo Oba Road	~90	F	~7	A
Adeta	Kuntu Road	~75	F	~6	A
Mandate	Western Reservoir Rd	>220	F	~22	C
Mandate	Al-Hikmah Univ. Rd	>130	F	~14	B
Mandate	Cails Road	~90	F	~9	A
Mandate	Gerewu Road	~85	F	~8	A

5.5 Discussion

The results of this study demonstrate unequivocally that the three roundabouts examined are operating at critically deficient levels of service during peak hours. DS values ranging from 1.30 to 6.28 across existing single-lane approaches indicate that demand consistently and dramatically exceeds capacity, a finding consistent with qualitative observations of severe congestion at these locations. The ARCADY-style linear capacity model and PTV VISSIM simulation provided complementary and mutually validating assessments of this operational reality: the empirical model supplied quantitative capacity and saturation estimates, while the microsimulation translated those conditions into tangible delay and LOS outcomes that are directly interpretable by transport planners and decision-makers.

The sensitivity of approach capacity to circulating flow a fundamental feature of roundabout operation is clearly illustrated in the results. At Pakata Roundabout, the Ita Ogunbo Road approach, which bears the highest circulating flow (729 veh/h), records the lowest entry capacity (583 veh/h) and the highest DS (5.90), while the Adeta Road approach, with minimal circulating flow (126 veh/h), achieves the highest capacity (1,036 veh/h). This inverse relationship between circulating flow and entry capacity is well established in the roundabout literature and underscores the importance of balancing demand distribution across approaches in roundabout design.

The proposed three-lane widening scenario produced dramatic improvements in capacity, DS, delay, and LOS across all approaches at all three roundabouts. These results are consistent with international evidence demonstrating that entry-approach widening by increasing the entry flow rate per unit time and distributing circulating demand across a greater number of lanes is one of the most cost-effective geometric interventions available for capacity enhancement at existing roundabouts (Al-Madani, 2016; Chen and Kim, 2017). However, it is important to acknowledge that the effectiveness of such interventions depends on the availability of adequate right-of-way, the capacity of the circulatory carriageway to accommodate increased entry volumes without becoming the binding constraint, and the ability of drivers to navigate multi-lane roundabout environments safely a behavioural adaptation that may require accompanying measures such as lane markings, signage, and driver education in the Nigerian context.

The study also highlights the value of integrating PTV VISSIM microsimulation into roundabout performance evaluation practice in Nigeria. Whereas conventional capacity calculations provide static, approach-level estimates under idealised assumptions, microsimulation captures the dynamic, network-level interactions between approaches including the propagation of queues, the spill-back of circulating flow, and the stochastic variability of driver behaviour that profoundly influence real-world roundabout

performance. The deployment of such tools by transportation agencies in Nigeria would significantly enhance the quality of evidence underpinning infrastructure investment decisions.

6. Conclusions

This study has evaluated the operational performance of three major roundabout junctions Pakata, Adeta, and Mandate on arterial roads in Ilorin Metropolis, Nigeria, using an integrated ARCADY-style empirical capacity model and PTV VISSIM microscopic traffic simulation methodology. The following principal conclusions are drawn:

- All three roundabouts operate under severely oversaturated conditions during the evening peak hour (4:00–6:00 p.m.), with degree of saturation values ranging from 1.30 to 6.28 across existing single-lane approaches. These conditions result in breakdown-level LOS F classification, excessive vehicular delays, and persistent queue formation at all approaches.
- The ARCADY-style linear capacity model provides a robust and computationally efficient framework for estimating entry capacity and degree of saturation at Nigerian roundabouts, with model outputs consistent with observed field conditions.
- PTV VISSIM microsimulation corroborates the empirical capacity analysis and provides additional operational insight into the magnitude of vehicular delay and service quality degradation at oversaturated approaches.
- A proposed geometric intervention widening entry approaches from one lane to three lanes would dramatically increase entry capacities (by factors of 1.5 to 3.2), reduce degree of saturation values to below 1.0 at all approaches (range: 0.14–0.94), reduce average vehicular delays to LOS A–C levels, and restore acceptable operational performance at all three roundabouts.
- The combined application of the empirical capacity model and PTV VISSIM simulation constitutes a robust, transferable methodology for roundabout performance evaluation and intervention assessment in Nigerian and comparable sub-Saharan African urban contexts.

These findings provide actionable, evidence-based guidance for transportation engineers, urban planners, and policy-makers responsible for the planning, design, and management of roundabout intersections in rapidly urbanising Nigerian cities.

7. Recommendations

On the basis of the findings and conclusions presented above, the following recommendations are proposed:

- The widening of entry approaches from single-lane to three-lane configurations should be prioritised at all three roundabouts, with particular urgency at the Al-Hikmah University Road approach at Adeta Roundabout and the Western Reservoir Road approach at Mandate Roundabout, which recorded the most severe levels of oversaturation.
- The right-of-way implications of approach widening should be assessed at each location, with early engagement of land ownership and utility relocation stakeholders to facilitate timely project delivery.
- Adequate road markings, lane delineators, advanced warning signs, and channelisation islands should be installed at all widened approaches to guide drivers in multi-lane roundabout environments and to enhance safety during the behavioural adaptation period.
- On-street parking, street trading, and encroachment of kiosks on approach pavements which effectively reduce carriageway width and impede traffic flow should be prohibited and enforced along all study corridor approach roads.
- Traffic management agencies in Kwara State should integrate PTV VISSIM or equivalent microsimulation tools into their standard planning and design workflows to enable rigorous performance evaluation of proposed traffic interventions prior to capital commitment.
- Routine traffic monitoring and operational audits should be conducted at six-monthly intervals following any geometric intervention to confirm that the intersection continues to perform at or above the LOS D standard as background demand grows.
- Future research should investigate the incorporation of non-motorised transport modes particularly motorcycles (okada), which constitute a significant fraction of vehicle flows at these roundabouts into the capacity model and simulation framework, and should explore the potential of

adaptive traffic signal control as an alternative or complementary intervention where right-of-way constraints preclude physical widening.

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