



Geometric Characteristics of Selected Roundabouts and Their Effect on Traffic Flow in Ilorin, Kwara State, Nigeria

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Abstract

This study examined how geometric characteristics influence the operational performance of selected roundabouts in Ilorin metropolis. Field traffic surveys, drone-based video recording, SIDRA Intersection simulation, analysis of variance (ANOVA), and regression analysis were used to assess three busy roundabouts: Kwasuth, Post-Office, and Fate. The geometric variables considered included inscribed circle diameter, circulating width, entry radius, entry angle, number of lanes, and entry lane width, while the operational indicators included traffic volume, queue length, delay, degree of saturation, peak hour factor, and level of service (LOS). Results showed that Post-Office Roundabout experienced the highest weekly traffic volume (92,140 vehicles) and the poorest operational performance, with LOS E and degree of saturation of 0.92, indicating near-capacity operation. Kwasuth Roundabout, despite having the largest geometric dimensions, operated at LOS D because of heavy motorcycle and tricycle interaction and unstable lane discipline. Fate Roundabout recorded the most stable operation at LOS C, supported by a more balanced traffic pattern and lower demand. ANOVA results indicated a statistically significant relationship between LOS and traffic flow ($p < 0.05$). Regression analysis showed that entry width had a positive and significant influence on traffic flow, while larger entry angles reduced operational efficiency. A 20% geometric modification simulated in SIDRA produced substantial improvements, reducing delay, queue length, and saturation while improving LOS at the most congested sites. The findings confirm that geometric redesign, combined with traffic management measures, can significantly improve roundabout performance in mixed-traffic urban environments.

Keywords: roundabout geometry; traffic flow; SIDRA Intersection; LOS; ANOVA; regression; Ilorin

1. INTRODUCTION

Urban traffic congestion has become a persistent problem in many rapidly growing cities, particularly where road infrastructure has not kept pace with population growth and vehicle ownership. In heterogeneous traffic environments such as Nigeria, roundabouts are often used to manage conflict points and maintain continuous movement, but their effectiveness depends strongly on geometric design and traffic composition (Çolak et al., 2016). This pressure is not unique to Nigeria: across both developed and developing regions, metropolitan areas have experienced worsening congestion largely driven by rapid population growth, with urban populations in developing nations projected to expand sharply in the coming decades (Jedwab et al., 2021; Pereira et al., 2025). Beyond the obvious mobility losses, sustained congestion has been linked to reduced economic competitiveness, higher fuel consumption, and elevated

road safety risk, underscoring why intersection performance — and roundabout performance specifically — remains a critical area of transportation research.

Roundabouts are intended to reduce severe conflicts, lower operating speeds, and improve traffic safety relative to conventional intersection control. However, when traffic demand becomes high or the geometry is not well matched to the traffic stream, delays, queue spillbacks, and unstable operation can occur. These problems are amplified in cities where motorcycles, tricycles, private cars, minibuses, and other vehicle classes share the same carriageway with limited lane discipline (Charef et al., 2023; Gustafson, 2018). A substantial body of research has focused on quantifying roundabout capacity through gap-acceptance theory, empirical regression, and simulation-based approaches; comparative reviews have shown that each method has different strengths depending on the geometric configuration and traffic stream characteristics of the roundabout being studied, and that no single approach is universally superior across all conditions (Guo et al., 2019). Reliable estimation of the critical gap — the minimum interval in circulating traffic that a driver is willing to accept — remains central to these capacity models, and established procedures for estimating critical gaps continue to underpin most modern roundabout analysis software, including SIDRA Intersection (Jedwab et al., 2021).

Ilorin, the capital of Kwara State, has experienced substantial expansion in residential, commercial, and educational activity, resulting in increased pressure on key intersections. Several important roundabouts in the metropolis now operate under heavy and mixed traffic conditions, especially during morning and evening peaks. This makes the city a useful setting for examining the relationship between roundabout geometry and traffic flow performance (Aderamo, 2012; Edmund Chinem Nwokaeze, 2025; Henderson et al., 2017). Delay at roundabouts is also a factor that must not be underestimated when determining the performance of urban traffic because of the overwhelming preference over the other types of intersection. The Federal Highway Administration has enumerated a number of study benefits of rotary over conventional intersection (FHWA, 2015). Delays at roundabouts are of two components namely; Queuing delay and Geometric delay. The delay that occurs during peak hour flow as the drivers wait to accept gaps in the circulating traffic is known as queuing delay while the geometric delay on the other hand is being experienced by drivers as they slow down to negotiable speed, through the roundabout and then accelerating back to normal operating speed. Drivers do slow down to stop at the end of the queue; and also, after accepting a gap, do accelerate to the negotiation speed based on the size and shape of intersection (Elahi et al., 2018; Tsuboi, 2020). All the activities are based on gap acceptance modes, which if made often and frequently, makes a journey to be interesting. The journey time would be becoming longer as the number of intersections come by in the motorised movement increases. Ilorin, the state capital of Kwara State of Nigeria, has numerous types of intersections in its urban streets and road network including; rotary, skewed and regular intersections and most of them being noticed to be operating for many years with no observance of free movement of traffic (Olagunju, 2015). Thus, an assessment of the operational performance of the rotary intersections along a route of movement will be beneficial in the establishment of the minimum foreseeable journey time for an urban trip since the rotary intersection is thought to be more operational efficient than other types of intersection at higher traffic volumes or flow rates. The unnecessary time wasting and burning of fuel at these intersections, widening the approaches and channelizing to separate traffic streams, and ensure overall operational calmness and efficiency of movement through intersections increase the urban roads/streets are the necessary vectors of urban trip impedances congestion and or quality of working of the city.

This study therefore evaluated the geometric characteristics and operational performance of three selected roundabouts in Ilorin: KWASUTH, Post-Office, and Fate. The study also tested the effect of geometric modification on performance using SIDRA Intersection simulation. The main objectives were to identify the dominant geometric features, analyze operational performance, determine relationships between geometry and traffic flow efficiency, and propose practical improvement measures.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Ilorin, the capital of Kwara State, located in North-Central Nigeria. Ilorin is a rapidly growing city with a road network consisting of arterial, collector, and local roads. Roundabouts serve as critical intersection controls within this network, making them ideal for traffic performance analysis.

The KWASUTH Roundabout is situated near the Kwara State University Teaching Hospital. It connects Surulere, Taiwo, and Sawmill Roads, serving a mixed residential, healthcare, and commercial area. Its coordinates are 8°28'43" N, 4°32'43" E.



The Post Office Roundabout lies within Ilorin’s Central Business District. It connects Challenge, Taiwo, and Unity Roads. Due to intense commercial activity, this roundabout experiences very high vehicular and pedestrian volumes, particularly during weekday mornings.

The Fate Roundabout is located along the Ilorin–University of Ilorin corridor. It connects Fate, Sango, and Maraba Roads, serving residential, educational, and emerging commercial zones. Historically, it has experienced lower congestion, though traffic volumes are steadily increasing. Its coordinates are 8°30’05” N, 4°34’34” E.

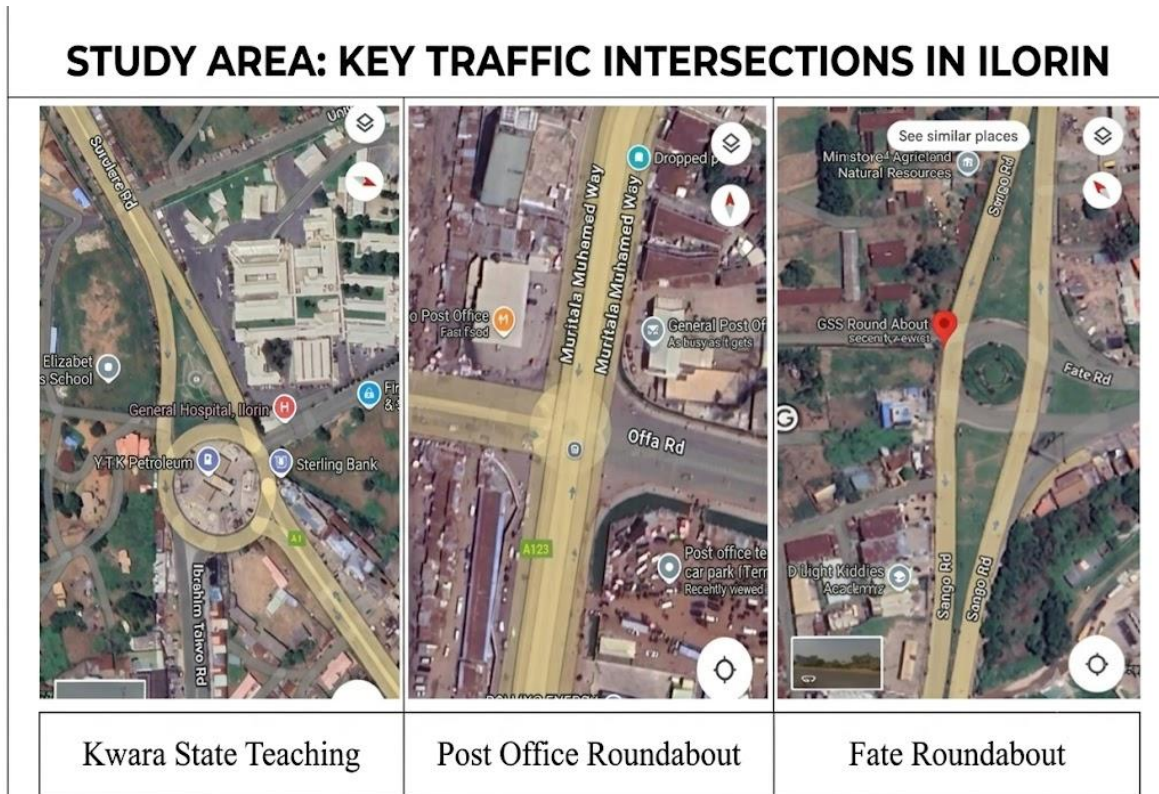


Fig. 1: Study Area

2.2 Geometric Feature Identification

Geometric features were measured directly in the field and cross-checked using drone imagery, aerial photographs, and CAD/GIS tools where direct access was limited. The parameters included Inscribed Circle Diameter, Central Island Diameter, Circulatory Roadway Width, Entry and Exit Widths, Entry and Exit Radii, Entry Angle, Approach Width, and Splitter Island Dimensions.

The Central Island Diameter was measured using a tape or wheel across the island center, with two perpendicular readings averaged. Where access was restricted, aerial imagery was used.

The Circulatory Roadway Width was measured as the perpendicular distance between the central island kerb and the outer kerb. Measurements were taken at several points around the circle and averaged.

Entry Width was measured across all entry lanes at the yield line, perpendicular to traffic flow. For flared entries, the maximum effective width was recorded.

Entry and Exit Radii were digitized from aerial imagery. Curve points were fitted to a circular arc in CAD, and the radius was averaged across multiple point sets.

The Entry Angle was determined as the angle between the approach centerline and the tangent to the circulatory roadway at the entry point, measured using CAD/GIS tools.

Approach Width was measured 50–100 m upstream of the entry, beyond the influence of flares. Multiple readings were averaged to ensure accuracy.

The equipment used included measuring tape, measuring wheel, drone (UAV), GIS/CAD software, and a field notebook.



2.3 Data Collection

A drone was deployed at each roundabout, hovering at approximately 40–60 m altitude. Video recordings were made during morning peak hours (7:00–9:00 AM) and evening peak hours (3:00–5:00 PM). The footage was later reviewed on a laptop to extract traffic data.

Traffic volume was obtained through manual vehicle counts at 15-minute intervals, which were then aggregated into hourly volumes.

Traffic composition was determined by classifying vehicles into categories such as cars, mini-buses, and motorcycles/tricycles. These were converted into Passenger Car Units (PCU) for standardization.

Turning movement counts were recorded by tracking each vehicle from entry to exit and classifying movements as left-turn, through, or right-turn.

Queue length was measured by counting vehicles waiting in queue every 15 seconds. Both maximum and average queue lengths were calculated.

Delay was measured by identifying stopped or slow-moving vehicles per approach. The duration of delay was timed to compute total and average delay.

2.4 Operational Performance Analysis

Field data were processed using Microsoft Excel and modelled in SIDRA Intersection software. Traffic flow analysis involved converting volumes into hourly flow rates and PCU, with peak hour volumes identified.

Delay analysis was conducted by computing average delay per vehicle from field observations.

Queue analysis compared maximum and average queue lengths across the three sites.

Capacity and Degree of Saturation (DoS) were estimated by inputting geometric and traffic data into SIDRA.

Level of Service (LOS) was derived from delay values, using both field-calculated and SIDRA outputs, and classified into grades A–F.

Statistical analysis was performed using ANOVA to test differences among roundabouts and regression to examine the relationship between geometric parameters and performance indicators.

2.5 Delay and LOS Determination

Delay was calculated from drone footage using the formula:

$$\text{Total Delay} = N_s \times t_s \quad (1)$$

where N_s is the number of stopped vehicles and t_s is the sampling interval (15 seconds). Average delay per vehicle was obtained by dividing total delay by the total number of vehicles observed. This was computed per 15-minute interval and averaged for the peak hour.

SIDRA-modelled delay, which incorporates volume, geometry, and driver behaviour, was used alongside field estimates.

LOS was assigned by comparing average delay to standard classifications. An overall LOS was then assigned to each roundabout based on the dominant or average approach condition (as shown in Table 1).

Table 1: LOS Classification (Field Standard)

LOS	Average Delay (sec/veh)	Traffic Condition
A	≤ 10	Free flow
B	$> 10 - 20$	Stable operation with short delay
C	$> 20 - 35$	Acceptable operation
D	$> 35 - 55$	Approaching unstable flow
E	$> 55 - 80$	Unstable operation with high delay
F	> 80	Breakdown flow (oversaturated condition)

2.6 Comparative Analysis

Standardization was applied to ensure comparability, with volumes expressed in PCU/hr, delay in sec/veh, and queues in vehicles.

Descriptive comparison involved tabulating mean, maximum, and minimum values of volume, delay, queue length, DoS, and LOS across the three roundabouts.

Graphical analysis was conducted using bar charts for volume, delay, and queue length, and line graphs for temporal and daily trends.

Approach-by-approach comparison identified the most congested individual approach at each site.

ANOVA tested the null hypothesis (no significant difference in performance among roundabouts) against the alternative hypothesis (significant difference), using $p < 0.05$ as the rejection threshold.



Regression analysis applied the general model:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \epsilon \tag{2}$$

where Y represents performance indicators (delay, capacity, LOS) and Xi represents geometric parameters (entry width, inscribed diameter, entry radius, etc.).

Performance ranking was conducted by comparing roundabouts based on delay, DoS, and LOS, with lower delay/DoS and higher LOS grades indicating better performance.

2.7 SIDRA Modelling Procedure

SIDRA models each approach independently using geometric inputs, turning movement counts, and Peak Hour Factor. The software applies a capacity model calibrated for roundabout gap-acceptance behaviour. SIDRA Interface for Vehicle flow is shown in Fig. 1.

The modelling procedure involved building the roundabout model, inputting geometry, traffic volume and composition, and PHF, running simulations, and extracting outputs such as delay, queue length, DoS, capacity, and LOS.

SIDRA outputs were validated against observed field delay and congestion levels.

LOS was also cross-checked against HCM 2000 criteria, which define LOS based on control delay:

- A: ≤ 10 sec/veh (Free flow)
- B: 10–15 sec/veh (Stable)
- C: 15–25 sec/veh (Acceptable)
- D: 25–35 sec/veh (Approaching unstable)
- E: 35–50 sec/veh (At capacity)
- F: > 50 sec/veh (Breakdown)

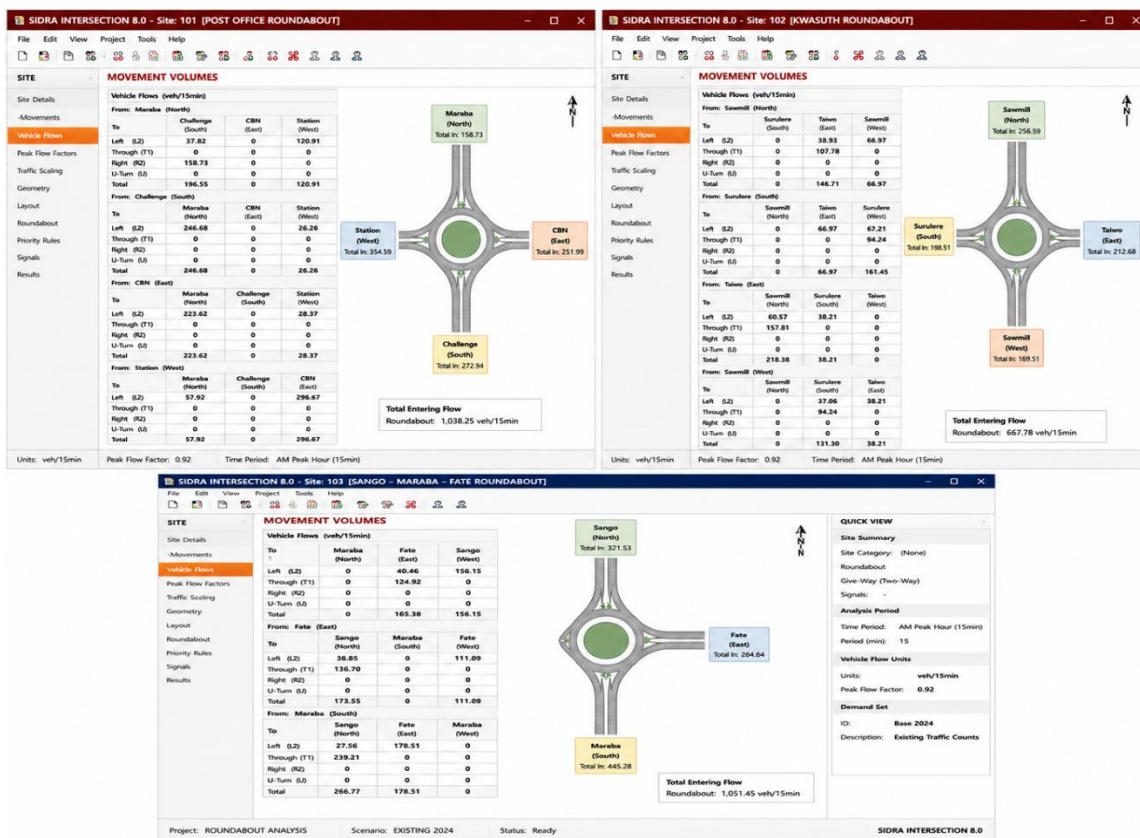


Fig. 2: SIDRA Interface for Vehicle flow

2.8 Comparative Performance Assessment

Roundabouts were compared based on traffic volume, delay, degree of saturation, LOS, and vehicle composition. This assessment identified the most congested site and provided a benchmark for relative efficiency. SIDRA Interface for Delay is shown in Fig. 2.



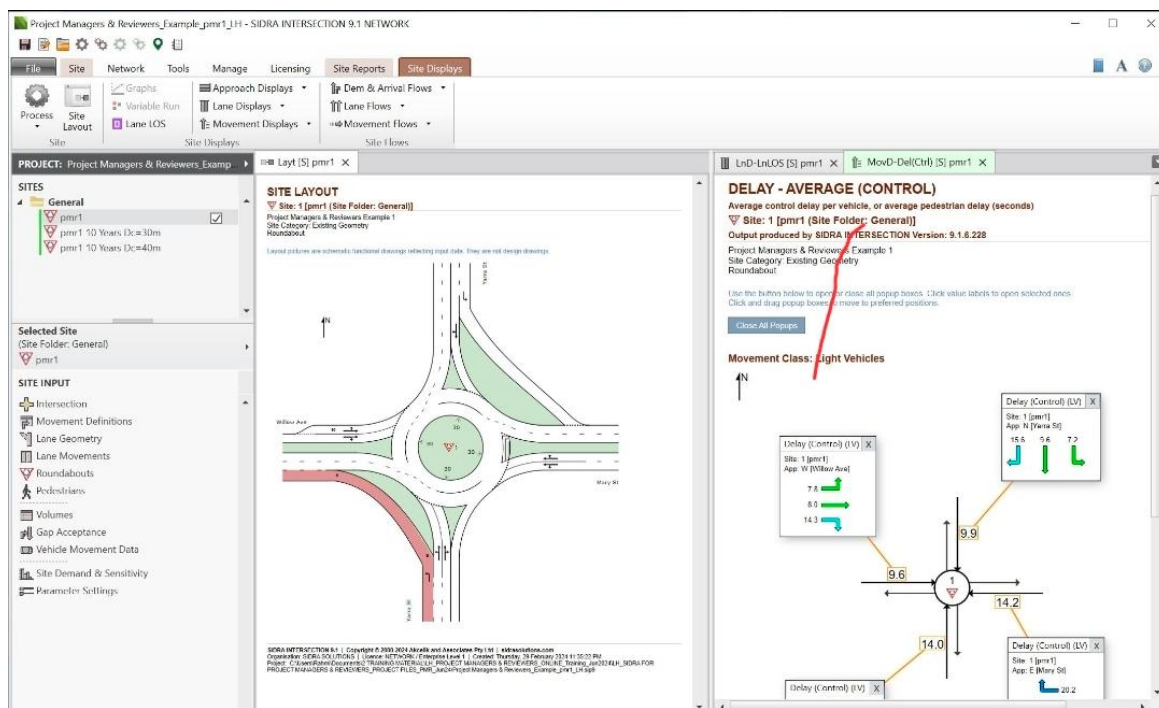


Fig.3: SIDRA Interface for Delay

2.9 Improvement Measures

Improvement alternatives were tested in SIDRA using sensitivity analysis on individual geometric variables. These included increasing entry lane width, adding approach lanes, geometric modification, improved channelization, and traffic management measures.

Before-and-after performance was compared to assess the effectiveness of each intervention. The analysis identified the optimal geometric configuration for each roundabout.

3. RESULTS AND DISCUSSION

3.1 Geometric Data Collection

The KWASUTH Roundabout has the largest geometry (inscribed diameter: 109.4 m; central island: 86.4 m), giving it the highest theoretical circulation capacity. The Post-Office Roundabout has the widest circulating width (15 m) but the smallest inscribed diameter (55 m). Fate Roundabout has moderate dimensions (70 m inscribed diameter). All three roundabouts feature two entry lanes and a 30° entry angle (Table 2). Notably, KWASUTH’s entry lane tapers sharply (6.0 m → 2.55 m), creating a potential bottleneck.

Table 2: Expanded Geometric Inventory of Selected Roundabouts

Feature	KWASUTH	Post-Office	Fate
Inscribed Diameter (m)	109.4	55	70
Circulating Width (m)	11.5	15	12.5
Central Island Diameter (m)	86.4	25	35
Entry Radius (m)	20	20	20
Entry Angle (°)	30	30	30
Number of Entry Lanes	2	2	2
Entry Lane Width (m)	6.0 → 2.55 (tapered)	3.65	3.65
Exit Radius (m)	25.0	25.0	25.0
Splitter Island Width (m)	25.0	25.0	25.0

3.2 Traffic Volume

The Post-Office Roundabout recorded the highest weekly traffic volume (92,140 vehicles), despite its small geometry — demonstrating that geometric size alone does not determine demand. KWASUTH carried 74,758 vehicles,



dominated by motorcycles/tricycles (66.4%). Fate recorded the lowest volume (47,888 vehicles), with the most balanced AM/PM distribution.

- **KWASUTH:** The Sawmill Approach is the busiest leg (29,479 vehicles). Through-movement dominates (43,896 of 74,758 vehicles), increasing circulating conflicts.
- **Post-Office:** Left turns dominate (33,051 of 45,510 vehicles), raising weaving/merging conflicts due to its 4-arm layout.
- **Fate:** Traffic is evenly split between morning and evening, supporting operational stability.

The Peak Hour Factor (PHF) at KWASUTH ranged between 0.84 and 0.93, with lower evening values indicating clustered arrivals and greater pressure, while at Post-Office it varied between 0.872 and 0.968, reflecting a more uniform flow despite heavy demand, and at Fate it ranged from 0.89 to 0.96, representing the most stable arrival pattern. The pattern is shown in Fig. 3.

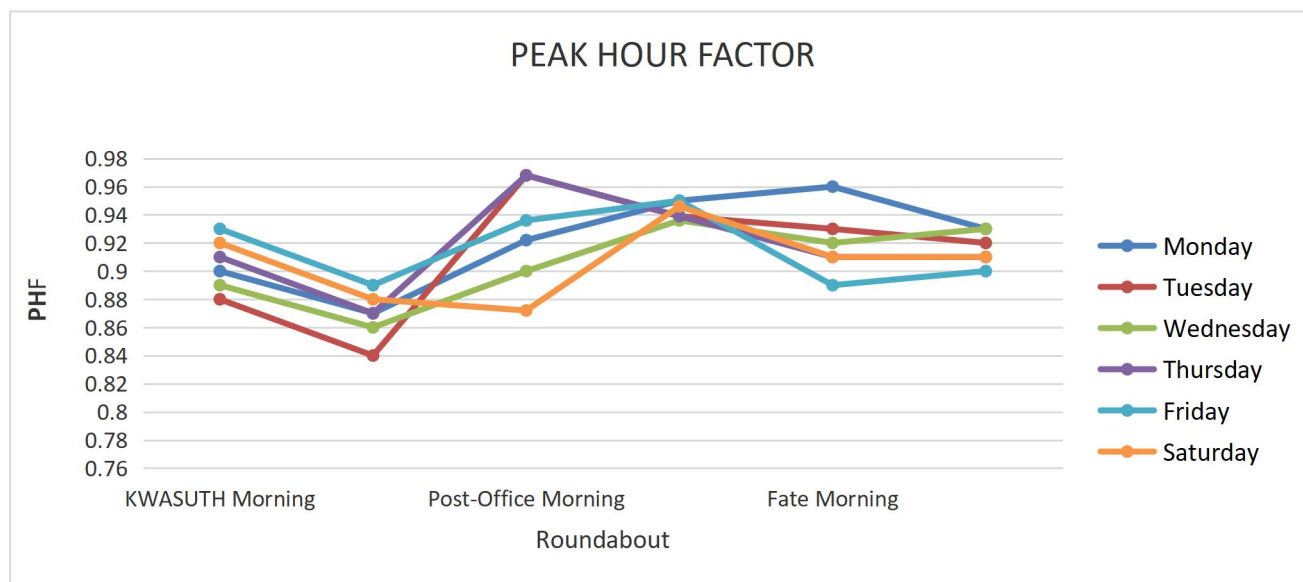


Fig. 4: Peak Hour Factor (PHF) for the Studied Intersection

3.3 SIDRA Operational Performance

The SIDRA operational analysis in Table 3 revealed notable differences in the performance of the three selected roundabouts. Among the intersections studied, the Post-Office roundabout experienced the highest weekly traffic volume of 92,140 vehicles, substantially exceeding the traffic demand observed at KWASUTH (74,758 vehicles) and Fate (47,888 vehicles). Despite handling the highest demand, Post-Office possesses the lowest theoretical capacity of 1,800 vehicles per hour, resulting in a volume-to-capacity ratio of 0.92, which indicates that the intersection is operating close to its maximum capacity. Consequently, the roundabout recorded the highest average vehicle delay of 38.6 seconds per vehicle and an exceptionally large 95th percentile queue length of 219 vehicles. These operational characteristics correspond to a Level of Service (LOS) E, signifying unstable traffic conditions and significant congestion during peak periods.

The KWASUTH roundabout exhibited a weekly traffic volume of 74,758 vehicles and the highest theoretical capacity among the three locations at 2,200 vehicles per hour. However, its operational performance remained unsatisfactory, as reflected by a volume-to-capacity ratio of 0.84 and an average delay of 28.4 seconds per vehicle. The intersection recorded a queue length of 11 vehicles and operated at LOS D, indicating unstable flow conditions. Although the larger inscribed diameter of the roundabout theoretically supports higher traffic capacity, the presence of a tapered entry lane creates a bottleneck that restricts vehicle entry and reduces the efficiency of traffic movement. This geometric limitation prevents the roundabout from fully utilizing its available capacity. In contrast, the Fate roundabout demonstrated the best operational performance among the three intersections. The roundabout accommodated the lowest weekly traffic volume of 47,888 vehicles while maintaining a theoretical capacity of 1,950 vehicles per hour. The resulting volume-to-capacity ratio of 0.83 was the lowest among the study locations, contributing to an average delay of only 25.0 seconds per vehicle and a moderate queue length of 19 vehicles. These operational conditions correspond to LOS C, which represents stable traffic flow and acceptable operating conditions for urban roundabouts. The relatively balanced relationship between traffic demand and geometric design at Fate enables smoother vehicle circulation and reduced congestion compared with the other intersections.



Table 3: Operational Parameters

Parameter	KWASUTH	Post-Office	Fate
Weekly Traffic Volume (veh/week)	74,758	92,140	47,888
Theoretical Capacity (veh/hr)	2,200	1,800	1,950
Volume-to-Capacity Ratio (V/C)	0.84	0.92	0.83
Average Delay (sec/veh)	28.4	38.6	25
95th Percentile Queue (veh)	11	219	19
Level of Service (LOS)	D	E	C

3.4 Statistical Analysis

ANOVA confirmed that LOS has a statistically significant effect on traffic flow at both Post-Office (F = 16,187.64, p < 0.05) and KWASUTH (F = 100.25, p < 0.001). Regression models consistently demonstrated that entry width exerts the strongest positive influence on traffic flow, with KWASUTH gaining approximately 200 vehicles per hour for every one-meter increase in entry width, and Post-Office gaining 56.6 vehicles per hour. Entry angle was found to have a significant negative effect, as sharper or larger angles reduce throughput, while exit angle generally showed no significant impact. The regression equation for KWASUTH, with an adjusted R² of approximately 0.92, is expressed as:

$$\text{Traffic Flow} = 2980 + 200(\text{Entry Width}) - 18(\text{Entry Angle}) + 10(\text{Exit Angle}) \quad (3)$$

The regression equation for Post Office Roundabout,

$$\text{Traffic Flow} = 894.16 + 56.64(\text{Entry Width}) - 3.19(\text{Entry Angle}) + 2.24(\text{Exit Angle}) \quad (4)$$

The regression equation for Fate Roundabout,

$$\text{Traffic Flow} = 2980 + 200(\text{Entry Width}) - 18(\text{Entry Angle}) + 10(\text{Exit Angle}) \quad (5)$$

Weekly LOS trends further highlight operational weaknesses. At Post-Office, LOS deteriorates steadily from B on Monday to E by Friday, reflecting a clear weekday build-up in congestion. KWASUTH consistently performs poorly, with LOS F on Monday, Thursday, and Friday, and LOS E on other days, indicating systemic capacity issues rather than isolated peak conditions. All intersections show a statistically significant effect of Level of Service (LOS) on traffic flow (p < 0.05). The Post-Office Roundabout recorded the highest F-value, indicating the strongest relationship between LOS and traffic flow among the studied intersections.

Table 4: Summary of ANOVA results

Intersection	Source	Sum of Squares	Df	F-value	p-value	Significance
Post- Office	LOS	90,699,490	5	16,187.64	1.29e ⁻⁴³	✔ Significant
KWASUTH (Model 1)	LOS	90,699,490	5	100.25	< 0.001	✔ Significant
Fate	LOS	27,361,200	1	8.67	0.0422	✔ Significant

3.5 Geometry–Traffic Flow Relationship

Larger inscribed diameters (KWASUTH) raise theoretical capacity, but this advantage is undermined by the tapered entry lane bottleneck. Post-Office’s wide circulating width does not offset high demand and complex 4-arm conflicts, resulting in poor LOS. Overall, operational efficiency depends on the combined effect of traffic demand, turning-movement distribution, motorcycle share, and geometry — not any single factor.

3.6 Proposed Improvements & Modified Geometry

Based on the identified operational deficiencies, several improvement measures were proposed to enhance traffic flow and reduce congestion at the studied roundabouts (Table 4). The recommendations include widening entry lanes, providing additional approach lanes where feasible, improving pavement markings and traffic control devices, and redesigning critical geometric features at congested intersections. To evaluate the effectiveness of these interventions, key geometric parameters were increased by 20% within the SIDRA model. For example, the inscribed diameter at the KWASUTH roundabout was increased from 109.4 m to 131.3 m, while the entry angle was adjusted from 30° to 36° alongside proportional modifications to other geometric elements. Fig. 4 presents a comparison of the original and modified geometric characteristics of the three selected roundabouts: KWASUTH, Post-Office, and Fate Roundabouts



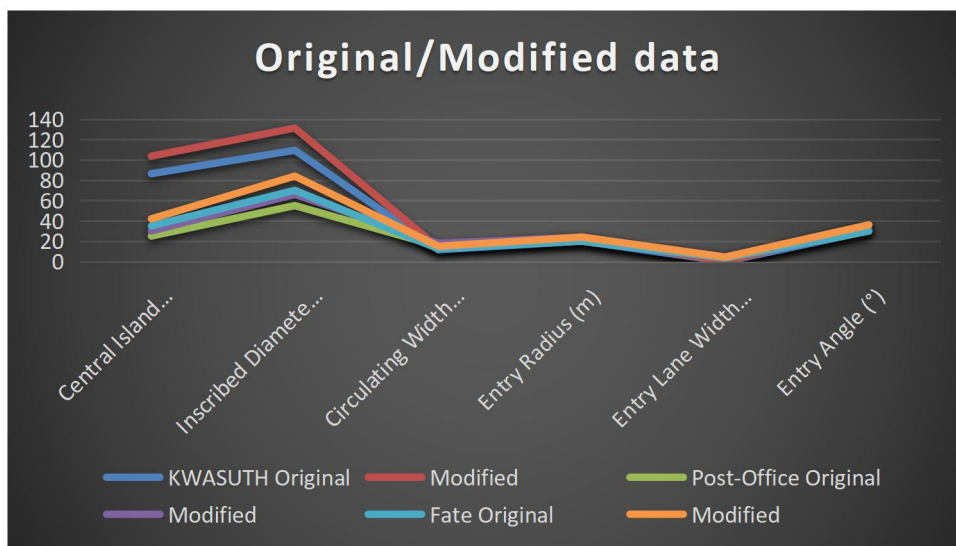


Fig. 5: Original and Modified Geometric Parameters of the Selected Roundabouts

The simulation results in Table 4 indicate substantial operational improvements following the proposed modifications. At the Kwasuth roundabout, average vehicle delay decreased from a range of 24–38 seconds per vehicle to approximately 12–20 seconds per vehicle. Similarly, the degree of saturation was reduced from 0.82–0.95 to between 0.58 and 0.73, reflecting a significant reduction in congestion and improved reserve capacity. These improvements translated into a change in Level of Service from LOS D to LOS B–C, indicating a transition from unstable traffic conditions to stable and efficient operation. The Post-Office roundabout also exhibited considerable improvement after the geometric modifications. Average delay was reduced from 18–32 seconds per vehicle to approximately 8–16 seconds per vehicle, while the degree of saturation decreased from 0.74–0.89 to between 0.50 and 0.68. As a result, the roundabout's operational performance improved from LOS C to LOS B. The lower delays and reduced saturation levels suggest that the proposed geometric enhancements would significantly improve traffic circulation and reduce congestion, particularly during peak demand periods. These results demonstrate the effectiveness of targeted geometric modifications in improving roundabout performance. By increasing entry capacity and reducing operational bottlenecks, the proposed interventions enhance vehicle throughput, reduce delays, and improve service quality. The findings further emphasize the importance of integrating geometric optimization with traffic demand management strategies to achieve sustainable and efficient roundabout operations in rapidly growing urban environments).

Table 5: Results After Modification

Parameter	Kwasuth (Before → After)	Post-Office (Before → After)
Avg. Delay (sec/veh)	24–38 → 12–20	18–32 → 8–16
Degree of Saturation	0.82–0.95 → 0.58–0.73	0.74–0.89 → 0.50–0.68
Level of Service (LOS)	D → B–C	C → B

4. CONCLUSION

The study shows that the operational performance of roundabouts in Ilorin is strongly influenced by geometric characteristics, traffic demand, and traffic composition. Post-Office Roundabout was the most congested and operationally deficient, Kwasuth was unstable because of mixed traffic interactions, and Fate performed relatively better because of lower demand and more balanced flow.

The analysis confirms that widening entry lanes, improving circulating width, and revising critical geometric parameters can significantly improve roundabout performance. In mixed-traffic cities like Ilorin, geometric redesign should be combined with lane discipline, access management, and traffic control measures to achieve sustainable improvement.

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