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Traffic Signaling Control for a Three-Leg Busy Intersection in Nnewi Commercial Metropolis

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Abstract
Transportation enables and enhances the movement of people, goods, and services from one location to another. It is an important aspect of human existence. As urban travel demand increases, traffic congestion has become a persistent challenge. This has brought about several attempts to improve the efficiency of movement through various traffic control mechanisms. This research focused on evaluating traffic flow characteristics and developing an appropriate traffic signal control scheme for the First Bank intersection at Nkwo Nnewi, Nnewi North Local Government Area of Anambra State Nigeria. The intersection has three legs. The widths of the approaches vary, measuring 8.4 m on the Northbound approach, 9.9 m on the Eastbound approach, and 11.25 m on the Westbound approach. Traffic volume studies was conducted to ascertain the peak hour traffic flow at the intersection. The traffic volumes were normalized based on the Passenger Car Unit (PCU) values. The traffic signal design was developed primarily based on Webster's signal design method, while accounting for the geometric characteristics of the approaches to the junction. The signal design analysis produced an optimum cycle length of 43 seconds and a total effective green time of 28 seconds. Peak-hour delay prior to signalization was observed to be 92 seconds per vehicle. The delay which was estimated using the simplified Webster delay model was reduced to 26.33 seconds per vehicle, representing a 71.38% decrease in average delay. The proposed traffic signal design is therefore recommended for implementation at First Bank Junction and at similar congested intersections to improve traffic operations, reduce delays, and enhance intersection performance.

Keywords: Amber Time, Green Time, Optimum Cycle Length, Red Time, Signal Design, Traffic Count

1. Introduction

Traffic refers to the movement of vehicles and other road users on public roads. Traffic study, also known as traffic analysis, is the systematic collection and evaluation of data relating to traffic conditions, movement patterns, and roadway operations within a given area for the purpose of understanding traffic behavior and improving transportation efficiency (Nwakaire et al., 2016). Road transport accounts for approximately 75% of mobility demand in Nigeria, with over seven million vehicles operating daily on Nigerian roads (Ajayi and Olusina, 2024). Due to rapid urbanization, population growth, and increased vehicle ownership, traffic congestion has become a major challenge in many Nigerian cities. This situation has resulted in increased travel delay, road accidents, fuel wastage, environmental pollution, and economic losses.

Traffic studies are generally classified into inventory studies, administrative studies, and dynamic studies (Al-Khaissi et al., 2021). Inventories provide a list of graphic display of existing information, such as street widths, parking spaces, transit routes, traffic regulations, and so forth. Some inventories – for example available parking spaces and traffic regulations change frequently and therefore require periodic updating while others such as street widths do not. Administrative studies use existing engineering records, available in government agencies and departments. This information is also used to prepare an inventory of the relevant data. Inventories may be recorded in files but are usually recorded automated data processing (ADP) systems. Administrative studies include the result of surveys which may involve field measurements or aerial photography. Dynamic traffic studies, which involve field data collection under actual operating conditions such as traffic volume counts, speed studies, and delay analysis, are particularly useful for evaluating current traffic conditions and designing effective control measures which was used in this study.

Traffics signal involves regulatory and warning signs (Mustapha, 2022). Several authors like Anene et al, (2023) conducted a research at Orlu junction and concluded after his design using Webster's method of traffic signal control that application of traffic signal control system at Orlu junction Ihiala Anambra State will automatically control and minimize intersection accidents, eradicate jams, bottlenecks especially peak hours and festive periods. Adedeji, (2023) designed a traffic signal at Jibowu under bridge Lagos State employing sensor based systems which takes care of both emergency vehicles using PLC (Programmable logic control) and smart traffic control systems which seems to operate more efficiently than the existing traffic control system resulting in reduced waiting times, improved emergency mode operation and decrease in accident risks in the study area.

Road marking involves regulatory, warning and guidance signs (Mustapha, 2022). They are lines and symbols that show road alignment, indicate the number of lanes, where it is possible to overtake, don't overtake and stop. They include centre, edge and centre lines, Zebra or pedestrian crossing, permanent messages. Centre lines are reflective for visibility (day and night) and should be reestablished when cleaned to fulfill its obligation. It is important to educate the road users especially drivers on its importance for safety. Examples of road marking includes, Centre line which enables drivers maintain lanes, Double solid yellow or white line which means no overtaking (FMW, 2013)., Broken solid white or yellow means passing permitted, Solid yellow or white line means passing not permitted, Zebra or pedestrian crossing means only pedestrians are allowed to cross. Drivers and road users are meant to pay attention and understand those signs for its effectiveness to promote safe driving as they were designed to convey critical information quickly (Chao et al., 2013).

Barricade is one of the traditional methods used in traffic management but seems unsuccessful in congested areas (Rajak, 2019). Umar et al, (2019) proposed a density-based traffic management system in Niger State which would replace involvement of human in the management of traffic congestion especially during peak, rainy and sunny hours, management of people and vehicles as they obey the system. However, Umar et al. (2019) submitted that traffic signaling remains very efficient for traffic control at busy intersections and requires no direct human effort for implementation.

This study focuses on investigation of the traffic characteristics of a very busy three-leg intersection at Nnewi metropolitan city. An attempt has been made towards managing the observed congestion by designing a suitable traffic signaling scheme for that intersection. This demonstrates a significant reduction in traffic congestions by implementation of traffic signal control scheme for a busy intersection.

2.0 Research Methods

2.1 Description of the Study Area

The study area, First bank junction Nkwo Triangle Nnewi, a town in South Eastern Part of Nigeria located in the Southern part of Anambra State and within Igbo land with a population of about 1,301,000 as of January 2024 **(***Nigeria Metro Area Population, 2024).* The area is well known for large scale commercial activities and referred to as Nkwo Nnewi (The Japan of Africa). Nkwo Nnewi market is the second largest market in Anambra State after Onitsha main market. The market is known for sales of motorcycle, motor, tricycle and generator parts which has contributed to the economic boom of the area, State and Nigeria at large. The area experiences high volume of traffic in morning and evening hours, the traffic worsens during ceremonial or festive periods. This can be seen by constant gridlock and prolonged waiting times that occurs across the study location. The road network of the study location is shown in Figure 1.

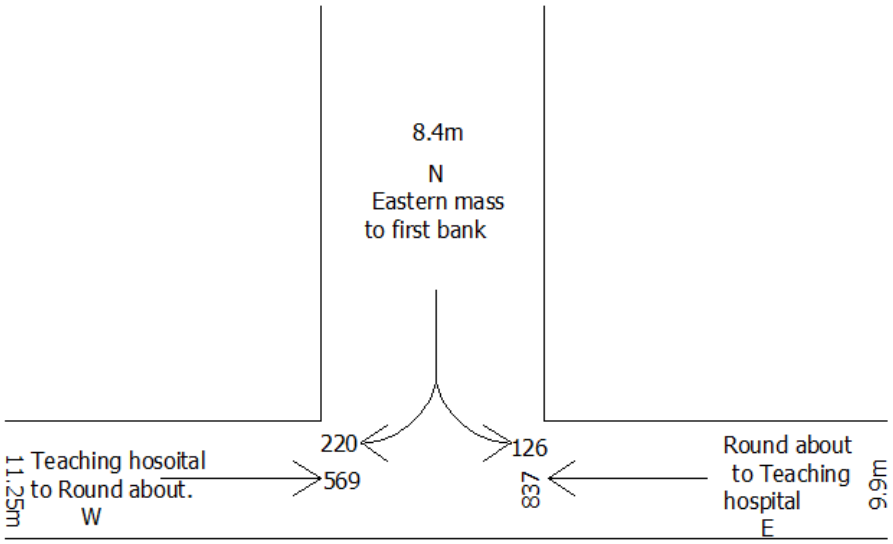

Figure 1: The road network of the study location, First bank junction Nkwo triangle Nnewi

2.2 Data Collection and Signaling Design

The methods used for the traffic data collections and the signaling designs are discussed in this section as summarized in Figure 2.

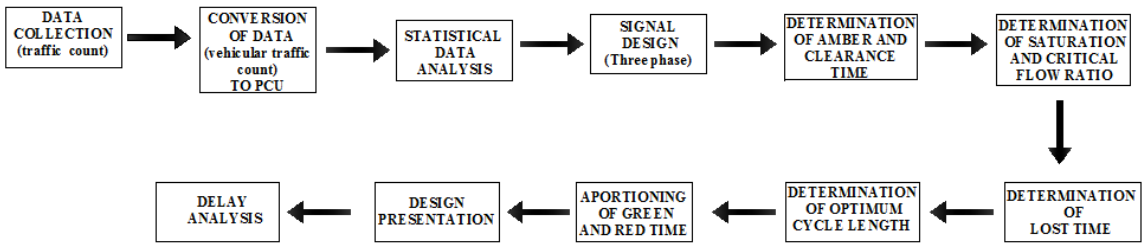

Figure 2: Step used in traffic signaling design

The manual method of data collection was implored to obtain the volume of traffic count in an interval of one hour that is from 7am to 8am, 8am to 9am and 9am to 10am in morning hours and 3pm to 4pm, 4pm to 5pm, 5pm to 6pm four weeks in. After the average of these values were taking in both morning and evening hours to determine average morning and evening daily traffic demands. Since done for four weeks, average weekly demand for morning and evening was also generated. There after the peak hour data which occurs between morning and evening hours were spotted and used for traffic design. The following categories of vehicles will be noted during the traffic count: trucks, buses, cars, tricycles, motorcycles or bikes. The Websters method was adopted for the traffic signaling design, however the Saturation flow was estimated in accordance with IRC: 93-1985.

3.0 Result and Discussion

3.1. Traffic Volume Studies

Daily traffic flow data in First bank junction morning hours in PCU/hr are shown in Table 1.

Table 1 Traffic flow data in PCU/hr week 1 to week 4 morning hours junction Y (First Bank junction Nkwo triangle Nnewi)

Weeks	Time	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Average
Week 1	7-8am	1737	331	1363	1480	1724	1639	1706	1426
	8-9am	1480	301	1150	1600	1650	1610	1450	1320
	9-10am	1270	240	1700	1400	1630	1710	1600	1364
Week 2	7-8am	1379	331	1727	1532	1650	1584	1692	1414
	8-9am	1496	317	1181	1652	1596	1600	1720	1366
	9-10am	1260	250	1200	1436	1612	1698	1610	1295
Week 3	7-8am	1700	250	1397	1555	1614	1612	1727	1408
	8-9am	1474	317	1203	1587	1687	1598	1703	1367
	9-10am	1247	333	1184	1472	1578	1702	1588	1301
Week 4	7-8am	1254	253	1386	1536	1718	1703	60	1130
	8-9am	1488	317	1192	1663	1605	1601	116	1140
	9-10am	1711	329	1193	1454	1593	1603	178	1151

Week 1 recorded relatively high traffic volumes, especially on Sundays, Thursdays, Fridays, and Saturdays. The highest flows were generally observed between 7–8 am and 8–9 am, indicating the beginning of peak-hour activities. Monday traffic was comparatively low, while weekend traffic remained significantly high due to commercial and social activities around the junction.

Traffic flow in Week 2 showed slight fluctuations compared to Week 1. Thursday, Friday, and Saturday maintained heavy traffic conditions, while Monday continued to record the least traffic volumes. The average traffic counts remained high, showing that the junction consistently experiences congestion during morning periods.

Week 3 recorded one of the highest traffic volumes within the study period. Sunday and Saturday showed very heavy traffic movement, particularly during the early morning period (7–8 am). Commercial activities and increased weekend movements likely contributed to the rise in traffic volume. Overall, Week 3 indicated intensified congestion levels at the junction.

Week 4 showed a slight reduction in some traffic counts compared to Week 3, though traffic volumes still remained high. Thursday and Friday continued to experience heavy traffic flow, while Monday remained the least busy day. The averages suggest that congestion persisted throughout the week despite minor reductions.

Generally, traffic from 7–8 am period consistently recorded the highest traffic volumes, indicating the peak traffic hour. Mondays generally experienced the lowest traffic flow, while Thursdays, Fridays, Saturdays, and Sundays recorded the highest volumes. Weekend traffic was significantly high due to trading and commercial activities around Nkwo Triangle. The study confirms that the junction experiences recurrent traffic congestion during morning hours, especially during peak business days and weekends.

Table 2 Summary of average morning daily traffic flow in PCU/hr at First Bank junction Nkwo triangle Nnewi

Week/Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	1496	291	1404	1493	1668	1653	1585
2	1378	299	1369	1540	1619	1627	1674
3	1474	300	1261	1538	1626	1637	1673
4	1484	300	1257	1551	1639	1636	118

This average was calculated from adding up the values of traffic count at 7-8am, 8-9am and 9-10am and taking the average. The values were used to plot a graph of traffic in PCU/hr on vertical axis against days in horizontal axis as shown in Figure 3.

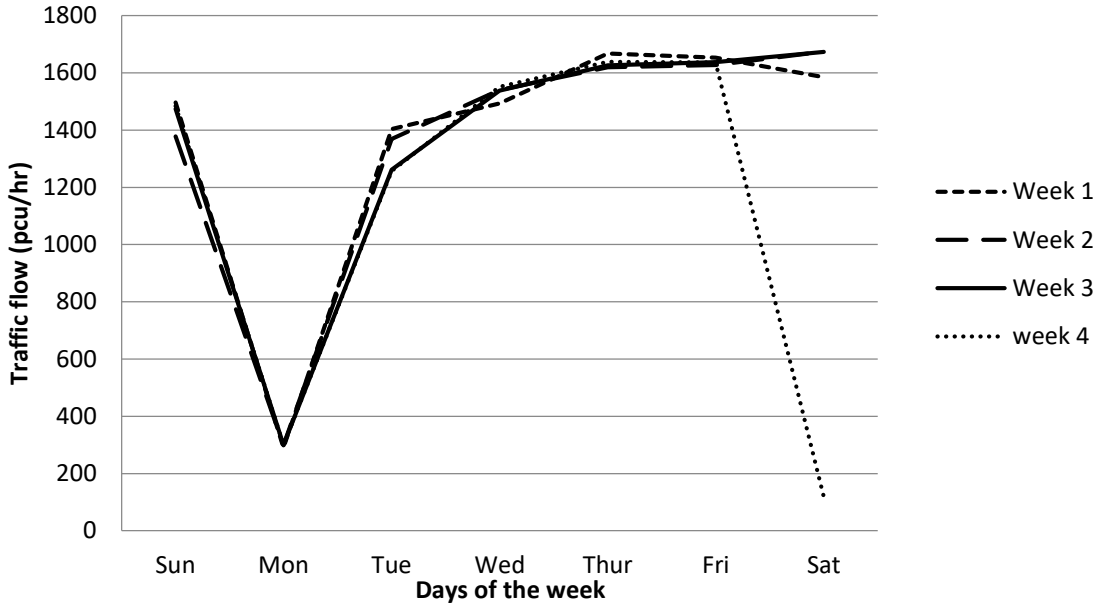

Figure 3: Graphical presentation summary of average morning daily traffic at First bank junction Nkwo triangle Nnewi

Thursday is the busiest morning in the morning (1688PCU/hr), followed closely by Friday and Saturday. Monday is consistently the lowest 291 – 300PCU/hr indicating limited travel time at the start of the week. Tuesday to Wednesday show rising trends, bridging the low Monday flows to the high peaks of Thursday and Friday. The traffic pattern is regular and predictable except for week 4 Saturday which is an outlier with very low flow because of general sanitation in the study area. Evening hour traffic count was done in this junction with a time interval of 3-4pm, 4-5pm and 5-6pm in the study area and converted to PCU as shown in Table 3.

Table 3 Traffic flow data in PCU/hr week 1 to week 4 evening hours junction Y (First Bank junction Nkwo triangle Nnewi).

Weeks	Time	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Average
Week 1	3-4pm	1010	710	1570	1595	1700	1600	1650	1405
	4-5pm	1100	750	1790	1800	1750	1710	1780	1523
	5-6pm	1132	764	1846	1830	1800	1781	1838	1570
Week 2	3-4pm	1500	750	1620	1700	1700	1760	1750	1540
	4-5pm	1520	700	1630	1680	1720	1780	1700	1533
	5-6pm	1540	800	1660	1720	1800	1820	1790	1570
Week 3	3-4pm	1475	725	1600	1675	1730	1780	1700	1526
	4-5pm	1495	755	1610	1700	1700	1750	1685	1528
	5-6pm	1515	875	1640	1695	1720	1790	1745	1569
Week 4	3-4pm	1480	840	1650	1690	1720	1770	1791	1563
	4-5pm	1500	780	1610	1695	1710	1760	1710	1538
	5-6pm	1520	855	1620	1705	1730	1800	1690	1560

Week 1 recorded heavy evening traffic flow across most days of the week. Traffic volumes increased gradually from 3–4 pm to 5–6 pm, indicating the buildup of evening peak-hour congestion. Wednesday, Thursday, Friday, and Saturday recorded the highest traffic counts, while Monday remained the least congested day.

Traffic flow in Week 2 showed a further increase compared to Week 1. The highest traffic volumes were recorded on Tuesdays, Wednesdays, Thursdays, Fridays, and Saturdays, especially during the 5–6 pm period. This indicates that evening business activities and commuter movements intensified during the second week.

Week 3 maintained very high traffic conditions throughout the evening hours. Traffic volumes remained consistently heavy between 4–5 pm and 5–6 pm, showing prolonged congestion periods. Fridays and Saturdays recorded some of the highest vehicle counts within the study period, reflecting increased commercial and weekend activities.

Week 4 also experienced heavy evening traffic flow with only slight variations from Week 3. Traffic volumes remained high on Tuesdays through Saturdays, especially during the late evening peak period (5–6 pm). Monday continued to record the lowest traffic flow, while Fridays and Saturdays remained the busiest days. Generally, 5–6 pm period consistently recorded the highest traffic volumes, indicating the major evening peak hour. Mondays experienced the lowest traffic flow, while Fridays and Saturdays recorded the highest traffic volumes throughout the study period. Traffic congestion increased significantly toward the evening due to business closures, market activities, and commuters returning home. The consistently high evening traffic volumes suggest that First Bank Junction experiences recurrent congestion during evening peak periods.

Table 4: Summary of average evening daily traffic in PCU/hr at First Bank junction Nkwo triangle Nnewi

Week/Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	1081	741	1735	1742	1750	1697	1756
2	1520	750	1637	1700	1740	1787	1747
3	1495	785	1617	1690	1717	1773	1710
4	1044	825	1627	1697	1720	1777	1730

This average was calculated from adding up the values of traffic count at 7-8am, 8-9am and 9-10am and taking the average. The highest average evening traffic PCU value was on Friday week 2 with 1787PCU/hr and least on

Monday week 1 with 741PCU/hr. The values were used to plot a graph of traffic in PCU/hr on vertical axis against days in horizontal axis as shown in Figure 4.

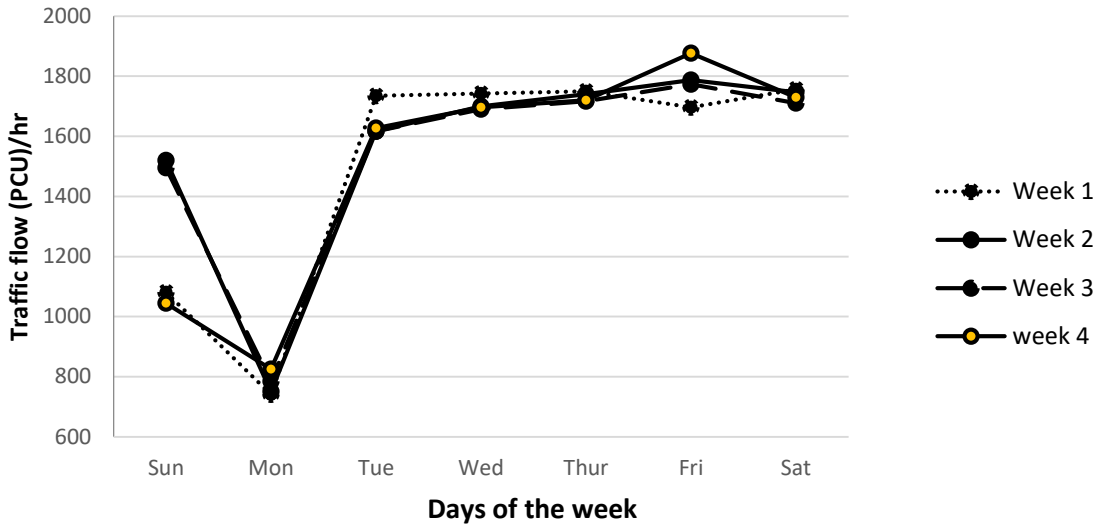

Figure 4: Graphical presentation of average daily evening traffic in PCU/hr at First Bank junction Nkwo triangle Nnewi

The evening traffic pattern at First bank junction Nkwo triangle Nnewi shows high variability on weekends and gradual stability from Tuesday to Thursday. Friday and Saturday consistently emerge as peak periods for vehicular movement, highlighting the need for efficient traffic signal control or traffic management strategies on these days to reduce congestion and delays. Comparison of average weekly traffic in morning and evening hours is shown in Table 5.

Table 5 Summary and Comparison of average weekly traffic morning and evening hours for First Bank junction Nkwo triangle Nnewi

Weeks/time	AVERAGE TRAFFIC (PCU/hr)					
	MORNING			EVENING		
	7-8	8-9	9-10	3-4	4-5	5-6
1	1426	1320	1364	1450	1523	1570
2	1414	1366	1295	1540	1533	1570
3	1408	1367	1301	1526	1528	1569
4	1350	1356	1370	1563	1538	1560

Week 1,2,3,4 has a total of 4110, 4075, 4073, 4076 PCUs/hr making it a total of 16334 PCU/hr in morning hours from 7-10 am while the total PCUs in the evening hours of 3-6pm is 18470 PCU/hr with individual weekly PCU of 4543, 4643, 4623 and 4661 PCU/hr. This signifies a heavier traffic flow in evening hours in the junction, with overall average 13.08% increase from morning to evening hours in First bank junction Nkwo triangle Nnewi. Graphical representation of average weekly traffic at First bank junction is shown in Figure 5.

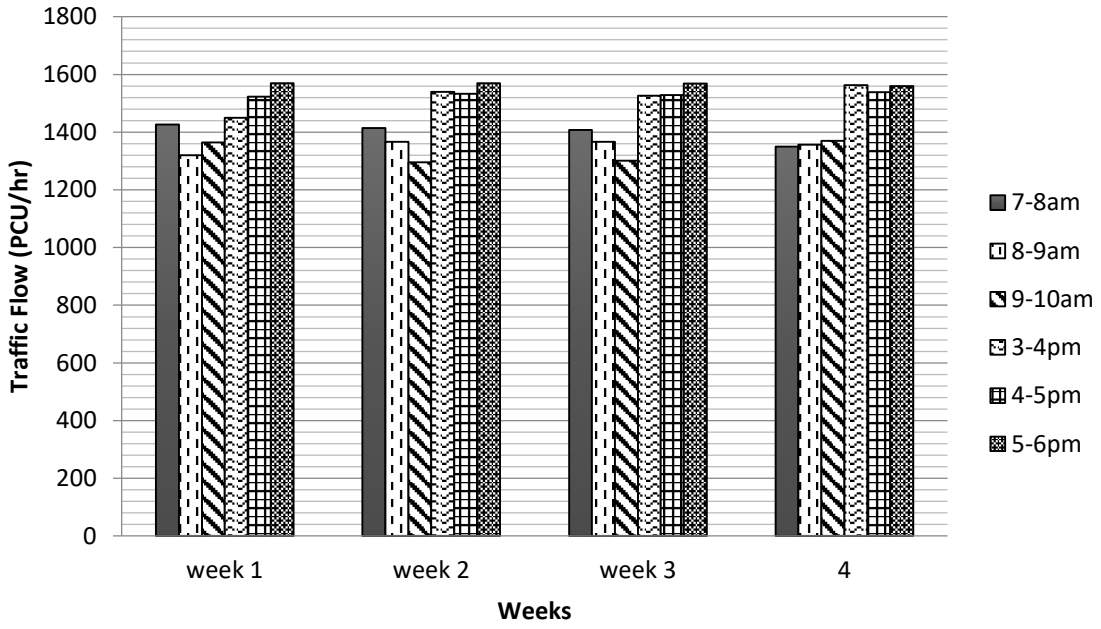

Figure 5: Graphical presentation and comparison of average weekly traffic (PCU/hr) in morning and evening hours First Bank junction Nkwo triangle Nnewi

In week 1, the highest morning traffic is around 7-8 am at 1426 PCU/hr and evening peaks at 1570 PCU/hr by 5-6 pm. In week 2, morning dropped slightly around 9-10am at 1295 PCU/hr evening still strong around 1570 PCU/hr at 5-6pm. In week 3, a slight increase in morning mid-peak around 8-9 am of 1367 PCU/hr, steady evening values of 1528-1569 PCU/hr. In week 4, lowest morning values are overall but evening traffic remained high, peaking at 1563 PCU/hr by 3-4 pm.

Table 6: Percentage composition of vehicles at First bank junction Nkwo triangle Nnewi

Vehicle	Number of vehicles	Percentage composition
Car	1566	$\frac{1566}{14689}\ x\ \frac{100}{1} = 10.66\ \%$
Tricycle	2247	15.30 %
Bus	3257	22.17 %
Truck	2052	13.97 %
Bike	5567	37.90 %
Total	14689	100 %

Bike is seen to be highest for grounding traffic followed by bus, tricycle, truck and car. Bike is mostly used for ease of movement and considered the cheapest with regard to fuel consumption for dwellers within the study location. All dwellers in the study location have at least 2 to 3 bikes in each household.

3.3 Design Calculations for the Traffic Signal suitable for the Junction

Calculation was made based on the most critical traffic flow (volume) observed on this junction, Tuesday evening 5-6 pm week 1 at First bank junction with traffic flow value of 1846 PCU/hr. Based on the directional flow of traffic at the junction, Figure 7 was produced to described the traffic movements at the junction.

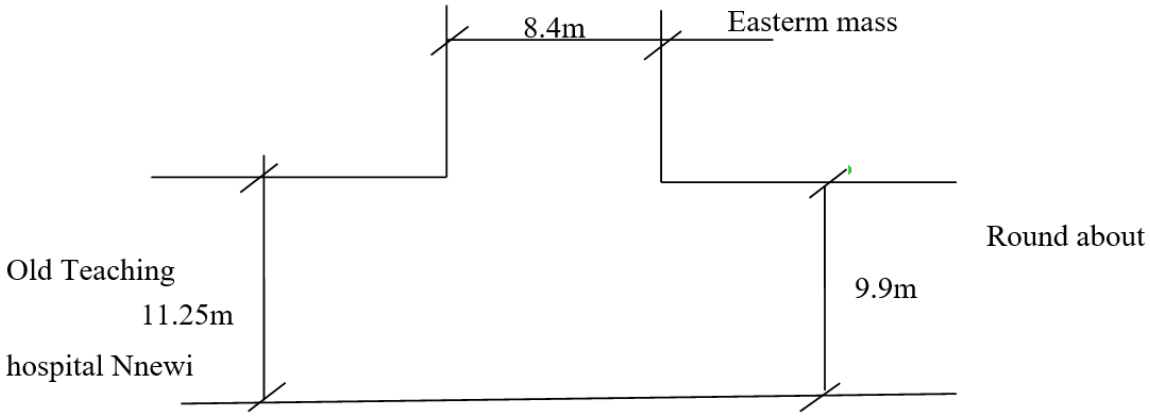

Figure 7: Geometry of First bank junction Nkwo triangle Nnewi

First bank junction is bounded by three roads (T-junction), namely from the North Eastern mass road, from the East Round- about road and from the West Teaching hospital road. The junction is asymmetrical in all directions the roads leading to the junction are of different span widths. Its spans 8.4 meters Northwards, 9.9 meters Eastwards and 11.25metres Westwards. The direction of traffic flow is shown in Figure 8 below.

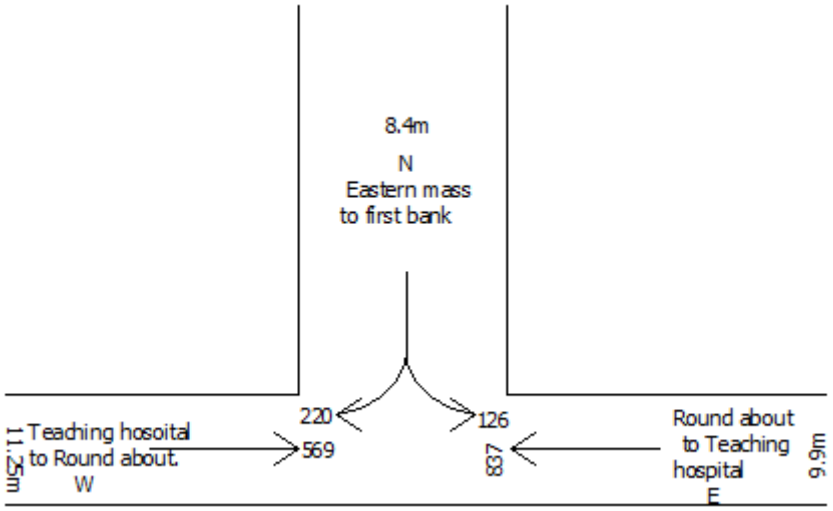

Figure 8: Phase diagrams showing direction of flows at First bank junction Nkwo triangle Nnewi

Calculating using the most critical traffic flow which is Tuesday evening (5-6pm) in First bank junction Nkwo triangle Nnewi with 1846PCU/hr. Using 1.75 correction factor for left turning vehicles, the actual flows and saturation flows were calculated as presented in Table 7.

Table 7: Saturation flow for First Bank junction Nkwo Triangle Nnewi

Phase	Direction of the road approach	Width of road (m)	Actual Flow q (PCU/hr)	Saturation flow S (PCU/hr)525 x w	Flow Ratio q/S
1	Eastern mass junction to first bank junction	8.4m	440	525x8.4 = 4410	440/4410= 0.1
2	Teaching hospital to round about	11.25m	569	525x11.25=5906	569/5906= 0.1
3	Round about to teaching hospital	9.9m	837	525x9.9= 5198	837/5198=0.16

The eastern approach recorded the highest actual flow of 837 with the least saturation flow of 4410 in phase 1. It is consequently the critical leg for the signaling design. It is expected that the effective green time for the design will be highest for this phase. The critical flow ratio for the Eastern approach is 0.16 followed by the Northern and

western approach of 0.1. The total loss time in all the phases is taken as 15 seconds. Using Webster's method, the amber or yellow signal light indicates clearing the road when the signal changing from green to red. Its purpose is to warn approaching traffic of the imminent right of way change.

Phase Amber time = tr+ $\frac{v}{2d} + \frac{w+L}{v}$ ……..equation (1)

tr = Minimum amber time taken as = 1 second

v =Assumed Road design speed = 20kmls = $\frac{20x100}{60x60} = 5.56mls$

d = Comfortable deceleration rate = 5mls^2

w = Intersection Road width = 11.25m

L = Length of vehicle (max) = 12m

Tmin = $1 + \frac{5.56}{2x5} + \frac{11.25+12}{5.56} = 5.7secs \sim 6\ secs$

The optimum cycle length or time is the time it takes to complete sequence of changing indications. The optimum cycle time was thus obtained, Co = $\frac{1.5L+5}{1-£yn}$…… equation (2)

Where Co = optimum cycle length

L = Lost time = 15 seconds

$Y_n = Summction\ of\ critical\ flow\ ratio$

Yn=0.1+ 0.1+ 0.16 =0.36

L= 15 seconds

Co = $\frac{1.5x14+5}{1-0.36} = \frac{26}{0.64} = 42.968\ seconds \simeq 43$ seconds

The total effective green or actual green time for First bank junction Nkwo triangle Nnewi

Gt= Co – L

= 42.968 – 15

= 27.968 seconds ≃ 28 seconds

The Lost Time for First Bank junction Nkwo triangle Nnewi

This shows the time during which a phase intersection is not effectively used for any traffic movement.

The lost time per phase is the summation of spent up time and movement time

L phase = S time + M time …… equation (3)

S time = Startup time

M time = Movement time

M time = 0.5xAmber time = 0.5 x 6= 3secs

Take startup time to be 2 seconds

Total lost time in each phase = 3+2 = 5 secs

Total lost time for the three approaches = 5x3= 15 seconds

Table 8: Effective green times for first bank junction Nkwo triangle Nnewi

Phase	Green time (seconds) $g_t = \frac{Yi}{\Sigma y}(Co - L)$	Amber (s)
1	$g_1 = \frac{0.1}{0.36} x\ 28 = 7.7 \simeq 8\ seconds$	6
2	$g_2 = \frac{0.1}{0.36} x\ 28 = 7.7\ \simeq 8\ seconds$	6
3	$g_3 = \frac{0.16}{0.36} x\ 28 = 12.4\ \simeq 12\ seconds$	6

Table 9: Red times for each phase at first bank junction Nkwo triangle Nnewi

Phase	Red time (secs) R_t = Co – (g_t+ Amber)	Amber(s)
1	R_1 = 43 – (7.7+6) = 29.3 seconds	6
2	R_2 = 43 – (7.7+6) = 29.3 seconds	6
3	R_3 = 43 – (12.4+6) = 24.6 seconds	6

Table 10: The summary of final signal timing for each phase at First bank junction Nkwo triangle Nnewi

Phase	Direction of approach	Green time(s)	Amber time(s)	Red time
1	Eastern mass to first bank junction	7.7	6	29.3
2	Teaching hospital to round about	7.7	6	29.3
3	Round about to teaching hospital	12.4	6	24.6

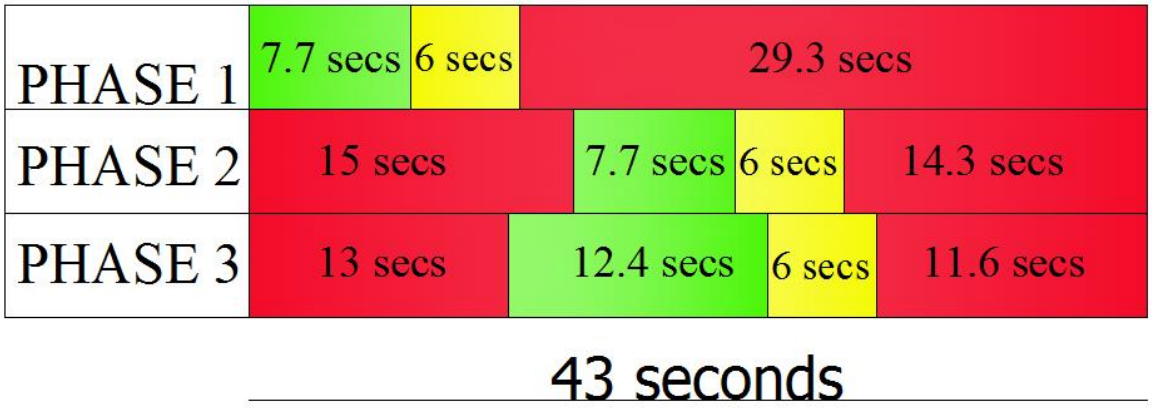

Figure 9: Phase diagrams for each road approach at First bank junction Nkwo triangle Nnewi

4.0. Conclusion

Traffic congestion is one of the major challenges facing the world because of increasing population. First bank Nkwo triangle Nnewi is not exempted as growing markets, schools, churches, recreational centers and most especially Lagos Park in the study area poses an extra challenge which includes delays, pollution, delays, accidents leading to injuries, loss of lives, more so loss of human capital as long hours are wasted which cripples the economy of the study area, Local, State and Federal levels. This study on the Analyses of traffic Characteristics and design of traffic signaling control for Management of Busy Intersections was done using First bank Nkwo Triangle Nnewi as a case study. Traffic Volume studies was conducted in the junction and based on the volume studies, traffic signaling scheme was designed.

There is variation in daily traffic and a similar traffic trend from week 1 to week 4. Results from signal design are as follows: optimum cycle lengths of 43 seconds, total effective green time and amber time of 28 and 6 seconds respectively in the junction. Implementation of this design is proposed for efficient control of the busy traffic flows at that intersection. Other factors contributing to the congestion of the intersection has been suggested for consideration. The Lagos motor park at the intersection if relocated could reduce congestion at the intersection. Increase of the lane widths and turning radii at the junction is also recommended to prevent congestion induced by turning vehicles.

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