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PERFORMANCE EVALUATION AND REDESIGN OF OFFA GARAGE ROUNDABOUT IN ILORIN, NIGERIA USING MICROSCOPIC SIMULATION

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Abstract: An urban traffic system is a composite network, which consists of varying types of intersections. In this paper, the focal point is on a heterogeneous traffic system. In this paper, the focus is on a heterogeneous traffic system featuring a non–signalized intersection (roundabout), with the aim of replacing it with a signalized one. It has always been a difficult process to carry out Traffic analysis, with the ever increasing volume of vehicles and densely populated roadways. It is definitely difficult to suggest an alternative answer especially in developing countries like Nigeria. This paper analyses an intersection in the city of Ilorin Kwara State Nigeria. The intersection is modelled with the VISSIM 21, which is a traffic microscopic simulation software that has been extensively used in assessing traffic conditions. The paper also simulates the modelled intersection and determines the possibility of installing a traffic signal at the skewed T– intersection and checks its usefulness by comparing the Level of service, Queue length and carbon emission when the signals is installed and after.
Keywords: PTV Vissim, signalized, Simulation, Vehicle Input, Level of Queue Length

1. INTRODUCTION

The ever increasing Nigeria population has given rise to a high demand for vehicles and hence there is a need for proper, efficient and well–maintained transportation system. The sudden rise in population and urbanization of the country without commensurate traffic management advancement has led to a low–level performance of most urban road networks in Nigeria (Adeleke et. al., 2020). Traffic management should begin from the base levels and it should ensure safeness and convenience concurrently. Ilorin is the Capital of Kwara state, Nigeria and has witnessed tremendous development in recent years and thereby faces huge traffic rushes during the peak hours of the day. A good conception of vehicular traffic flow is an important challenge for current–day societies (Risni et. al., 2019)., traffic means considerable costs for the populace and a great deal of effort is devoted in every big city to minimize the trouble caused by extreme numbers of vehicles. The difficulties of a traffic mode (such as, accidents, queues and pollutant emissions) is considerable at intersections. The intersection being the target of conflict in vehicular movements sometimes needs to be signalized. Signalized intersections are time sharing, the different states of lights (green, amber or red) indicating the permission to go towards the intersection (green) or the need to stop before the junction (red) are used (Ishant et. al., 2015). Roundabout contrastingly is a space sharing that gives major priority to the rotational flow.

Roundabouts have been used across the globe and are being the most used in recent days in Nigeria, as an element of urban areas since several past years but not every intersection and under all circumstances are roundabouts the perfect intersection control (Trueblood et. al., 2013).

There are situations under which roundabouts are not at all feasible, certain times when they need to consider with caution ((Li et. al., 2011). This are at times when intersection traffic flow is severely unbalanced which was observed at the Offa Garage roundabout

This paper discusses the performance of roundabouts and compares them to that of signal timing at the same intersection

The outcome of the study was able to indicate that, a signalized intersection will be more appropriate than the present rotary intersection and provides design parameters that would cater for future growth. Findings from the paper would serve as a basis for using VISSIM for assessment of other roundabouts in Ilorin and Nigeria as a whole.

2. METHODOLOGY

The studied intersection is Offa Garage rotary intersection, located in Ilorin metropolis, on longitude N 8027'12.14" and latitude E 4034'52.20" (Google Earth Pro). The rotary intersection, shown in Figure 1, has three intersecting roads namely: Ita alamu, Offa garage, and Asa dam road. Ita alamu road has through traffic towards Offa garage road, and left turner go around the roundabout to Asa dam road. Offa Garage has through traffic towards Ita Alamu and right turner towards Asa dam road, while Asa dam road has right turners towards Ita alamu and left turners towards Offa garage.

Figure 1: Satellite image of the intersection

Traffic volume is the total number of vehicles crossing a section of road per unit time at any selected period. It is used in the design of transport facilities and good management and redesign of existing ones. Traffic volume is determined in the study using videotaping method (Kwame et. al., 2014) using a camera phone mounted on a tripod stand and stationed at strategic locations on a high–rise building overlooking the intersection. The building is on the Ita Alamu axis; the position was identified from a reconnaissance survey as the most suitable position for the video recording. The study was conducted during AM and PM traffic peak periods to get the maximum possible number of vehicles. Peak hour volume count of vehicular movements in all the directions was thus obtained. The obtained heterogeneous vehicle count was classified, converted into Passenger Car Unit (PCU) and used as input.

The recording was broken down in four intervals of 15 mins each for ease of recording. The traffic count was carried out for three days with the videotaping done at the morning peak hours (7:00 to 9:00a.m.), midday (12:00 to 2:00p.m.) and the evening peak hour (4:00 to 6:00p.m.). The mid–day off peak period is important so as to note the off–peak hours traffic volumes.

The traffic data collected will be indicative of the existing peak hour traffic conditions for the Offa garage roundabout. A single peak hour data for the intersection approaches was eventually used, for the analysis of comparing the existing non–signalized roundabout with when it is a signalized intersection.

3. RESULTS AND DISCUSSION

Webster method for signal timing

Webster method for signal timing is used. The Maximum signal cycle is given as (Webster, 1958):

$$C_0 = (1.5L + 5) / 1 - Y \quad (1)$$

where, Co = Maximum cycle time in seconds

L = total time lost per cycle

$Y = y_1 + y_2 + y_3 + \ldots\ldots\ldots\ldots + y_n$

where, $y_1, y_2, y_3 \ldots. y_n$ are the ratios of flow to saturation flow $y_i = q_i / S_i$

where, q = total flow in pcu/hr

S = saturation flow =525w w = width of approach measured from kerb to centre line (m)

where, $y_1, y_2 \ldots$, yn are the critical flow ratios for phases 1, 2…, n.

L is given as

$$L = n\,(t + R) \quad (2)$$

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where n = number of phases t = amber time for each phase
R = all–red clearance time provided for each phase

Signalized intersection replacement Data Analysis

Using the value of t as 3 seconds of amber time and 2 seconds of all red clearance time for each phase (MUTCD, 2009; Federal Highway Administration, 2008) and n = 3 (number of phases) in Eqn (2): L = 3(3+2) = 15 seconds

Table 1: Traffic Data Collection (Peak hour Volume)

Routes	Volume pcu/hr
Offa Garage – Asa Dam RT	675
Offa Garage – Ita alamu TT	1702
Ita alamu– Offa Garage TT	1813
Ita alamu – Asa Dam LT	803
Asa Dam – Offa Garage LT	813
Asa Dam – Ita alamu RT	521

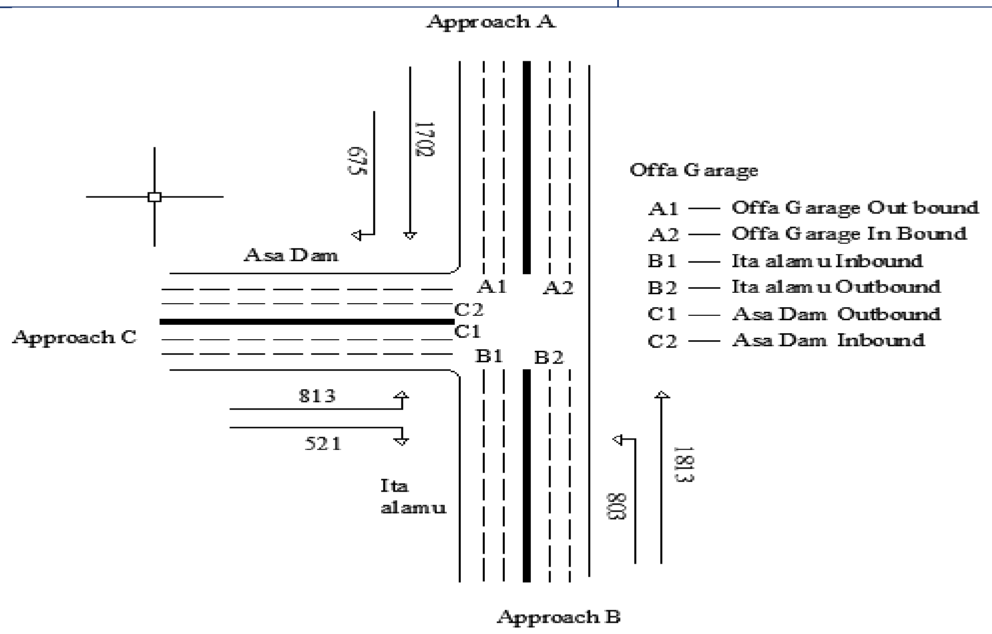

Figure 2: Schematic representation of vehicle distribution and directional movements

Table 2: Software volume input

Intersection Lane	Direction of flow	Volume (pcu/h)	Total Volume (pcu/h)
Offa Garage Inbound	Ita alamu – Offa garage TT	1813	2626
	Asa dam – Offa garage LT	813	
Offa Garage Outbound	Offa garage – Ita alamu TT	1702	2377
	Offa garage – Asa dam RT	675	
Ita alamu Inbound	Asa dam – Ita alamu RT	521	2223
	Offa Garage – Ita alamu TT	1702	
Ita alamu outbound	Ita alamu– Offa Garage TT	1813	2616
	Ita alamu – Asa dam LT	803	
Asa Dam Inbound	Offa garage – Asa dam RT	675	1478
	Ita alamu – Asa dam LT	803	
Asa Dam Outbound	Asa Dam – Ita alamu RT	521	1334
	Asa dam – Offa garage LT	813	

The critical flow ratios y_1, y_2 and y_3 as shown in Table 3 are 0.298, 0.132 and 0.131 respectively, thus Y for the three arms is obtained as

$$Y=y_1+y_2+y_3 \quad (3)$$

which is

$$Y = 0.298+ 0.132 + 0.131 = 0.561$$

Therefore, $\mathbf{Co} = \frac{1.5(15)+5}{1-0.561}$ = 62.6 secs ~ 63 secs

Maximum cycle time **Co** is 63 sec

Green time for the 3 phases is obtained as:

$$G1 = \frac{Y1}{Y}(Co - L) = \frac{0.298}{0.561}(63 - 15) = 25.5\text{secs (26 secs is used for design)}$$

$$G2 = \frac{Y2}{Y}(Co - L) = \frac{0.132}{0.561}(63 - 15) = 11.3\text{secs (12 secs is used in design)}$$

$$G3 = \frac{Y3}{Y}(Co - L) = \frac{0.131}{0.561}(63 - 15) = 11.3\text{secs (12 secs is used in design)}$$

Allowable maximum cycle time of 65 is used for ease of calculation.

Table 3: Signal phase, Actual Capacity and Group Lanes.

Phase	Movement	Critical Volume (pcu)	S = Saturation flow rate 525 w = S	Flow Ratio (y_i) v/s	Proposed Green Time (sec)
1	Through traffic from Offa garage Through traffic from Ita alamu	1813 1702	525 * 11.6 = 6090	0.298	26
2	Left turn to Asa Dam from Ita alamu	803	525 * 11.6 = 6090	0.132	12
3	Left turn from Asa Dam to Offa Garage	813	525 * 11.8 =6195	0.131	12

Modelling of the present condition and the proposed redesign replacement

There are 3 basic parameters used in PTV Vissim modelling, they are the Vehicle input, vehicle compositions and vehicle routes.

- Vehicle Input: The vehicle inputs show the number of vehicles that are simulated.
- Vehicle Composition: The vehicle composition includes the type of vehicles that are simulated i.e., Cars, Bus and Heavy goods vehicle (HGV); since tricycles can't be simulated, they are converted into passenger car units.

Vehicle routes: This determines where a vehicle goes in a network, in the study there are 6 vehicular directional movements which include through traffic (TT) on Approach A Right turn to Approach C, Approach B has through traffic and left turn to Approach C while Approach C has a left turn to Approach A and right turn to Approach B as shown in Figure 4a and 4b for both the present condition and the proposed redesign.

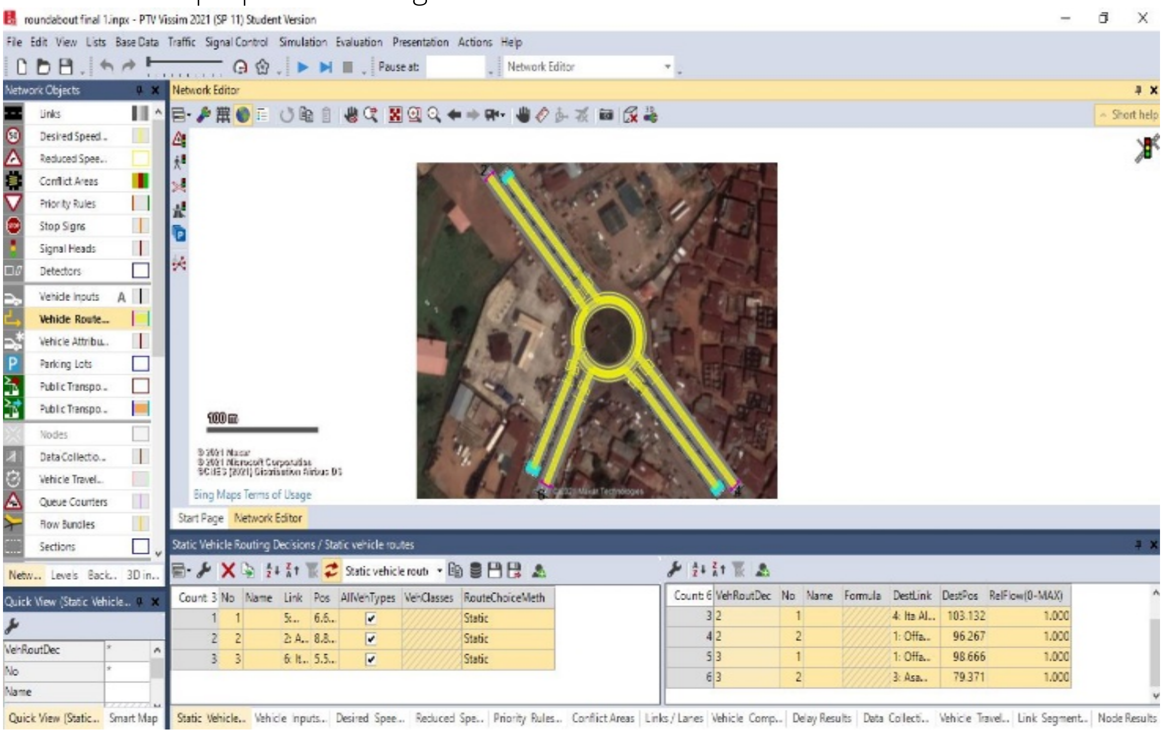

Figure 4a: Vehicle Input and Composition Roundabout

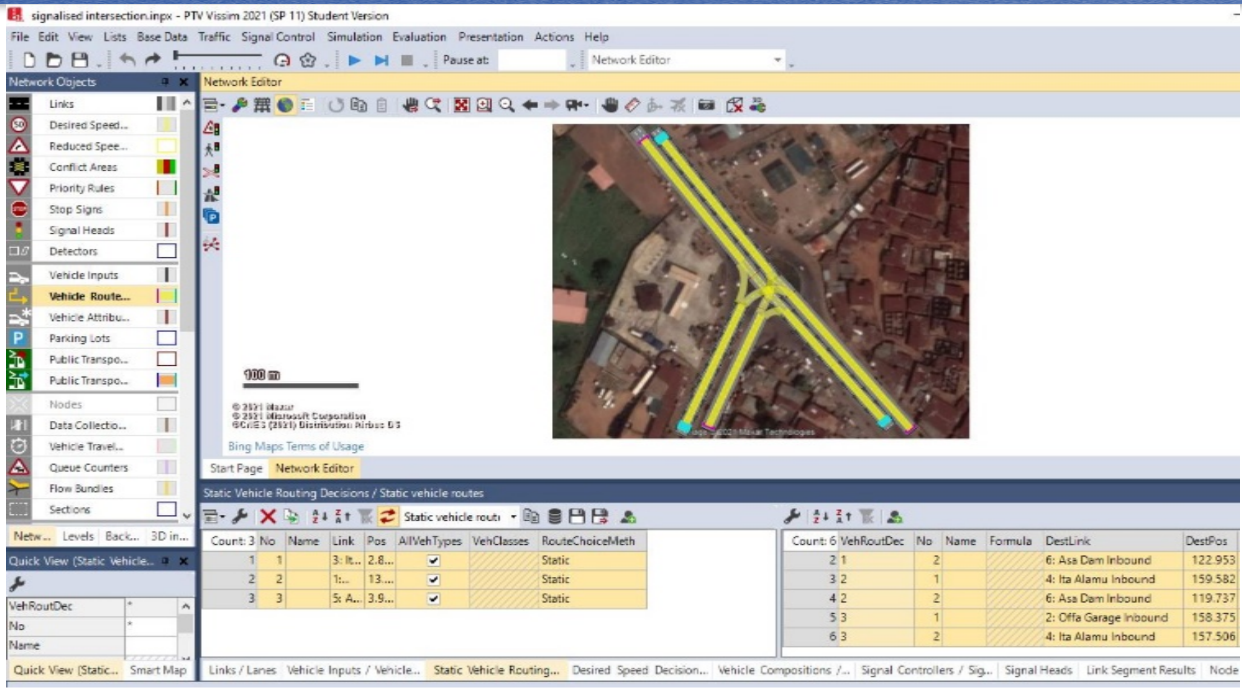

Figure 4b: Vehicle input and composition for the proposed redesign replacement

Table 4: Node result unsignalized(roundabout) extracted for clarity From PTV VISSIM

Time Interval (sec)	Movement	Queue length (m)	Queue length max (m)	LOS	Stop delay (sec)	Emissions Co$_x$ in (grams)	Emissions No$_x$ (grams)	Emissions VOC (grams)	Fuel consumption (USGallons)
0 - 3600	A1 - B1	68.26	80.60	LOS E	9.83	142.312	27.689	32.982	2.036
0 - 3600	A1 - C2	68.26	80.60	LOS F	15.58	170.509	33.175	39.517	2.439
0 - 3600	B2 - A2	69.92	83.92	LOS F	14.95	363.686	70.76	84.288	5.203
0 - 3600	B2 - C2	69.92	83.92	LOS F	20.5	388.735	75.634	90.093	5.561
0 - 3600	C1 - A2	61.6	74.72	LOS F	36.6	316.234	61.528	73.29	4.524
0 - 3600	C1 - B1	61.6	74.72	LOS B	1.58	58.836	11.447	13.636	0.842
0 – 3600	Movement Summary	66.59	83.92	LOS F	16.5	1432.146	278.644	331.914	20.488

Table 4 shows the Summary for the present condition of traffic at Offa Garage roundabout during a typical peakiest hour for all movements.

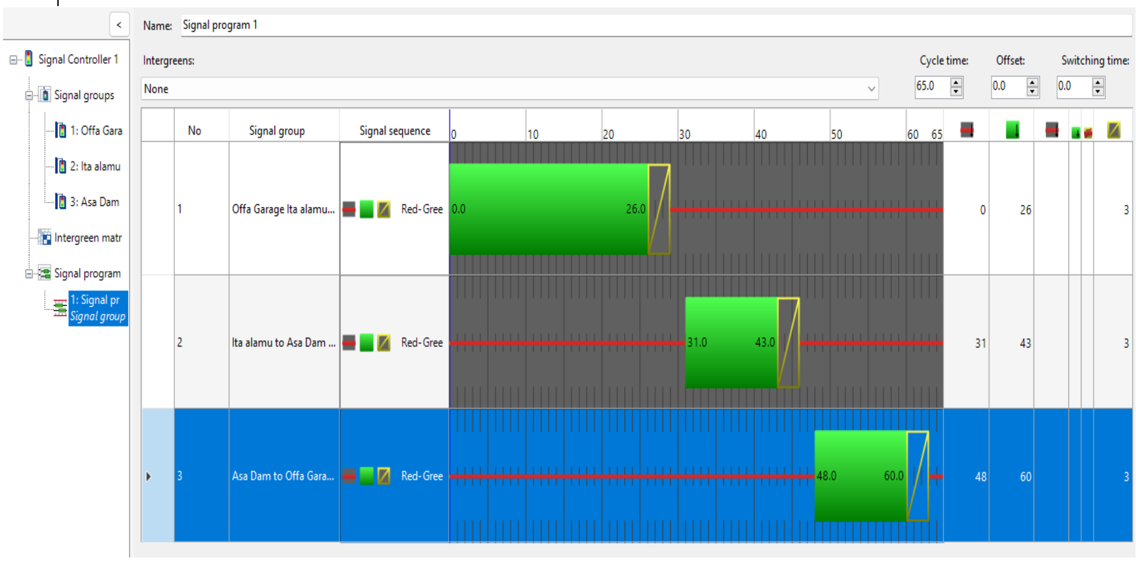

Figure 5: Signal Programming in PTV VISSIM

In the scenario where the intersection was simulated by installing signal heads appropriately and calculating the cycle time using webster method the tabulated result in table 5 was obtained. Table 5 shows the Summary for the signalized replacement of traffic at Offa Garage roundabout during a typical peakiest hour for all movements.

Table 5: Node result signalized extracted from PTV VISSIM for clarity

Time Interval	Movement	Queue length	Queue length max	LOS	Stop delay	Emissions Co_x in grams	Emissions Nox	Emissions VOC	Fuel consumption
0 – 3600	A1 - B1	20.85	115.14	LOS B	7.1	160.08	31.146	37.1	2.29
0 – 3600	A1 - C2	5.98	76.82	LOS A	2.42	131.712	25.626	30.526	1.884
0 – 3600	B2 - A2	28.05	116.84	LOS A	2.76	128.654	25.031	29.817	1.841
0 – 3600	B2 - C2	28.05	116.84	LOS A	2.19	158.004	30.742	36.619	2.26
0 – 3600	C1 - A2	26.41	68.55	LOS D	12.68	146.408	28.486	33.932	2.095
0 – 3600	C1 - B1	0.09	7.94	LOS A	1.86	42.75	8.318	9.908	0.612
0 – 3600	Movement Summary	16.28	116.84	LOS B	6.23	766.122	149.059	177.556	10.96

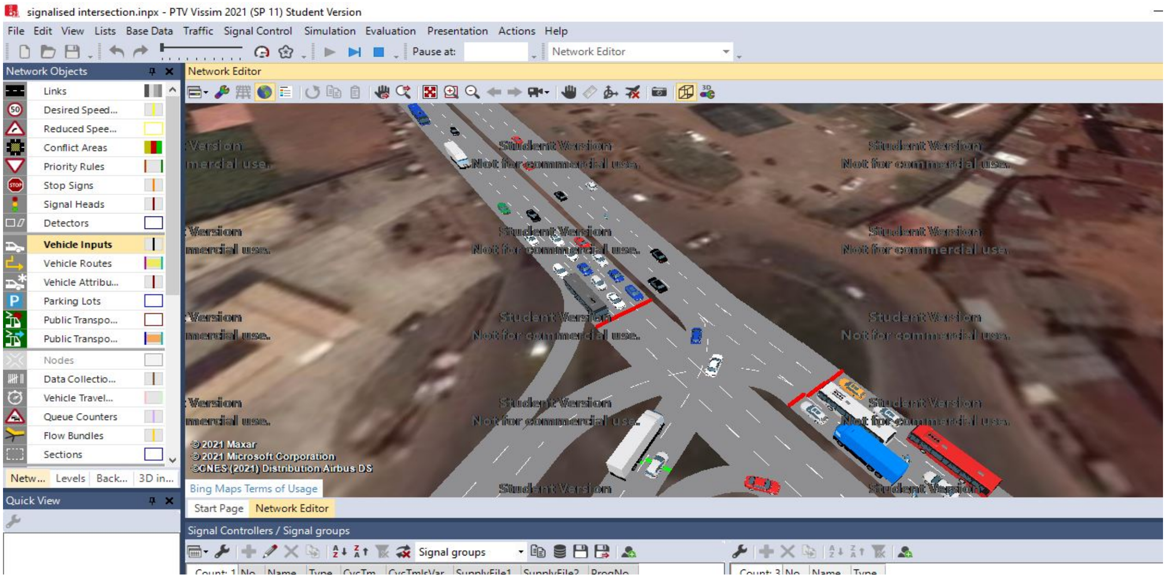

Figure 6: Signal Head Assigned

Figure 6 shows the signal head which helps communicate movements and control the flow of vehicles i.e., means the red yellow and green light at signal–controlled intersection

After manual calculation with Webster method a 3–signal phase/group was assigned, they are the Offa Garage and Ita Alamu Through traffic, Ita Alamu to Asa Dam Left turns, Asa Dam to Offa Garage Left Turns. The geometrics of the roundabout was redesigned and channelized as shown in Figure 7 to make sure Right Turners are not in any way hindered in their movement.

The result keywords include the following:

- Time Interval: Time step of 1hr is converted to seconds.
- Movement: the 6 possible directional movements in the roundabout are shown in Figure 4a.
- Queue Length: Average queue length in each time interval, the current queue is measured and the arithmetic mean is thus calculated per time.
- Queue Length Maximum: In each time step, the current queue length is measured and the maximum is thus calculated.
- LOS(ALL): Level of service A–F as computed by the associated Level of service scheme.

- VEH DEL (ALL): the delay of a vehicle in leaving a travel time measurement is obtained by subtracting the theoretical (ideal) travel time from the actual travel time.
- STOP DEL (ALL): Stopped delay per vehicle in seconds without stops at PT stops.
- Emission Cox: Emission Co quantity of carbon monoxide.
- Emission NOx: Quantity of nitrogen oxides (grams)
- Emission VOC: Volatile organic compounds (grams)

4. DISCUSSION OF THE REDESIGN OF THE EXISTING ROUNDABOUT TO A SIGNALIZED INTERSECTION

Using the maximum Traffic data experienced on each approach on the roundabout the following comparison are made

Using Level of Service:

- Offa Garage Through Traffic to Ita Alamu i.e. A1 to B1 presently operates at LOS E but if replaced with the designed signalization it will operate at LOS B.
- Offa Garage Right Turn to Asa Dam i.e. A1 to C2 presently operates, at LOS F on the roundabout but if replaced with the signalized intersection it operates at a LOS A
- Ita Alamu Through Traffic to Offa Garage i.e., B2 to A2 presently operates at LOS F on the roundabout but if replaced with a signalized intersection it operates at a LOS A
- Ita Alamu Left Turn to Asa Dam i.e., B2 to C2 presently operates at LOS F on the roundabout but also if replaced with a signalized intersection it operates at a LOS A
- Asa dam Left Turn to Offa Garage i.e., C1 to A2 presently operates at LOS F on the roundabout but if replaced with a signalized intersection it operates at a LOS D.
- Asa dam Right Turn to Ita Alamu i.e., C1 to B1 presently operates at LOS B on the roundabout but if replaced with a signalized intersection it operates at a LOS A.

The Average level of service at the peak hour period is LOS F for the present situation in Offa Garage while for the scenario when replaced with a signalized intersection is LOS B.

Using Queue length:

- The Queue length for the present peakiest hour condition is found to be generally higher in the present condition than when replaced by a signalized intersection.
- Movement A1 to B1 has an average Queue length of 68.26m for the Unsignalized roundabout and 20.85m for the Signalized intersection
- Movement A1 to C2 has an average Queue length of 68.26m for the Unsignalized roundabout and 5.98m for the Signalized intersection
- Movement B2 to A2 has an average Queue length of 69.92m for the Unsignalized roundabout and 28.05m for the Signalized intersection
- Movement B2 to C2 has an average Queue length of 69.92m for the Unsignalized roundabout and 28.05m for the Signalized intersection
- Movement C1 to A2 has an average Queue length of 61.60m for the Unsignalized roundabout and 26.41m for the Signalized intersection
- Movement C1 to B1 has an average Queue length of 61.6m for the Unsignalized roundabout and 0.09m for the Signalized intersection

Figure 8 shows the average Queue Length experienced in each movement for both the existing condition (Unsignalized) at Offa Garage Intersection and when replaced with Signalized intersection. It can be deducted that all the average queue lengths are generally higher without signalization experienced by a typical vehicle movement is mostly lower when signalized.

Using Emission: Harmful Emissions which include Carbon monoxide, Nitrogen monoxide, Volatile Organic Compound VOC, and fuel consumption are found to be higher in the present condition than when replaced by a signalized intersection.

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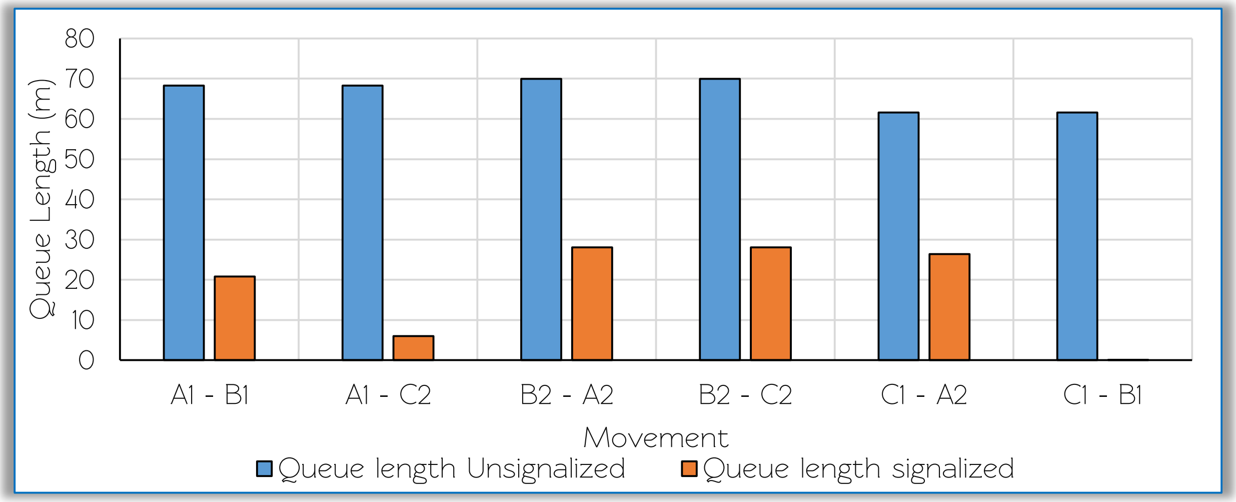

Figure 7: Queue Length for each movement

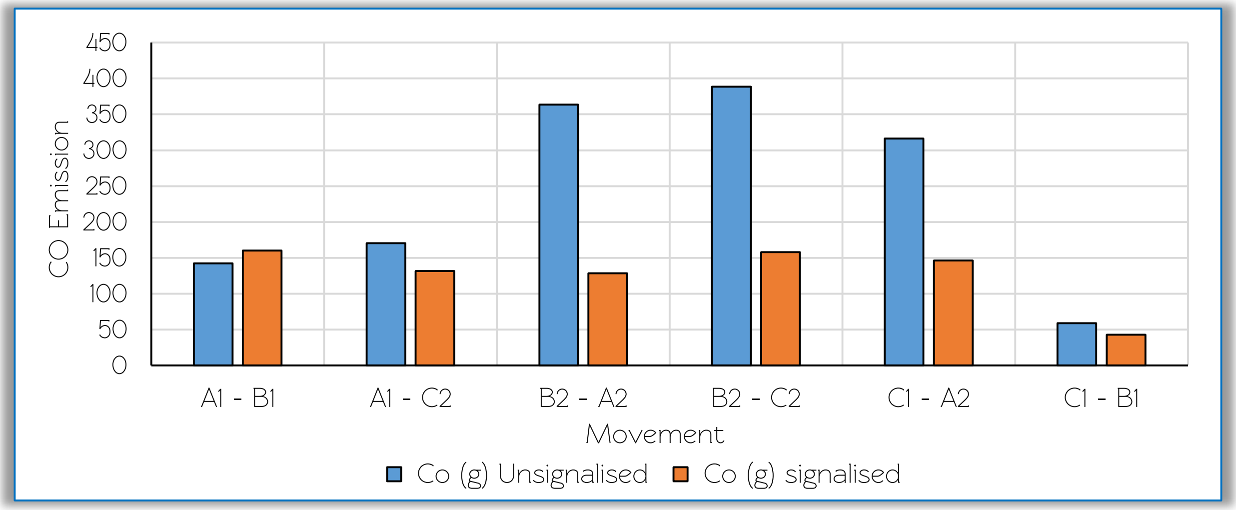

Figure 8: Carbon Monoxide Unsignalized and Signalized Intersection

Figure 8 shows the comparison of Carbon Monoxide Emission for the Unsignalized and Signalized Intersection replacement. It can be deduced that for most of the movements on average more COx is emitted on unsignalized than when replaced with signals.

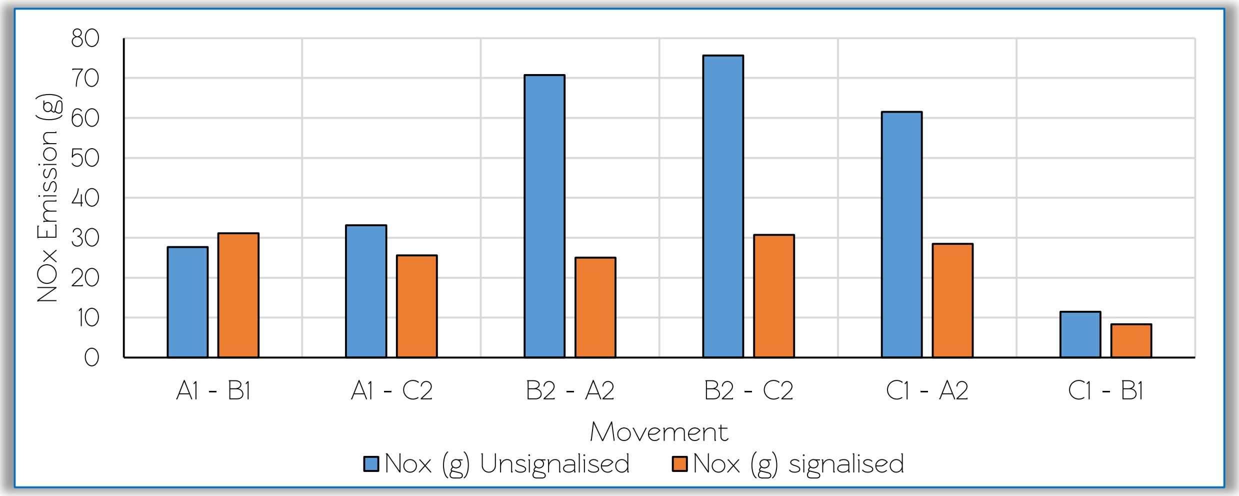

Figure 9: Nitrogen Monoxide Unsignalized and Signalized

Figure 9 shows the comparison of Nitrogen monoxide Emission for the Unsignalized and Signalized Intersection replacement. It can be deduced that for most of the movements on average more NOx is emitted on unsignalized than when replaced with signals.

4. CONCLUSIONS

At any intersection in an urban area with so much traffic, there is likely to be delays and congestion. It is then important to improve on the traffic performance at such intersection.

Therefore, planning and design of intersection with the provision of signalization where necessary should be encouraged to maintain acceptable level of service and provide for future traffic growth. A 3–phase traffic signal control scheme with an optimum cycle length of 63 seconds is therefore designed for the Offa Garage roundabout for a reliable signal traffic control. The green time for phases 1, 2 and 3 are 26 seconds, 12 seconds and 12 seconds respectively, an amber time of 3 seconds and an all–red clearance time of 2 seconds was utilized for each of the phases in the design. Phase 1 allows movement simultaneously for the through movements on Offa Garage and Ita Alamu approaches. Phase 2 and 3 are for Left turn movement on Asa Dam and Ita Alamu Approaches respectively. By providing traffic signal at the Offa Garage intersection, there will be curtailments in the conflicts experienced at the intersection that would consequently yield to orderly movement of traffic. There will also be no further need for traffic wardens to control the traffic at the intersection. The redesign gave an average LOS of B, A, and C for the Offa Garage, Ita Alamu, and Asa dam approaches respectively and improved the overall performance of the intersection from its present general Level of service, LOS F to LOS B.

A proper signalization using the traffic micro–simulation can provide critical indicators to identify traffic occurrence for each specific environment. In this study, a model was used to describe the heterogeneous traffic system with signalized and non–signalized intersections.

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