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Design of Traffic Signal in a Four Lane Intersection: A Case Study of Opolo Roundabout, Yenagoa Bayelsa State Nigeria

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Abstract: *Traffic signals, also known as traffic lights, stop light and traffic control signals are signaling devices located at road intersections, pedestrian crossing, and other location to control conflicting flows of traffic. The increasing number of vehicles on the road intersection has given rise to many problems like road accidents, congestion and conflict. These problems can only be solved by designing proper traffic signals at intersection for continuous and smooth movement of vehicles. Yenagoa city is also facing the same problem. This research work presents the proper designing and stimulation of traffic signals at Opolo roundabout Yenagoa in Bayelsa state Nigeria. The research deals with the stimulation of design through the use of Webster's method in carrying out the design and data collection involves using manual traffic volume count, with traffic survey route. The conversion of traffic count at the intersections to passenger car unit (PCU) for the design of traffic signal, it was observed that PCU obtained at the four intersections in the roundabout where 2480, 3172, 2382 and 821.Based on the calculations done on the PCU values obtained from the traffic survey, the optimum Signal Cycle Length was found to be 60 seconds. The cycle length at the existing intersection is same for three major roads, 189 seconds and for the minor road 259 seconds. The implementation of this design will therefore go a long way in the reduction of traffic congestions and delays around the Opolo roundabout.*

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INTRODUCTION

Background of Study

From the last decade the traffic in Nigeria has increased dramatically. Congestion is increasing as a result of increase in the number of vehicles and the space is getting narrow. As a result there is a delay in reaching the destination. The total delay can be categorized into declaration delay, stop delay and acceleration delay*(Jimoh etal, 2012)*. Traffic engineers usually adopted computerized methods to find the optimum traffic signal timing and to predict the performance of signalized intersections in terms of delays and queue lengths that aid in the calculation of optimum cycle length that seeks to minimize vehicle delay. Some researchers have argued that this model tends to fail whenever saturation flow ratio is approximately unity. That is when demand is approximately equal to lane capacity (Zakariya and Rabia, 2016).

As human population grows rapidly in urban areas, vehicular traffic volume has also increased proportionally following increased mobility and the geometric increase in the rate of automobile ownership. This accounts for the intense traffic congestion that is associated with urban areas which affects their livability in terms of congestion, pollution; high travel cost and delay (Sheehan, 2010).

Traffic congestions are usually caused by excessive delays at intersections in most cases (Reddy and Hussain, 2016). Because the capacity of an intersection is usually lower than that of other sections of the street, bottleneck effects are bound to be experienced at intersections.
Traffic signals generally play an important role for functioning of urban Street traffic system. Effective signal helps in improving the mobility of road and reducing the congestion in the rural and urban area. Yenagoa is the largest city in Bayelsa State. Yenagoa is facing traffic congestion in different road intersection due to rapid and uncontrolled development in traffic. Transportation network which result in environmental degradation as well as delay in traffic and loss of fuel. When the vehicle are waiting for their turn to pass the intersection the driver normally cannot off the engine and unnecessarily blow or hoot the horn, as a result delay the vehicle, cause loss of fuel, noise pollution at all the signalized intersection.

Traffic signals are standardized devices for the regulation and control of vehicular traffic, pedestrians and pedal cyclists which are used at signalized intersections, signalized pedestrian and cyclist crossings, railway crossings and at locations where control of traffic flow is required (FMW, 2013) . Various kinds of techniques and computer tools have been developed to help traffic engineers find the optimum traffic signal timing and to predict the performance of signalized intersections in terms of delays and queue lengths. One of such techniques is in Paul *et al.*(2018).The Opolo roundabout in Yenagoa Metropolis of Bayelsa state is known to experience congestion and delay in traffic owing to lack of effective traffic controls. Therefore, this project aimed at designing traffic signal using Wester method for effective traffic flow.

MATERIALS AND METHODS

METHOD

Description of Study Area

Four existing at-grade 4-leg un-signalized road intersections in Yanegoa town, Bayelsa state of Nigeria were considered for this study. The intersections are Bayelsa palm road, AIT road, Tombia link road and the Opolo junction. The Bayelsa palm road connects the Sani Abacha Express way which connects to the popular Begger flyover. The AIT road connect to the various communities in Ogbia Local Government Area. While the Tombia link road leads to the popular Tombia junction,which connects to the busy Meford Okilo road as shown in Fig. 1.

Fig. 1: Google map showing Opolo town and locations of the intersections(Source.Google Earth,2025)

Data Collection
Traffic count was carried out at each of the candidate intersections from 6:00 am to 6:00 pm for seven (7) days. Traffic enumerators carried out daily counts manually at intervals of 15 minutes. Parameters measured at both intersections included; vehicular traffic flow rate (pcu/h) for all movements (through, left and right); geometric characteristics such as number and width of lanes, and vehicles approaching speeds using speed gun. The field work measured parameters for the base year (2017) which were used to project traffic demand on the intersections for design life of ten years (2027) using 3% annual traffic growth rate. Saturation flow rates per hour on each approach were also computed using standard lanes saturation flow rate values.
The signal design procedure involves few important steps as described in Fig.2.

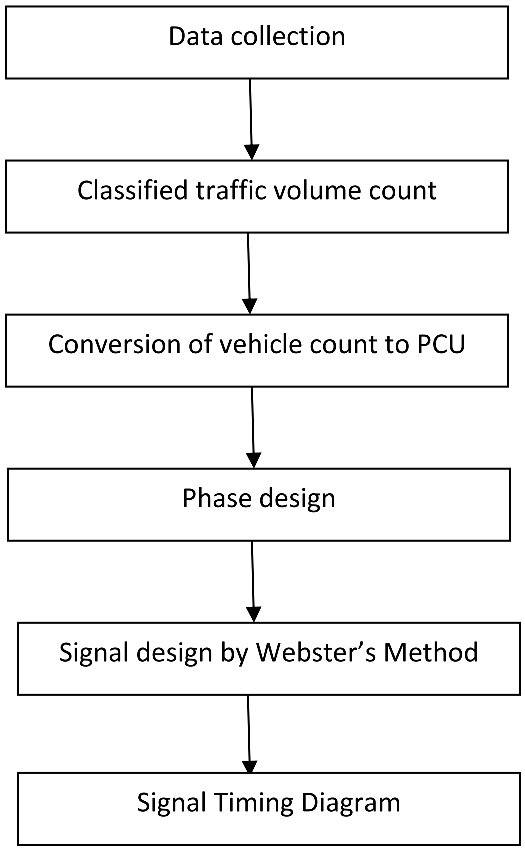

Fig 2: Signal design procedure flow chart (source: Kamlesh etal, 2015)

2.3 Webster's Method

It is a critical approach of determining the optimum signal cycle time (C0) corresponding to minimum delay to all the vehicles at the approach roads of the intersection.

C O = 1.5L+5 (1)

Where,
L= Total lost time per cycle sec = $2n + R$
n = is the number of phases
R=all-red time or red-amber time;
$Y = y1 + y2$ (2)

$y1 = q1/s1 \ and \ y2{=}q2/s2$ (3)

The field work consists of determining the following set of values on each approach road near the intersection:

The normal flow "q" on each approach during the design hour.

The saturation flow, S per unit time The normal flow values q1 and q2 on road 1 and road 2 are determined from field studies conducted during the design hours or the traffic during peak 15 minute's period. The saturation flow of vehicles is determined from careful field studies by noting the number of vehicles in the stream of compact flow during the green phases and the corresponding intervals precisely (*Pate,2014)*. Based on the selected values of normal flow, the ratio y1=q1/S1 and y2=q2/S2 are determined on the approach roads 1 and 2.In the case of mixed traffic, it is necessary to convert the different vehicle classes in terms of suitable of PCU values at signalized intersection; in case these are not available they may be determined separately. The normal flow of the traffic on the approach roads may also be determined by conducting field's studies during off-peak hours to design different sets of signal timings during other periods of the day also, as required so as to provide different signal setting.

2.3.1 Signal Timing Design Procedure

The input parameters for the signal timing design included the peak 15 minute demand flow rate and the saturation flow rate on all approaches; these were obtained from analysis of the intersection traffic count data and geometric characteristics. The design process involved computation of flow ratios (defined as the ratio of demand flow rate to saturation flow rate), phase design, determination of change and clearance interval, cycle length and green time for each phase.

2.3.2 Signal Phasing Plan

A 4-phase signal-control plan was developed for both intersections. The movements of each approach were assigned right-of-way followed by movements of other opposing approach in a given sequence using 4-stages. Every phase controlled both a through and left-turn movement. This phase plan was adopted because through traffic and turning traffic both shared the same lane in most cases. An example of traffic movement configuration or signal phasing plan of a 4-leg intersection is depicted by the phasing and flow diagram shown in Fig.2.

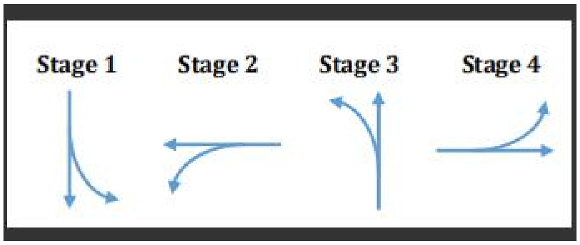

Fig 2: Signal phasing and flow direction

Traffic flow in phases 1, 2, 3, and 4 where assigned right-of-way to movements in 4 stages as shown in Fig. 2 to describe the North, East, South and West approaches respectively. in this study, right turning movements were ignored since they do not cause significant conflict to traffic flow. It was assumed that the green time for straight and left turning movements was sufficient to cater for the right turns.

2.3.3 Cycle Length Estimation

The optimum cycle length (Co) was calculated using the Webster model presented as Eq. (1);
Co = (1) where, L is the total lost time per cycle (sec), is the sum of flow ratios of individual lanes. In other words, equal to where *yi*, is the flow ratio of individual approaches denoted as *i*.

2.3.4 Estimation of Total Lost Time per Cycle

The time during which an intersection is not used effectively by any movement comprises the start-up lost time and the clearance lost time, which sum to represent total times experienced when a movement is started and stopped. In this project, 4 seconds time was applied per phase to account for the total lost times (2 seconds for start-up lost time and 2 seconds for clearance lost time). The total lost time per cycle (L) was calculated using Eq. (1); where n is number of phases, and represent start up and clearance lost times per phase respectively (Devesh etal,2022)

2.3.5 Green Time Estimation

The total lost time per cycle was subtracted from the total estimated cycle time to obtain total green time. The flow ratios were used to estimate the proportion of the total green time to be allocated to each phase. The effective green time (gi) for each phase was calculated using Eq. (2);

$$gi = \frac{yi}{\sum yi} G \qquad (2)$$

Where,
$yi$is the flow ratio of the *i*th lane or approach,
G is the total green time for the cycle. The actual green time was calculated as the sum of the effective green and total lost times less the amber time.

2.3.6 Estimation of Vehicle Control Delay

The model for estimating average vehicle control delay on queue for a given approach of a signalized intersection is as stated in Eq. (4):

$$d = \frac{c(1-\lambda)^2}{2(1-\lambda x)} + \frac{x^2}{2q(1-x)} - 0.65\left(\frac{c}{q^2}\right)^{\frac{1}{3}}$$

(4)
(Source:*Webster and Cobbe, 1966)*

Where,
d is vehicle control delay (s/veh),
C is the design cycle time of the intersection (s), is effective green time for a phase divided by the cycle length, x is the degree of saturation,
s is saturation flow rate (veh/s)
q is the demand flow rate (veh/s). The first, second and third terms of the delay model represent average delay to vehicles assuming uniform arrival, delay due to randomness of vehicle arrivals and probability of delay surges in vehicle arrivals caused by temporary over-saturation of the approach respectively.

2.3.7 Queue Length

Queue length is another performance measure that is used together with delay to determine the intersection Level of Service (LOS). The expression used for estimating queue length Q per approach is as shown in Eq. (5):

$$Q = \frac{q}{3600/c}$$

(5)
(Reddy and Hussain, 2016)

Where,
q is demand flow rate (veh/ln)
C is the cycle length (s).
Delay and queue lengths are important performance measures for road intersection that traffic engineers always try to minimize so as to improve the LOS of intersections.

3.0 Results and Discussion

3.1 Opolo Roundabout

Fig. 3 presents the layout of Opolo roundabout and average traffic flow rates measured in passenger car unit per hour (pcu/h) on all approaches for the base. The traffic volume count is done by manual method of survey at 8 a.m.to 11am.

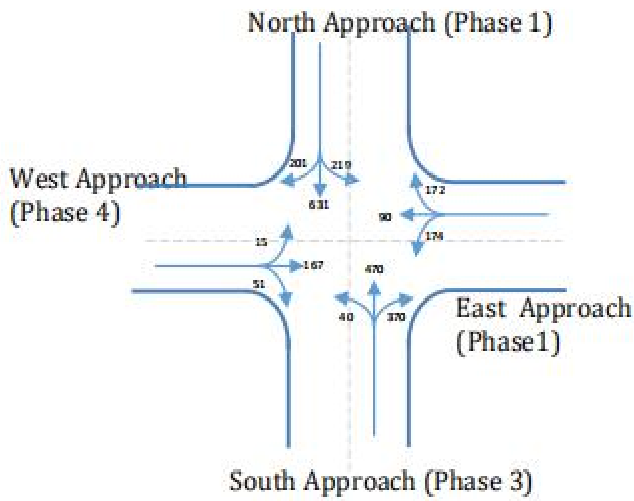

Fig.3: Layout and Traffic flow rate (pcu/h) on Opolo roundabout

Table1: Equivalency factor for use in signal design (Federal Republic of Nigeria Highway Design Manual, 2013)

Types of vehicles	PCU
Passenger car	1.0
Autoriskshaw	1.0
Bus, Truck	3.0
Tractor, Trailer unit	3.0
Motor cycle , scooter, bicycle	0.5

Table 2:Data count for vehicles at intersection

Phase	Direction	2-Wheeler	Light vehicle	4-Wheeler	Bus	Cycle
Phase 1	Tombia link road to Tombia juction	130	23	22	17	01
Phase 2	Palm road to Sani Abacha expressway road	148	14	17	12	00
	Palm road to Begger flyover	261	17	27	10	00
Phase 3	AIT road	464	32	34	11	00
Phase 4	Melford Okilo road	254	15	20		01

B. PCU sheet for intersection volume count (PCU/hr.)

C. Conflicts at Four-Legged Intersection: -

AIT ROAD

FROM Tombia ROAD

BEGGERFLYOVER ROAD

OPOLO JUCTION

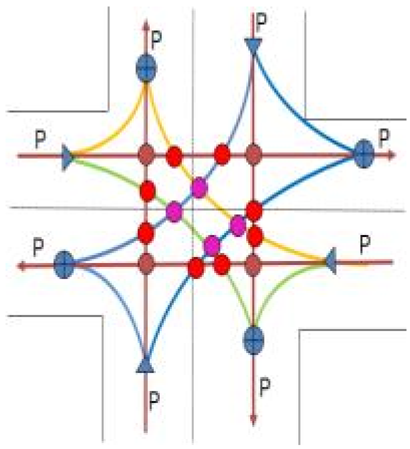

Fig.4: Conflict Points at Intersection

- 4 Through traffic
- 4 Right turn
- 8 Right turn-Through
- 4 Merging
- 4 Diverging
- P 8 Pedestrian

3.2 Phase Diagram

For this type of junction, the four-phase system is best ideally suited

Phase 1:

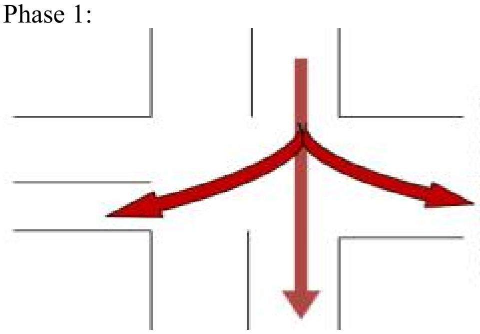

Fig 5:Directional flow of traffic at Opolo intersection originating from Opolo market road

Phase 2:

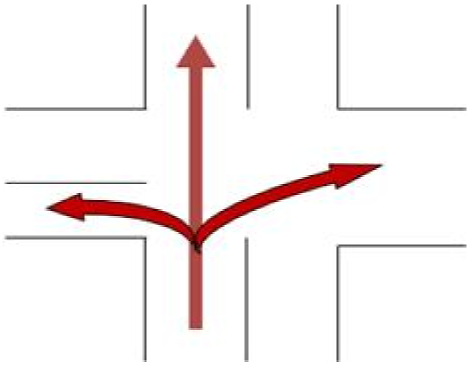

Fig.6:Directional flow of traffic at Opolo intersection originating from AIT road

Phase 3:

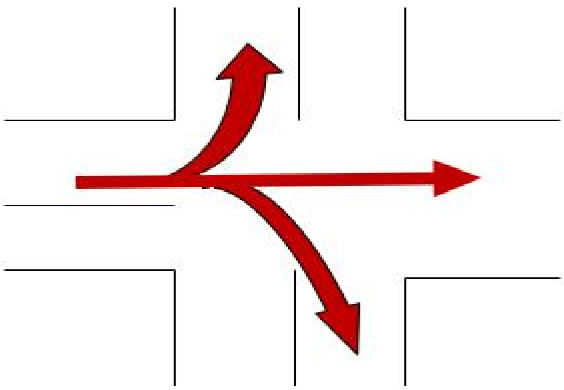

Fig.7: Directional flow of traffic at Opolo intersection originating from Berger flyoverroad

Phase 4:

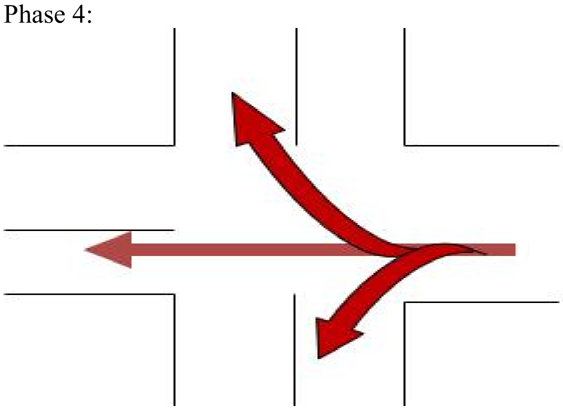

Fig.8:Directional flow of traffic at Opolo intersection originating from Tombia roundabout.

.From the traffic count as shown in table 2 the sum total value of the vehicles coming from different directions was obtained and through this, we can design the traffic signal properly using Webster's method.

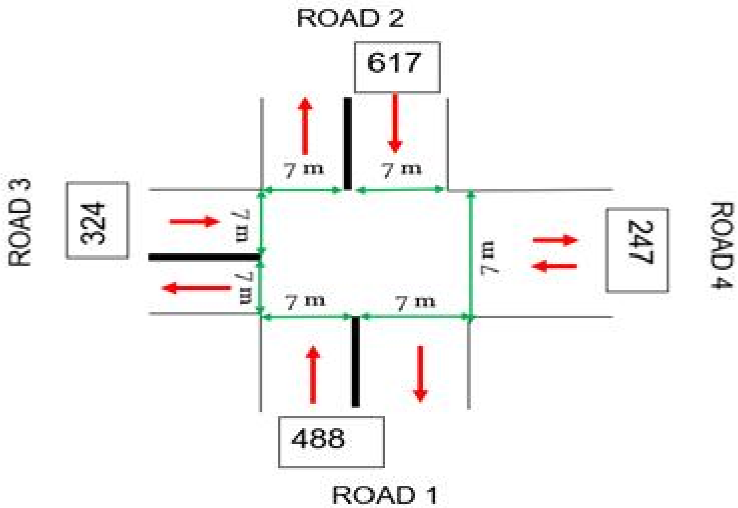

Fig. 9: Total PCU count of vehicles from all Directions

Amber time for phases = Ʈmin. = tr + 2* + +
Where; tr = perception reaction time = 1s;
V = design speed = 30kmph = 8.33m/s;
d = comfortable deceleration rate = 4m/s²;
W = width of intersection = 15m;
L = length of vehicle = 5m;
Ʈmin. = minimum amber time = 1 + 8.33 2* 4 + 15+5 *8.33
= **4.44s**

Table 3. Saturation flow rate

APPROACH	WIDTH (m)	SATURATION FLOW RATE
NORTHBOUND APPROACHES (ROAD 1)	7	525* width= 525*7=3675
SOUTHBOUND APPROACHES (ROAD 2)	7	525*width=525*7=3675
WESTBOUND APPROACHES (ROAD 3)	7	525*width=525*7=3675
EASTBOUND APPROACHES (ROAD 4)	7	525*width=525*7=3675

Table 4. Critical flow ratio

PHASE	CRITICAL FLOW RATIO
1	488/3675=0.133
2	617/3675=0.168
3	324/3675=0.0882
4	247/1969=0.0672

Total Lost Time (per phase) = Startup Time + Movement Time
Where, Movement Time = 0.5*Amber Time = 0.5*5 = **2.5s**

Therefore, Total Lost Time (per phase) = 2+2.5 = **4.5s**
Total Lost Time = 4*4.5 = **18s**
Optimum Cycle Time = Co = 1.5* +5 1− = 1.5* 18+5 1−0.456 = **58.82s ~ 60s**
Total Green Time = 60 – (5*4) = **40s**

Table 5. Calculation of green time and red time for different phases

PHASE	GREEN TIME (sec)	AMBER TIME (sec)	RED TIME
1	(0.133/0.456)*40=11.67~12	5	60-(12+5)=43
2	(0.168/0.456)*40=14.73~15	5	60-(15+5)=40
3	(0.0882/0.456)*40=7.136~7	5	60-(7+5)=48
4	(0.0672/0.456)*40=5.890~6	5	60-(6+5)=49

Table 6. Final signal timings

PHASE	GREEN TIME (sec)	AMBER TIME (sec)	RED TIME (sec)
1	12	5	43
2	15	5	40
3	7	5	48
4	6	5	49

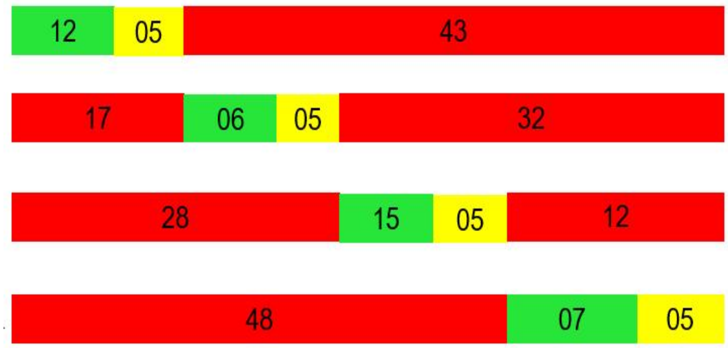

Fig10: Shows the Final signal timing diagram.

The calculations done on the PCU values obtained from the traffic survey showed that the major cause of accident is collision of vehicles at the intersections. The collision may be rear shunt on approach to junction, right angled collision, principle right turn collisions and pedestrian collision. These collisions can be avoided by implementing or adopting the signal timing diagram(fig. 10) in other to provide better and safe movement of traffic through at the intersection. The signal is designed as per IRC guidelines so that the signal can justify the proper movement of the traffic at the intersections

4.0 Conclusion

The existing system is a fixed time signal in which the cycle length are pre-determined and of fixed duration. This cycle length works for entire day for both peak and non-peak hours. The cycle length at the intersection is same for three major roads 189 seconds and for the minor road 259 seconds. The waiting time for the minor road is too large, there is a danger the good portion green time will be used by unsaturated flow of traffic which again leads to inefficiency. Therefore for each traffic flow volume there is an optimum cycle time which results in minimum delay to the vehicles. The traffic signals are operated manually when there is large volume of traffic at any part of day.
Based on the calculations done on the PCU values obtained from the traffic survey, the optimum Signal Cycle Length was found to be 60 seconds. The cycle length at the existing intersection is same for three major roads 189 seconds and for the minor road 259 seconds. The waiting time for the minor road is too large, there is a danger the good portion green time will be used by unsaturated flow of traffic which again leads to inefficiency. The timing of the signal provided at existing system is more than the optimum cycle length which causes delay to the vehicles. If the timing is causing extra delay to the vehicles than the driver will disobey the signal, resulting in cause of accident. Thus the signal timing should justify the movement of vehicles so that extra delay by the RED signal will not affect the total journey time. Main consideration in selecting the cycle length should be that least delay is caused due to the traffic passed through the intersection. The traffic volume was collected from 07:00-19:00 and it was observed that the maximum number of vehicles passed through signal were from morning 09:00-11:00 and in evening 17:00-19:00, As these hours of the day during which traffic congestion on roads and crowding on public transport is at its highest. Normally, this happens twice every weekday—once in the morning and once in the evening, the times during which the most people commute Based on the conversion of traffic count to PCU it was observed that PCU obtained on Elebele Road is 2480, Tombia road is 3172, Begger flyover road is 2382 and Opolo road is 821.

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