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EVALUATION AND RETIMING OF A PRE-TIMED TRAFFIC SIGNAL IN BENIN CITY, NIGERIA

H. A. P. Audu[1,*], O. O. Obhielo[2] and J. O.Ehiorobo[3]

[1, 2, 3] DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF BENIN, BENIN CITY, EDO STATE. NIGERIA,

E-mail addresses: [1] *henry.audu@uniben.edu,* [2] *obhielooriaifo@yahoo.com,* [3] *jacehi@uniben.edu*

ABSTRACT

This study evaluates and retimes a pre-timed traffic signal using the current volume of traffic and saturation flow headway. Traffic volume count was collected by stationing technicians at each approach lane to record the flow, composition and direction of vehicles through the intersection for every 15 minutes interval from 6.00am to 6.00pm. Saturation flow headway was obtained by placing a video recording device perpendicular to the stop line of each approach lane and allowed to record during the duration of traffic count. Retiming analysis and evaluation was carried out based on Highway capacity model for designing traffic signal timing parameters. The results obtained show an improvement by a reduction in the number of phases from four to three, a reduction in cycle length from 180 seconds to 120 seconds and an improved level of service from F to C.

Keywords: *pre-timed, traffic signal, saturation flow headway, cycle length level of service,*

1. INTRODUCTION

The use of traffic signals dates back to December 1868 when a traffic light was installed at the intersection of George and Bridge Street near House of Parliament in England. It was installed in response to a suggestion by a selected committee who believed that railway signal gear could be adapted to control street traffic. Its purpose was to give protection to members of Parliament and lesser street crossers to a point where vehicle traffic was heavy [8]. Over the years, this control device has been adopted in developed and developing countries as a means of controlling streams of vehicles at an intersection. It's been stated that vehicular traffic passing through an intersection must be controlled in order to overcome the conflicts arising between different directional flows (merging, diverging) of traffic [10].The installation and operation of traffic lights provides an effective method of controlling traffic when vehicle flows are relatively high [17]. There have been several methods of controlling conflicting streams of vehicles at an intersection. The choice of methods depends on the type of intersection and the volume of traffic in each of the conflicting streams [12]. Intersection controls are made up of yield signs, stop signs, multi-way signs, intersection channelization, rumble strips and traffic signals. Traffic signal controllers can be classified into pre-timed and traffic-actuated methods of operating traffic signals. In pre-timed operations, traffic signal utilizes pre-computed timing plans which are repeated throughout the day while traffic-actuated systems adjust its timing plans based on actual traffic flows [11]. Real-time vehicle flow measurements are obtained from vehicle detectors (inductive loops) and pedestrian push buttons buried in the pavement at or near the painted stop bar [10].

In Benin City, Nigeria pre-timed traffic signals have been used to control the flow of vehicles at many intersections. As traffic characteristics change with time, these timing parameters which were used to programme these pretimed traffic signals become outdated. One of the major problems associated with this is that of traffic congestion which has been a major problem on urban movements and a plague that has become an integral part of normal life in almost all urban areas in the world [9]. This is a severe problem at intersections, causing many critical problems and challenges such as delay incurred by motorists, increased fuel consumption of vehicles, rear-end collisions and air-pollution emissions from vehicles [7].

Corresponding author, Tel: +234-806-685-5914

One of the cost effective ways to reduce delays and mitigate congestion at signalized intersection using pre-timed traffic signals is theperiodic evaluation of their efficiencies and when necessary the retiming of the traffic signals timing parameters. This is achieved through a variety of low-cost improvements, including the development and implementation of new signal timing parameters, phasing sequences, improved control strategies and occasionally minor roadway improvement [7]. Research and experience have shown that retiming Pre-timed traffic signals is one of the most cost effective tasks that an agency can do to improve traffic flow through intersections [4]. Traffic flow improvements of up to 26 percent have been reported [13].

For signalized intersection, research has determined that average control delay per vehicle is the best available measure of level of service [1]. Vehicle delay is perhaps the most important parameter used by transportation professionals to evaluate the performance of signalized intersections [3]. The importance of vehicle delay is reflected in the use of this parameter in both design and evaluation practices. For example, delay minimization is frequently used as a primary optimization criterion when determining the operating parameters of traffic signals at isolated intersections. The Highway Capacity Manual [6] further uses the average control delay incurred by vehicle at intersection approaches as a base for determining the level of service provided by the traffic signals located at the downstream end of these approaches [2]. But due to the low maintenance culturein Nigeria, Benin City inclusive,it is observed that thepre-timed traffic signal controlledintersections operate at a reduced level of service due to the outdated signal timing plans in directing the movement of traffic.

Many studies on retiming of pretimed traffic signals have been carried out in developed countries but not much has been done in developing countries like Nigeria considering the fact that more than 80 percent of the traffic signals used in the country are pretimed traffic signals, a gap which this study stands to fill.

The objectives of this study are to: determine the existing pre-timed traffic signal timing parameters of the intersection of the study area; carry out intersection traffic volume counts and saturation flow headway survey; evaluate the retimed signal timing design using overall intersection control delay model; compare the retimed signal timing design to the existing signal timing design using overall intersection control delay model; based on the above, formulate recommendations that would assist transport agencies in retiming of pre-timed traffic signals.

2. DESCRIPTION OF STUDY AREA

The intersection used for this study is at Iyaro, and it is located along Urubi-Lagos Road in Oredo Local Government area, Benin City, Edo state, Nigeria. It is located between latitude 06°21' 6.38" to 06°21'7.80"N and longitude 05°37'43.22" to 05°37'44.80"E. It is a four-legged intersection which is on a dual carriageway with a relatively flat terrain. This intersection comprises of Federal Government roads which is the Dawson-Urubi-Uselu road from the East-West axis and the Lawani-Evbiemwen from the North-South axis as shown in Figure 1. The intersection is currently in isolation and it is controlled by a pre-timed traffic signal with a cycle length of 180 seconds. It uses a four phase system shown in Figure2 with the respective effective green time stated below: phase one effective green time of 58 seconds for through movements from the major roads (Urubi road and Dawson road), phase two effective green time of 26 seconds for protected left turn from the major roads (Urubi road and Dawson road), phase three effective green time of 36 seconds for permissive through and left turns from Lawani and phase four effective green time of 36 seconds for permissive through and left turns from Evbiemwen. It also uses an amber interval of 5 seconds per phase and an all-red period of 1.0 second. The pavement surfaces for the major roads are in good condition with a minor depression at the median while the pavement surfaces of the minor roads are in bad condition. Commercial buildings and filling stations and their accesses are found close to the intersections.

2.1 Data Collection

Traffic volume count was conducted using the manual method of observation. This involved the use of traffic technicians stationed at each approach lane of the intersection. With the help of a data form and stop watch, traffic volume data were recorded for each 15 minutes interval for the design period which lasted from 6.00am to 6.00pm for three days (Tuesday, Wednesday and Thursday) [5]. Both turning movements at the intersection and vehicular classification were also noted by the technicians.

Saturation flow headway was measured using the video recording techniques for data collection. This technique was appropriate for this study compared to other forms of data acquisition in capturing saturation flow headway as this technique could be replayed several times to minimize any error when extracting data. A camcorder was held by a traffic technician perpendicular to the stop line of each approach lane into the intersection [15]. This was carried out between 8.00am to 10.00am and 4.00pm to 6.00pm during the duration of traffic volume count.

2.2 Method of Data Analysis

Arrival flows were recorded in Vehicles per hour and had to be expressed as a homogenous entity by converting the individual vehicle categories into passenger car units (pcu) using values obtained [14]. Saturation flow rate was computed by dividing an hour by the average saturation flow headway for each lane. Phase design plan was calculated using the Highway Capacity Manual method for allocating protected or permitted left turns. Left turns was considered protected if the cross product of left turn demand and the opposing through demands for one hour exceeds 50,000 for one opposing through lane, 90,000 for two opposing through lanes, or 110,000 for three or more opposing through lanes [6]. The inter-green period consisted of the amber interval and the all-red period was calculated based on the accepted local practice. Cycle length was calculated using [16] given as:

$$C_{opt} = \frac{(1.5L + 5)}{(1 - Y)} \qquad (1)$$

Where C_{opt} is the optimum cycle time (s),L is the Intersection lost time (s) ,Y is the Intersection flow ratio. The total available green time within the cycle was calculated using equation (2) [16]:

$$\sum g_j = C - \sum I_j \qquad (2)$$

where; $\sum g_j$ is the total green time available in the cycle (s), C is the selected cycle time (s)I_j is the Inter-green period following phase j (s)

The basic equation used in [6] for estimating the overall control delay was

$$d = k_f d_1 + d_2 + d_3 \qquad (3)$$

where; d is the average overall delay (s/pcu), k_f is the adjustment factor for the effect of the quality of progression, with:

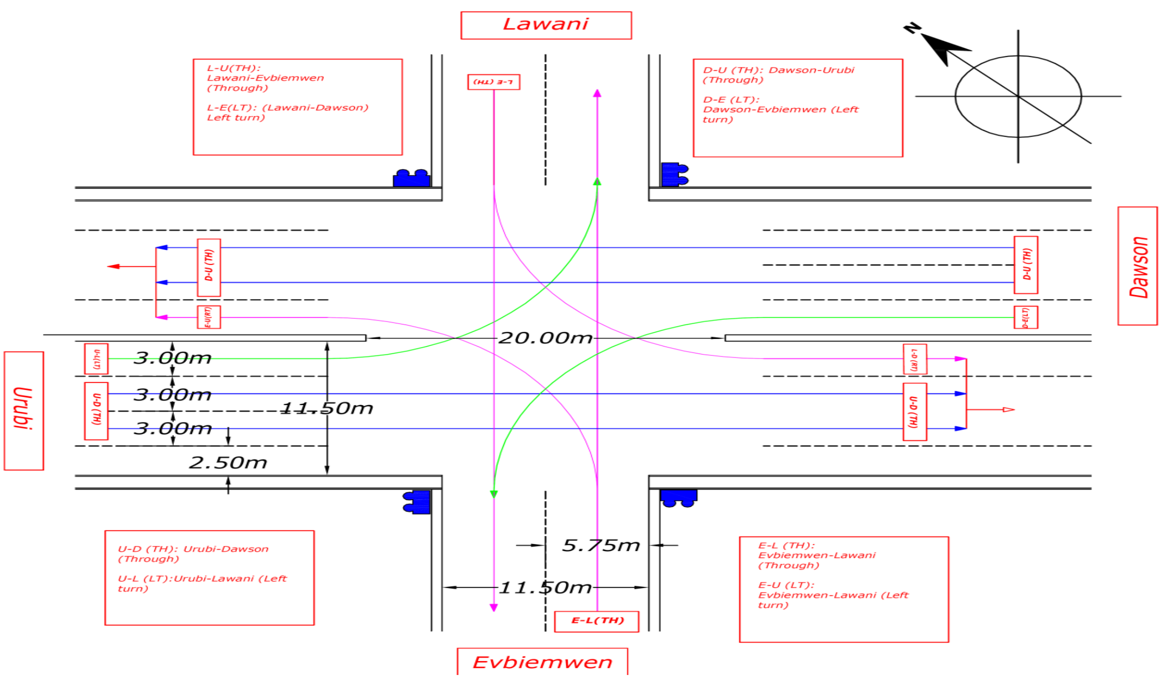

Figure1: Layout of the intersection at Iyaro showing the number of lanes, width of lanes, and location of traffic signal controllers

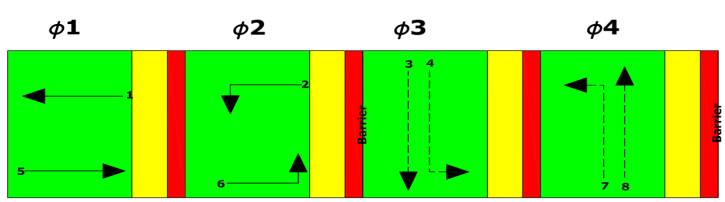

Figure 2: Existing phase diagram at Iyaro intersection.

$$k_f = \frac{\left(1 - \frac{q_{gr}}{q}\right) f_p}{\left(1 - \frac{g_e}{C}\right)} \quad (4)$$

q_{gr}/q is the proportion of vehicles arriving during the green time, d_1 is the average overall uniform delay (s/pcu), d_2 is the average overflow delay (s/pcu), with

$$d_1 = \frac{c(1 - g_e/c)^2}{[2(1 - x_1 g_e/c)\}} \quad (5)$$

$$d_2 = \left[(x-1) + \sqrt{(x-1)^2 + \frac{240x}{Ct_e}}\right] 15_{te} \quad (6)$$

d_3 is the Initial queue delay, c is the cycle time (s), g_e is the Effective green interval (s), x_1 is the minimum of (1.0, x), x is the degree of saturation, q is the arrival flow (pcu/h), C is the capacity (pcu/h)

From Highway Capacity Manual, the average overall intersection delay was calculated as the weighted average of the average overall lane delays for all intersection lanes:

$$d_{int} = \frac{\sum j \sum i \, q_{ij} d_{ij}}{\sum j \sum i \, q_{ij} i q_{ij}} \quad (7)$$

where;

q_{ij} is the Arrival flow in lane i in phase j (pcu/h), d_{ij} is the Average overall delay for vehicles in lane i departing in phase j (s/pcu), $\sum_j \sum_i$ is the Summation over individual lanes i and over phase j

3. RESULTS & DISCUSSION

The total traffic volume analysis trend in passenger car unit per hour for the study area is presented in Figure 3. This shows the hourly variation in the volume of passenger car unit making use of this intersection.

The phase diagram in Figure4 shows the designed three phase cycle for the intersection. It shows the allowed movements during the phases based on the examination of the arrival flows and allowable movements.

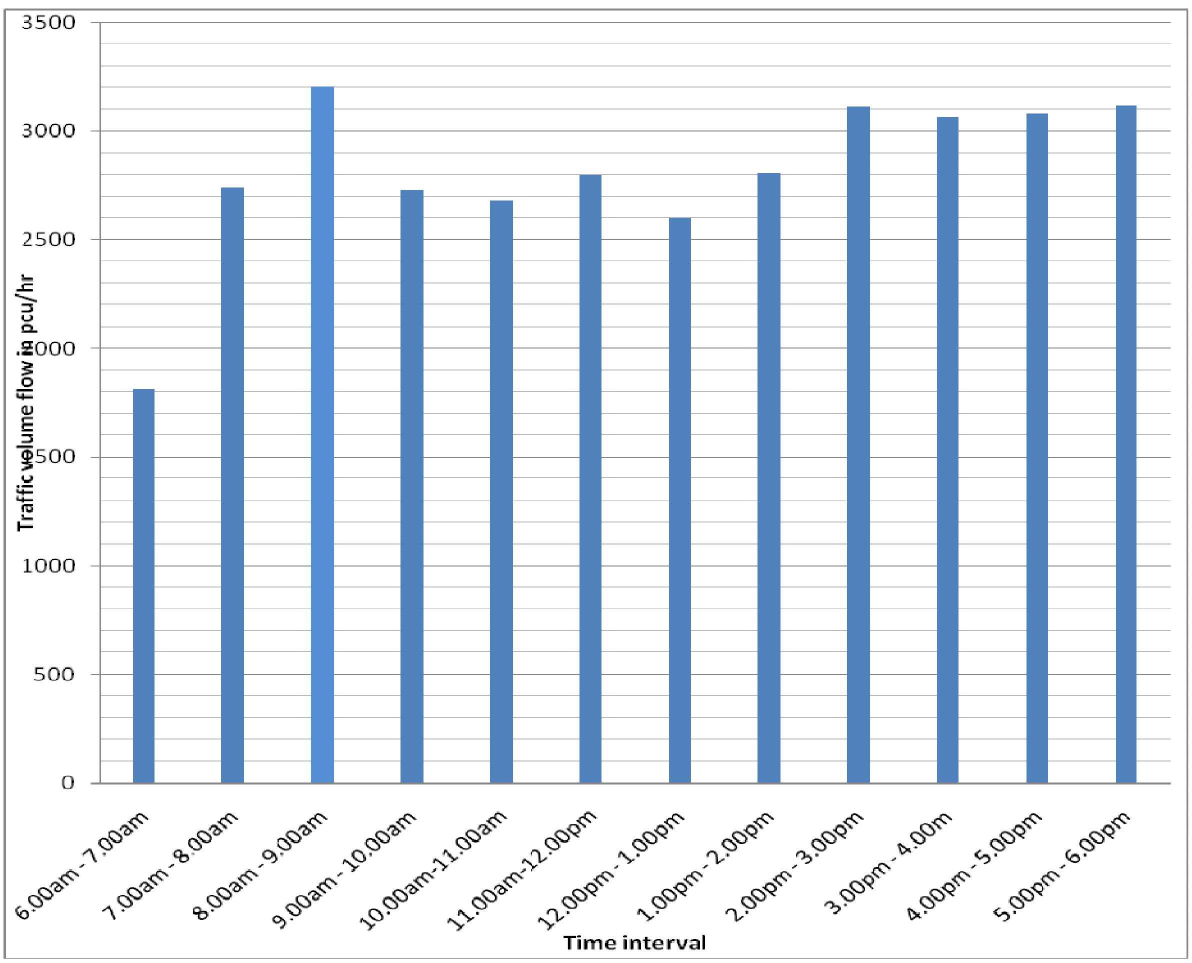

Figure 3: Total traffic volumes analysis trend at Iyaro intersection for each hour

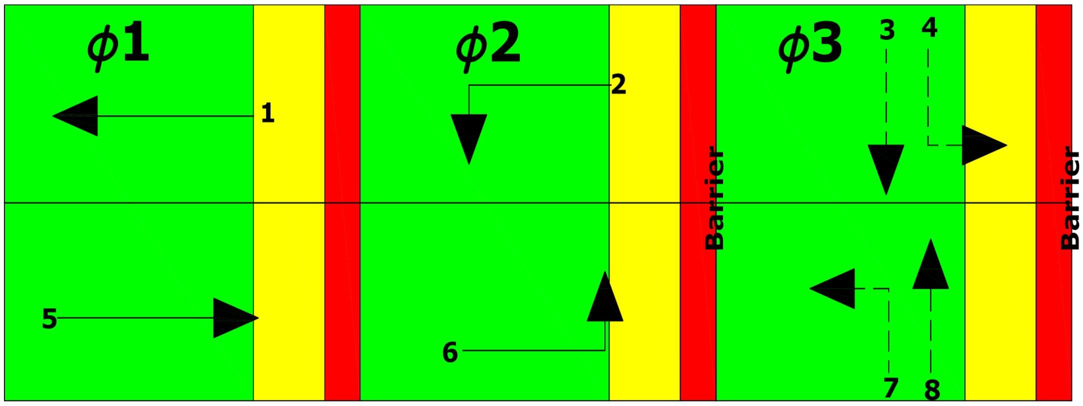

Figure 4:Phase configuration showing the allowed movements during three phases

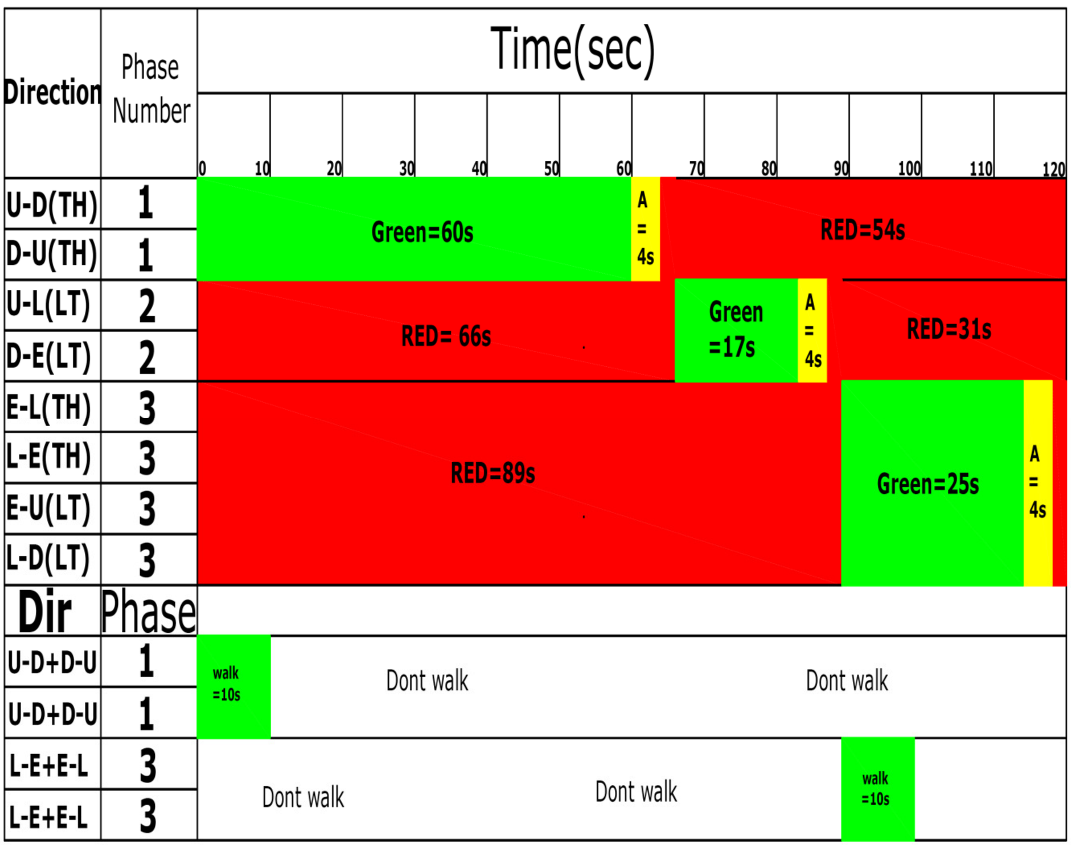

Figure 5: Final signal timing design shown in a timing diagram.

Table. 1:Saturation flow rate per lane

Movements	Saturation Flow pcu/hr/lane
D-U (TH)	1890
U-D (TH)	1970
U-L(LT)	1519
E-L (LT)	1101
D-E (TH)	1410
L-E (TH)	1023
E-U (LT)	1050
L-D (LT)	980

Table 1 shows the saturation flow rate from each lane for an analysis period of one hour. Figure 5 shows the final timing design for the intersection on a timing diagram. This shows the required green intervals of all phases to minimize control delay of the intersection. Table 2 and 3 show the overall control delay for the intersection after an evaluation study was carried out on the re-timed and existing signal timing parameters respectively.

Table. 2: Evaluation of re-timed signal timing parameters

Movement direction	Phase number	Effective green interval	Red interval	Max Degree of Saturation per phase	Arrival flow (pcu/h)	Average overall control delay (s/pcu)	Weighted Control delay $\sum_j\sum_i q_{ij}d_{ij}$ (s/h)
U-R(TH)	1	61	54	0.68	1218	22.41	27295.4
D-U (TH)					1316	24.30	31978.8
U-L(LT)	2	18	97	0.65	148	62.31	9221.9
D-E(LT)					100	54.17	5417.0
E-L (TH)	3	26	89	0.67	104	46.39	4824.6
L-E (TH)					92	46.13	4244.0
E-U (LT)					80	44.07	3525.6
L-D (LT)					142	59.79	8490.2
Summary =					3200		94997.4
Overall intersection control delay =						29.7 s/pcu	

Table.3: Evaluation of existing signal timing parameters

Movement direction	Phase number	Effective green interval	Red interval	Max Degree of Saturation per phase	Arrival flow (pcu/h)	Average overall control delay (spcu)	Weighted control delay $\sum_j\sum_i q_{ij}d_{ij}$ (s/h)
U-R(TH)	1	58	116	1.06	1218	78.38	95466.8
D-U (TH)					1316	195.15	256817.4
U-L(LT)	2	25	149	0.67	148	89.71	13277.1
D-E(LT)					100	79.36	7936.0
E-L (TH)	3	36	138	0.46	104	69.42	7219.7
L-E (TH)					92	69.01	6348.9
E-U (LT)	4	36	138	0.7	80	66.31	5304.8
L-D (LT)					142	84.47	11994.7
Summary =					3200		404365.5
Overall intersection control delay =						126.4 s/pcu	

It was observed from the traffic volume analysis that the morning peak volumes for the intersection occurred between the hours of 8.00 am to 9.00am. This was attributed to the fact that this intersection links federal institutions, state secretariats, banks, schools, hospitals and residential areas. The evening peak volumes occurred between the hours of 5.00pm to 6.00pm which indicates the period that most civil servants return from their various offices. Considering the size of the intersection and the location, an evaluation period of 60 minutes was used for this study. Right turns were not considered for both major and minor lanes due to their low volumes and the ability for them to be paired with through movements. An examination of the cross product of the left turns and opposing through movements shows that the logical cycle structure for this intersection was a three-phase operation. This was based on the Highway Capacity Manual criteria for providing protected left turn [6]. These phase cycle selected reduce the number of conflicts to the barest minimum based on the current volume of traffic making use of this intersection.

It was observed that the saturation flow which was measured directly from the study area, showed a drop in saturation flow rate per hour for the various approaches. This was attributed to the condition of the pavement surface. The pavement surfaces of the approaching lanes in the North-South axis are in terrible conditions which affects the average saturation flow headway between vehicles as their front axle passes the stop line. It was also observed that there was a depression in-between the opposing lanes of the East-West axis. This caused the variability in saturation flow of vehicles making left turns from the East-West axis.

The timing diagram shows the allocation of green intervals, amber interval, all red interval and red interval for the respective phases. The summation of these timing parameters sums up to 120 seconds, which is the cycle length of this intersection capable of handling the minimum pedestrian phase requirements and the current volume of traffic making use of this intersection. The first green interval of 60 seconds is allocated to through movements from Dawson and Urubi. While this movement is going on, all other signal heads are displayed red. After this interval, an amber interval of 4 seconds displays which is a warning to motorists that the green interval is about coming to an end. An all red interval of 2 seconds comes on before the next movements which is left turns either from Urubi to Lawani or Dawson to Evbiemwen displaying a green interval of 17 seconds, after which an amber interval of 4 seconds, then an all red interval of 2 seconds. The final phase is allocated to through movements and left turns from Evbiemwen and Lawani, both displaying a green interval of 25 seconds, after which an amber interval of 4 seconds then an all red interval of 2 seconds. Pedestrian are allowed to cross during phase 1 and phase 3, with a timing interval of 10 seconds each [15].

From this study, the major criterion for evaluating the new signal timing parameters was capacity/degree of saturation and overall control delay of the intersection. The critical volume to capacity ratio obtained from Table 2, shows that the maximum degree of saturation was less than 0.85 for all phases. This indicates that the intersection would be under saturated and would typically have sufficient capacity and stable operations for the designed signal timing parameters. The results gotten from the overall intersection control delay, shown in Table 2 for the peak period was consistent with the previously determined volume to capacity ratio. The average overall intersection control delay obtained was less than 35 seconds. This means that the design has a level of service 'C' [6]. At LOS C, many vehicles are expected to go through the intersection without stopping. Going further to evaluate the existing signal timing parameters, it shows from the critical volume to capacity ratio and overall intersection control delay obtained from Table 3 showed that queues of vehicles would not be served by each cycle causing there to be a shift in demand patterns and this signal timing parameters proffer a level of service 'F' [6]. At LOS F, operations with delays are unacceptable to most drivers, due to poor progression and extremely long cycle lengths.

4. CONCLUSION

This work considered the retiming and evaluation of a pre-timed traffic signal. The result of the analysis showed that, the number of phases and cycle length required based on the current volume of traffic making use of this intersection should be three and 120 seconds respectively. From the evaluation study carried out, maximum volume to capacity ratio was reduced from 1.06 to 0.68, overall intersection control delay was reduced from 126.4 s/pcu to 29.7 s/pcu and the level of service is expected to improve from F to C. It is believed that retiming of pre-timed traffic signal would be beneficial to the study area through reduced travel time, fuel consumption and exposure to fumes from idling vehicles which would indirectly offer better living conditions to commuters making use of this intersection. This information is necessary for planning, designing and maintenance of pretimed traffic signal which when improperly managed, will end up with congestion on adjoining streets and will in turn pose serious health and environmental problems to the area.

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