Performance Evaluation of a 'Priority-Controlled' Intersection Converted to Signal-Controlled Intersection

Ezenwa Chinenye Amanamba

Abstract**—**There is a call to ensure that the issues of safety and efficient throughput are considered during design; the solutions to these issues can also be retrofitted at locations where they were not captured during design, but have become problems to road users over time. This paper adopts several methods to analyze the performance of an intersection which was formerly a 'priority-controlled' intersection, but has now been converted to a 'signal-controlled' intersection. Extensive review of literature helped form the basis for result analysis and discussion. The Ikot-Ekpene/Anagha-Ezikpe intersection, located at the heart of Umuahia was adopted as case study; considering the high traffic volume on the route. Anecdotal evidence revealed that traffic signals imposed enormous delays at the intersection, especially for traffic on the major road. The major road has arrival flow which surpasses the saturation flow obtained from modelling of the isolated signalized intersection. Similarly, there were several geometric elements that did not agree with the specific function of the road. A roundabout, particularly flower roundabout was recommended as a better traffic control measure.

Keywords**—**Highway function, level of service, roundabout, traffic delays, Umuahia.

I. Introduction

ROAD transport is one of the oldest indications of present day civilization; dating back to the construction ancient of Roman roads. All modes of transportation depend on roads to satisfy the transport needs of its users. Hence, in most places, the dependence on road transport has been greatly abused; evidenced by the poor state of road transport infrastructure. Some of the effects of this overutilization of roadway infrastructure include: Excessive axle loading culminating in pavement deterioration; increased congestion owing to pavement failures and increased motorization; unreliability of journey time predictions; increased accidents; etc. Traffic congestion (caused by interaction of two or more road users, or by the interaction between road users and roadway elements) leads to delays, decreasing flow rate, higher fuel consumption, and increased negative environmental effects. There are certain roadway elements that could induce delays to the traffic stream; in which case, an interrupted flow is observed. However, some of these elements could have been installed to achieve better flow profile, but because of additional travel demand, the roadway elements can no longer cope with the current traffic stream. Some of these elements include rotary islands, traffic signals, and several traffic calming devices.

There are several traffic flow improvement strategies, selected according to the prevalent conditions on site. Some of these improvements include: Traffic signalization (equipment/ software updating, timing plan improvement, signal coordination/linking, signal removal); Traffic operations (conversion of two-way streets to one-way operation, restrictions of turning movements, roadway channelization, roadway/intersection widening); and Enforcement and management (enforcement of the above measures, incident management systems, ramp metering) [7]. One major characteristic feature of traffic signals is updating of plans according to the prevalent traffic situations; however, in most cases, in practice, these timing plans are not updated. This, therefore, introduces delays to the traffic.

Another roadway element that imposes delay to traffic flow is intersection. In highway design, intersections are almost inevitable considering that at several points, paths would be created for conflicting traffic directions. However, the frequency of occurrence of these intersections is a function of the classification of the highway. Highways are classified according to function (in terms of accessibility and mobility) or administrative responsibility (in terms of planning, design, construction, operation, and maintenance). In Nigeria, highways are commonly classified according to administrative responsibility; this administrative responsibility is shared amongst the three levels of government (i.e. Federal government, State government, and Local government). Following this, roads in Nigeria are classified into three categories: Trunk A roads, Trunk B roads, and Trunk C roads. The responsibility for these three road classes is borne by the Federal government, State government, and Local governments for Trunk A, Trunk B, and Trunk C respectively.

With focus on the two established roadway-induced delay elements, this paper considers traffic signals in the light of traffic flow improvement as initial design intention, while considering the delays it has induced over time. The Ikot-Ekpene/Anagha-Ezikpe intersection, in the capital of Abia State, Nigeria, formed the nucleus of this research as it is laden with several design and operational issues. The aim of this paper is to review the performance of the intersection in handling traffic flow.

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II. Highway Function

In practical terms, a road should either offer mobility function or accessibility function for road users. For the seven classes of highway described in [12], i.e. local street, minor collector, major collector, minor arterial, major arterial, and freeway (expressway); there exists a negative linear relationship between accessibility and mobility functions. It is such that when more attention is giving to accessibility, the mobility function is impeded; and vice versa (see Fig. 1). Therefore, for a freeway or expressway, accessibility should be fully or partially controlled. Conversely, for a local street, mobility should be fully or partially controlled. The mobility and accessibility functions should then vary between the extremes – expressway and local street. Planning for a highway with good mobility function would focus on the means – ensuring people can move from location A to B; but planning for accessibility focuses on the end – the attractiveness of the destination. The main idea in mobility function is to ensure that vehicle flow and speed is relatively uninterrupted; whereas accessibility function ensures vehicular traffic flow and speed is reduced, while active mobility is promoted. Since expressways should provide more of mobility, which entails relatively higher, and uninterrupted speeds and flow; it is necessary to consider speed/flow (volume) relationships.

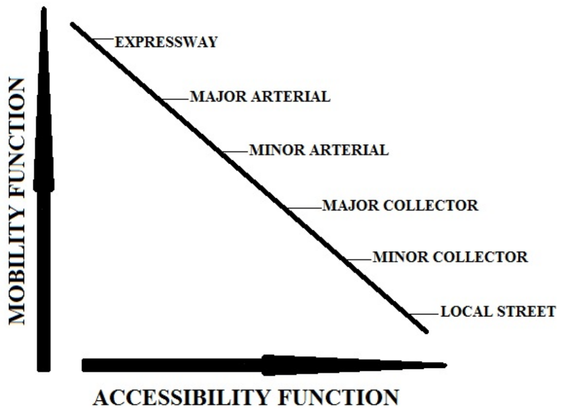

Fig. 1 Relationship between highway accessibility and mobility function

III. Highway Capacity

Speed and volume relationship affects other design parameters which are always considered in planning and design of highway facilities; one of such is capacity. The capacity of a road can be described from three perspectives; economic, environmental, and traffic capacity. The economic perspective describes the minimum traffic volume which should be attained on a road to justify its benefits in a cost-benefit analysis; environmental capacity can be described as the traffic volume an area can accommodate safely without negating its environmental standards with respect to noise and air pollution, visual intrusion, and safety of the vulnerable road users. The major focus here, however, is traffic capacity. Traffic capacity, according to Highway Capacity Manual (HCM), can be described as the maximum hourly rate at which people or vehicles can reasonably be expected to traverse a point or uniform section of a road or lane at a given time period under the prevailing conditions of the roadway, traffic, and traffic control [14]. The maximum volume here can be appreciated from the Greenshields model; it usually occurs at jam density hence measuring the capacity of a road is best done at near jam density. Roadway conditions in this sense refer to the geometric characteristics of the highway (lane width, lateral clearance, design speed, horizontal and vertical alignments). Traffic conditions refer to the distribution of the various classes of vehicle along the lanes of the highway. Traffic control conditions refer to the level of interruption of the traffic control devices (speed bumps, chicanes, intersections and traffic signals).

An average driver expects a highway facility to offer good speed (according to his perception), travel time, freedom to make man oeuvres (less congestion), uninterrupted travel, convenience, comfort, and less traffic control intrusion. All these are 'services' a road is expected to offer; most especially, expressways. The Level of Service (LOS) described by the HCM is a yardstick for measuring the extent to which an expressway satisfies the needs of the road users. The HCM, hence, considers LOS as the road users' perception of the qualitative measures which describes the operational conditions within a traffic stream [14]. For the various road types; there are six levels of service designated as LOS A through F; ranked in a descending order of operational conditions (LOS F being the worst condition). One of the assumptions of the Greenshields model is that speed decreases as traffic volume increases; speed and volume being integral parts of capacity. It can be concluded that as traffic volume increases, the driver's speed, freedom to make man oeuvres, convenience, and comfort decreases; while travel time, interruption, and traffic control intrusion increases. These parameters/factors as mentioned are known as Measure of Effectiveness (MOE); each LOS is defined according to how it meets these MOE.

The various LOS that could be observed on the expressway explained by the HCM are described as [4]:

I. LOS A: Free flow traffic; vehicles are completely (at least theoretically) unimpeded in the ability to maneuver within the traffic stream. Individual drivers are unaffected by the presence of other vehicles along the road section as spacing is about 161 m and density is less than 7 pcu/km/ lane. Free flow speed (speed of a vehicle when its movement is uninterrupted) is attainable. Incidences on the road are easily absorbed without queuing and there is high level of comfort.
II. LOS B: Steady traffic; free flow speed could be maintained with slightly restricted ability to make maneuvers. Average spacing is about 101 m and density is between 8-11 pcu/km/lane. Incidences on the road could still be absorbed though drivers simply need to keep an eye on nearby cars.
III. LOS C: Steady but limited traffic; speeds are still at or near free flow though maneuvering requires caution as the rate is noticeably restricted. Minor incidences could still be absorbed but queues may develop. Comfort is a bit reduced

as drivers become more tensed and cautious. Average spacing is about 67 m and density about 12-16 pcu/km/lane.

IV. LOS D: Steady traffic at high density; density begins to increase slightly as speed decreases. Freedom to make maneuvers is more noticeably limited. Minor incidences cause substantial queuing and can no longer be absorbed because traffic is approaching saturation (no space in traffic). Average spacing is about 50 m and density about 17-22 pcu/km/lane.

V. LOS E: Saturated traffic; capacity is at highest density and operations are mercurial. Maneuverability is almost impossible as the gaps are virtually unusable at an average spacing of about 34 m and density of about 23-28 pcu/km/lane. Any incidence at this point is expected to cause serious queuing as such disruptive waves extends through upstream traffic flow. The driver experiences poor physical and psychological comfort.

VI. LOS F: Congestion; total breakdown in vehicular flow caused by temporary reduction in capacity due to incidences or reoccurring merging and weaving movements. Ratio of arrival flow rate to capacity goes beyond unity. High level of vigilance is expected of drivers with practically no comfort. Average spacing is less than 2 m and density is greater than 28 pcu/km/lane (see Fig. 2)

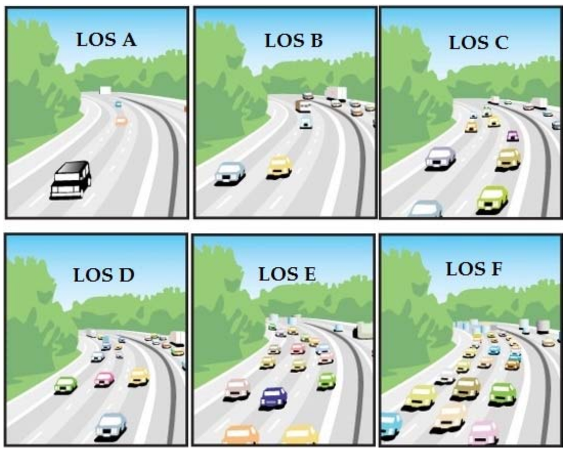

Fig. 2 Pictorial representation of the Levels of Service

IV. Intersection Types

In designing for good accessibility (connectivity being a corollary), there would be situations where one street would have to cross another; hence, intersections are formed. It is safe to conclude that intersections are characteristic features of minor arterials, collector roads, and local streets; not expressways. A road or street intersection can therefore be defined as the general area where two or more roads join or cross, including the roadway and roadside facilities which support traffic movement within it [1]. Care is taken in its design because intersections are conflict points of traffic movement; hence, accidents ensue, leading to reduction in capacity. Intersections are well known accident locations because of difficulty in coordinating the traffic; hence, the design considers efficiency, safety, speed, operational cost, and capacity. Good intersection design should consider first, the traffic flow along the individual routes which intersect so as to provide efficient flow of traffic from one approach to another.

An intersection comprises of several adjoining traffic streams which meet at common areas. The coordination of these approaches defines the various types of intersection. Intersections can be categorized in various ways; which include [15]: *Arrangement of intersection approaches* (T-intersection, Y-intersection, scissor, cross, multi-leg, staggered, skewed, and rotary intersections); *Grade* (defined by the road profile level at which the approaches intersect each other; described as grade-separated, and at-grade intersections. At-grade intersections are those having all approaches intersecting at the same profile level while grade-separated are those having at least one approach crossing over another at a high profile level); *Traffic control* (defined by the nature of traffic control adopted; they could be priority-controlled which is an exclusive feature on approaches comprising of low and high traffic volume roads. The other forms of intersection in this category are uncontrolled and signal controlled; the latter utilizes traffic signals to coordinate traffic flow); and *Channelization* (defined by the level of control provided in terms of directing traffic flow to definite paths. This category is of two forms; channelized and unchannelized intersections).

V. Intersection Design Considerations

A. Radii of Curves

Curves at intersections influence the operational characteristics of the highway. Selection of adequate curve radii would ensure free flow speed (vehicular speed is abated by the acuteness of the intersection vertex), and safety. The radii of curves should be selected to suit the dimensions of the design vehicle. However, care should be taken in the design of median openings at intersections involving left-turns; the design vehicle should negotiate a left turn at minimum radius so as to reduce the travel speed because of the high risk of conflicts at left turns. For a passenger car design vehicle, the minimum left turn radius that would safely and conveniently reduce its operating speed without the driver having to reverse or swing wide is 12 m. For the Single Unit truck it is 15 m, and for a WB-12 and WB-15 articulated trailer it is 25 m [9]. This should be selected considering the vehicle proportions of the road. For right turns, the recommended minimum is 17 m for minor intersections; this will accommodate a Single Unit truck. WB-12 and WB-15 design vehicles can turn on a 17 m radius provided they are permitted to encroach beyond the width of the turning lane. In situations where heavy traffic volumes are expected on both lanes, encroachment will not be permitted; hence, approximately 23 m radius would be provided for WB-12, and 30 m radius for WB-15 provided traffic-bearing lanes are set at 3.65 m [9]. Where proper channelization is done to cater for exclusive right turns, a wider radius can be selected.

Generally, width of carriageway at intersections needs to be increased in order to accommodate all turning vehicles. This is important because the rear tyres trace paths of varying radius with the front tyres.

B. Speed Change Lanes

On high volume roads, it is important that drivers entering or leaving adjust their speeds in order to negotiate the intersection safely. On priority control intersections, vehicles entering the major road require a separate lane where drivers can accelerate to the operational speed of the major road before going unto it; so that, vehicles already on the major road would not require unnecessary deceleration. On the other hand, vehicles leaving the major road unto the minor road require a separate lane where the drivers reduce their speed to enable them make safe maneuvers at the intersection. The former case requires an acceleration lane while the latter requires a deceleration lane. The speed change lanes can be used as storage pocket for turning vehicles; this would help reduce the induced delays experienced by the traffic on straight movement.

C. Operational Analysis

In designing an intersection, the capacity of each approach is integral. For signal-controlled intersections, knowledge of the capacity helps in time allocation to all approaches without causing unnecessary delays to other approaches. The higher the demand at each approach, the higher the time allocated especially when the capacity is not commensurate with the demand. For priority control intersections, knowledge of demand flow and capacity would help determine if vehicles on the minor (non-priority) road would experience long delays. If it is found that long delays and queue are bound to occur at the non-priority approach, signalization maybe considered. Intersection design focuses on Design Reference Flow which is the peak hour flow used to work up the design based on estimates of future flows 10 to 15 years after implementation of the scheme or commissioning of the highway. The ratio of demand to capacity (RFC) is used in predicting queues and a means of assessing the viability of the intersection design (see Fig. 3). From that relationship, it could be observed that delay increases rapidly at RFC of 0.85. Design best practices suggest that RFC of 0.75 should be adopted for rural and suburban roads, and 0.85 for urban roads. If an RFC value greater than 0.85 is adopted, the designed intersection would constantly run under the flow condition of overcapacity.

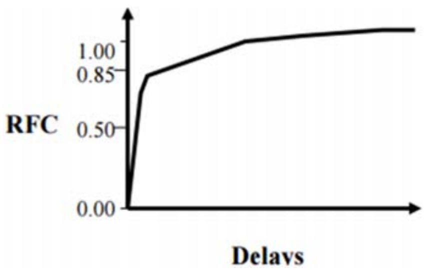

Fig. 3 Relationship between RFC ratio and delays [4]

VI. Traffic Signals

Traffic signals are traffic control measures used to achieve a time-based allocation of right-of-way to various streams of traffic on the roadway. There are two of such systems available to control urban networks; they are fixed time and traffic responsive systems, however, other configurations based on either of these exist. The fixed time system uses predetermined plans to control traffic; usually according to time of day. The traffic responsive systems use real time data to select appropriate green splits, cycle times, and offsets.

Fixed time systems use historical data, usually gathered on site, to build plans for the signal controller; most times, the plans are designed to cater for traffic flow variations at different times of the day. This implies that a different plan would be utilized for the morning peak, and another for the evening peak. Care is to be taken in the design of various plans so that the change in plans would not result in loss of efficiency. One major pitfall for the fixed time systems is that it is often very expensive to collect data and develop plans to be optimized by the signal controllers; this issue results in the plans not being updated even though traffic flow has increased over time. Reference [2] indicated that there is a 5% reduction in efficiency of traffic signals due to ageing of the time plans.

Given the limitations of fixed time systems, the traffic responsive systems were developed with a library of time plans which are selected following prevalent traffic conditions. As earlier mentioned, frequent change of time plans could result in loss of efficiency; this happens to be one of the pitfalls of traffic responsive systems. These systems are based on real time information, provided by queue detectors.

Generally, tackling the traffic volume situation at various sites requires evaluation of different possible solutions. Possible solutions in such cases include; installation of roundabout, installation of traffic signals, and grade separation. The installation of a roundabout will immediately introduce geometric delays to the major traffic stream; in the case of a priority-controlled intersection (where a major road meets a minor road). For roundabouts, the delays at off-peak times will still be relatively low and there will be a significant reduction in overall peak hour delay. Installation of traffic signals will increase delays to the major traffic streams owing to the fact that much of this traffic will have to stop at the lights; whereas they had an almost exclusive right-of-way ab initio. Generally, off-peak delays will be higher than those obtained at either roundabouts or priority-controlled intersections; however, under heavy traffic loading, they are much more efficient than priority-controlled intersections. Grade separation appears to be the best option in combating the issue of delays induced by conflicting traffic streams; however, it is a very expensive option.

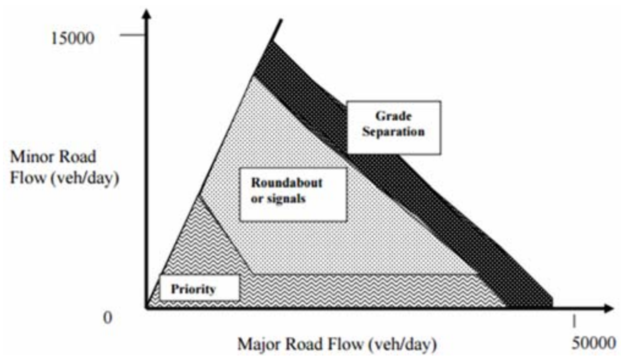

Fig. 4 Flow ranges by intersection type [6]

Fig. 4 describes traffic flow as the major consideration for selecting types of intersections. The decision to be taken between selecting roundabout or traffic signal installation is governed by speed, traffic volume, pedestrian volume, available land (space), accident rates, and the need for linking isolated signalized intersections. In certain circumstances, it may be impossible to design a signalized intersection which will have sufficient capacity to deal with all demands, and it may be necessary to balance the needs of pedestrians, public transport, and other road vehicles. However, signal-controlled intersections are characterized by the following:

a. Regulation of traffic and promotion of driver confidence by defining rights-of-way.
b. Reduction of the frequency of certain types of accident, except rear-end shunts.
c. Increase in intersection capacity.
d. Provision of a means of interrupting heavy traffic to allow side road traffic and pedestrian movement.
e. Provision for co-ordination of traffic by generating platoons which can be given green displays at downstream signalised intersections.
f. Possibility of increase in total intersection delay and fuel consumption; particularly at off peak times, compared with priority intersections and roundabouts.
g. Possibility of traffic migration to adjacent unsignalized routes.
h. Inefficiency at handling heavy left turns; roundabouts are often more effective.
i. Poor performance; if not correctly configured.
j. No provision for U turns.
k. Additional maintenance costs; including communication links to a control centre.

The initiative for considering the installation of a traffic signal at an existing intersection or midblock location often arises from complaints or from analysis regarding delay, congestion, safety, or pedestrian crossing problems; the investigation begins with the collection of traffic, pedestrian, collision, and geometric data. An assessment of whether or not a signal is technically justified is made using certain criteria. For a traffic signal installation to be technically justified, at least one of the following justifications must be fulfilled; if not, the installation of signals would likely result in an increase in overall intersection delay and/or a negative impact on intersection safety. These justifications include [10]:

- *Justification 1* – Minimum Eight-Hour Vehicle Volume: This is intended for application where the principal reason for installing a traffic signal is the cumulative delay produced by a large volume of intersecting traffic at an unsignalized intersection; as volumes increase beyond threshold criteria, delay to traffic on the minor road will increase, and the overall delay for the intersection will be greater than would be the case if minor delays were distributed between both main and minor roadways.
- *Justification 2* – Delay to Cross Traffic: This is intended for application where the traffic volume on the main road is so heavy that traffic on the minor road suffers excessive delay; or hazard in entering or crossing the main road due to the availability of critical gaps only.
- *Justification 3* – Combination Warrant: Signals may occasionally be justified where neither Justification 1 nor Justification 2 is 100% satisfied, but both justifications are at least 80% satisfied.
- *Justification 4* – Minimum Four-Hour Vehicle Volume: This is intended for application where the intersection experiences excessive delays for four or more peak hours of the day, but does not have the prolonged demands throughout the day to meet an eight hour warrant (as the case with justification 1). In practice, this is rarely considered, unless for commercial and industrial areas.
- *Justification 5* – Collision Experience: This is intended for application where traffic signals are considered as one means of improving intersection safety; where an unsignalized intersection has an unusually high collision history.
- *Justification 6* – Pedestrian Volume: The minimum pedestrian volume conditions are intended for applications where the traffic volume on a main road is so heavy that pedestrians experience excessive delay, or hazard in crossing the main road; or where high pedestrian crossing volumes produce the likelihood of such delays. This should be based on an eight-hour vehicular volume count, and a net eight-hour adjusted pedestrian volume survey.
- *Justification 7* – Projected Volumes: In some cases, it is desired to determine the future need for traffic signals at an existing or planned intersection. There are two basic scenarios. The first is that the intersection may exist and all that is changing is the addition of one or more developments which will add traffic to the intersection. The second is a development which will require, or be associated with, the construction of one or more new legs at an existing intersection or a completely new intersection or roadway. The prediction of future traffic demands is based on knowledge of growth in roadway usage, growth of local traffic generators and predicted traffic volumes, obtained from a traffic impact study, transportation planning study, environmental assessment or other similar evaluation. The preferred approach is that eight-hour volume projections are estimated as part of the engineering study, and evaluated against Justifications 1, 2 or 3.

VII. Methodology

A. Site Description

The intersection adopted for this study is the Ikot-Ekpene/Anagha-Ezikpe intersection situated in the heart of the capital city of Abia state, Nigeria. The intersection lies at the coordinates 5.518346 and 7.499852, along a federal Trunk 'A' highway; serving Abia and Akwa Ibom states, directly. The minor adjoining road is a state Trunk 'B' road that leads to the Abia State secretariat, Broadcasting Corporation of Abia State (BCA), Federal high court, Abia State e-library, Central Bank of Nigeria (CBN), Abia State International Conference Centre (ICC), and Abia State house of assembly; being the major trip generators. Also, there are residential buildings being served by this intersection arm; alongside several hotels. The major road serves trips originating from Abia and Akwa Ibom states to various states; it is the main route to World Bank Housing Estate and Ehimiri Housing Estate (these two being the major housing estates in the city, with almost 10% of the city's population); it is also the main route to the prestigious Federal Government College, Umuahia, Abia State university annex, National Root Crop Research Institute Umudike, and Michael Okpara University of Agriculture Umudike; and serves various village markets. The other wing of the road leads to various banks, Federal Medical Centre (FMC), Umuahia township stadium, Government House Umuahia, Abia State high court, and several residential streets. Also, there are various fuel stations along this route; which increases traffic volume at all times of the day. Fig. 5 shows the study site and other roads close to the intersection.

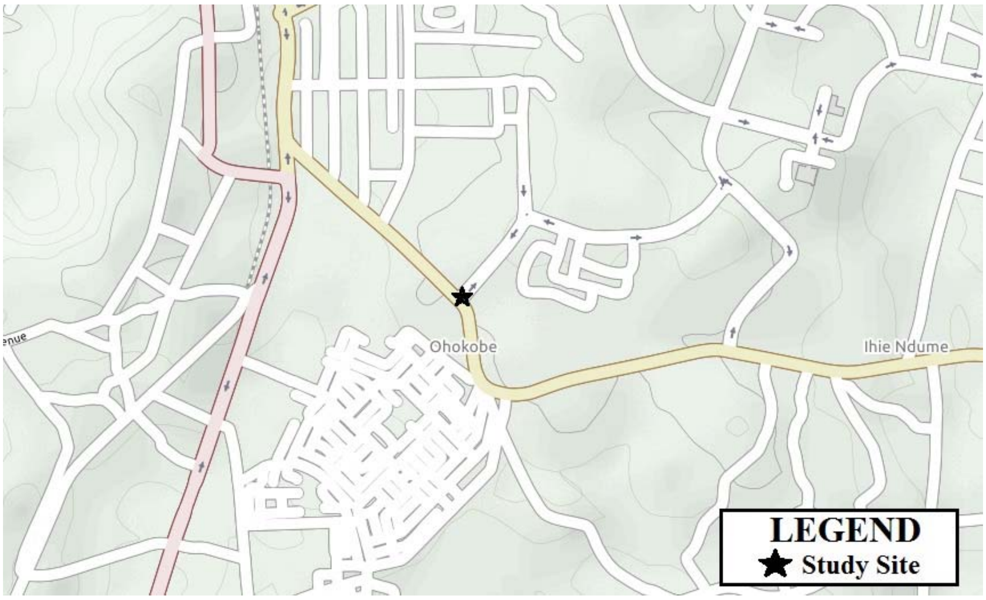

Fig. 5 Map showing the study intersection

Observation of the existing traffic signal timing, and road geometry revealed the following: There was a 3-seconds intergreen period for all traffic streams excluding the traffic moving straight along the Ikot-Ekpene/Umuahia Rd. (North), and turning movements on Anagha-Ezikpe Rd.; there was an amber display (2 seconds) for traffic moving straight along the Ikot-Ekpene/Umuahia Rd. (North), indicating road users should get ready to move; but there was no such display for all other traffic streams. There are pedestrian phases but they are uncoordinated, and are conflicting with vehicular movements. There are no obvious stop lines. The Ikot-Ekpene/Umuahia road has road width of 11 metres (5.5 m per lane, considering a two-directional split); while the exit lane of the Anagha-Ezikpe road has road width of 10metres (two defined lanes; 5 m per lane). There are no turning curves at the vertex of the adjoining roads. There is no left turn pocket, and deceleration bay/right turn storage pocket on the Ikot-Ekpene/Umuahia road. The signal timings were as shown in Fig. 6.

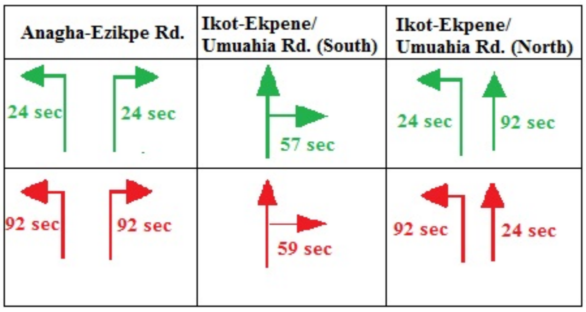

Fig. 6 Current signal timings at the study intersection

B. Method

The lane width of the major and minor roads was measured with a measuring tape; noting other geometric concerns. A traffic survey was conducted on both the major and minor roads for 7 days; to build in the variations of traffic flow by day of week. The traffic survey lasted from 6:00 to 12:00 (6 hours); the observed morning and evening peak times were between

6:00-9:00 (AM peak) and 16:00-19:00 (PM peak). The operation of the traffic signals was monitored afterwards; and existing layout and stage sequence of the study intersection shown in Fig. 7.

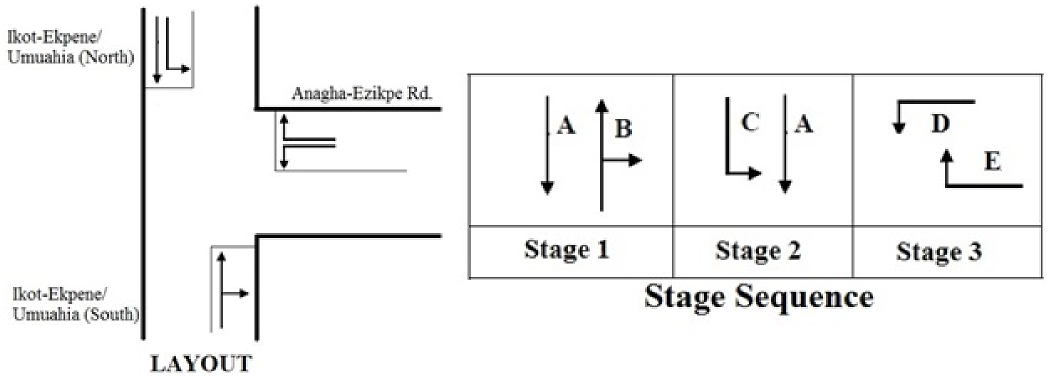

Fig. 7 Existing layout and stage sequence of the study intersection

A ten-man team was recruited for the manual traffic survey. The right- and left-turning traffic from Anagha-Ezikpe road was monitored; taking note of three classes of vehicles: passenger cars, Heavy Goods Vehicle (HGV), and tricycles. Similarly, traffic on both north and south wings of the Ikot-Ekpene/Umuahia road were monitored, at a point 3 metres upstream of the intersection; the three vehicle classes were also noted. The counts for passenger cars, HGV, and tricycles were tabulated independently for the 6 hour period. The 6 hour traffic count was converted to 16 hour flow, then to Average Annual Daily Traffic (AADT), and the effect of monthly variation was factored in following [11]. For an urban commuter road, the conversion factor from 6hour flow to 16 hour flow is 2.25; then the estimate is given by: $6hour\ survey\ count \times factor$ (coefficient of variation is 4.5%). Converting from the 16hour flow to AADT, given that the survey was carried out in May, on an urban route is given by: $Estimated\ 16hour\ flow \times 0.989$.

To allow for the effect of varying traffic composition, the AADT (veh/hr) was converted to Passenger Car Units (PCU); to ensure uniformity during signal analysis. The conversion factor followed the report of [8]; passenger car (1.0), HGV (2.3), and motorcycles (0.4). It was considered that tricycles have higher capacity than motorcycles; the latter being a two-wheeler with passenger capacity of 1, while the former is a three-wheeler with passenger capacity of 3. Provision was not made for tricycles in the [8] report; hence, the average of the conversion factor of the passenger car and motorcycle was adopted. This makes the conversion factor for tricycle 0.7.

The 6 hour traffic volume was averaged; then converted to 16hour traffic count; the estimated 16hour traffic volume was converted to AADT.

Following the approach proposed by [8], the Ikot-Ekpene/Umuahia intersection was modelled as an isolated signalized intersection with the parameters observed and measured on site; it was assumed that these were the same guiding principles behind the initial design of the traffic signals at the study intersection. This was done to determine the saturation flow, comparing the value to the observed arrival flow; hence, ascertain if the adoption of traffic signals as a traffic control measure was actually best suited.

VIII. Results and Discussion

A. Tables

TABLE I
6 Hour Traffic Survey on Ikot-Ekpene/Umuahia (North)

Mon	Tue	Wed	Thu	Fri	Sat	Sun	AVERAGE (veh/hr)
			PASSENGER CAR				
3351	3298	3318	3322	3369	2789	1511	2994
			TRICYCLE				
1211	1085	1314	1227	1156	1103	608	1101
			HGV				
207	184	198	200	211	178	114	185

TABLE II
6 Hour Traffic Survey on Ikot-Ekpene/Umuahia (South)

Mon	Tue	Wed	Thu	Fri	Sat	Sun	AVERAGE (veh/hr)
			PASSENGER CAR				
3599	3546	3570	3566	3622	2998	1624	3218
			TRICYCLE				
1403	1258	1523	1374	1329	1230	707	1261
			HGV				
221	198	212	214	226	191	122	198

TABLE III
6 Hour Traffic Survey Anagha-Ezikpe Road (Right-Turn)

Mon	Tue	Wed	Thu	Fri	Sat	Sun	AVERAGE(veh/hr)
			PASSENGER CAR				
710	653	680	694	699	571	289	614
			TRICYCLE				
188	167	200	189	213	116	83	165
			HGV				
18	11	23	14	16	19	2	15

TABLE IV
6 HOUR TRAFFIC SURVEY ANAGHA-EZIKPE ROAD (LEFT-TURN)

Mon	Tue	Wed	Thu	Fri	Sat	Sun	AVERAGE (veh/hr)
			PASSENGER CAR				
1277	1256	1267	1187	1287	988	617	1126
			TRICYCLE				
346	337	328	303	361	211	114	286
			HGV				
27	29	36	18	23	29	16	25

TABLE V
ESTIMATED 16 HOUR TRAFFIC COUNT

	Passenger car	Tricycle	HGV
Ikot-Ekpene/Umuahia (North)	6737	2477	416
Ikot-Ekpene/Umuahia (South)	7241	2837	446
Anagha-Ezikpe road (right-turn)	1382	371	34
Anagha-Ezikpe road (left-turn)	2534	644	56

TABLE VI
ESTIMATED AADT FROM 16 HOUR TRAFFIC COUNT

	Passenger car	Tricycle	HGV
Ikot-Ekpene/Umuahia (North)	6663	2450	411
Ikot-Ekpene/Umuahia (South)	7161	2806	441
Anagha-Ezikpe road (right-turn)	1367	367	34
Anagha-Ezikpe road (left-turn)	2506	637	55

TABLE VII
PASSENGER CAR UNIT (PCU) EQUIVALENT OF THE AADT VOLUME (VEH/HR)

	Passenger car	Tricycle	HGV	Total
Ikot-Ekpene/Umuahia (North)	6663	1715	945	9323
Ikot-Ekpene/Umuahia (South)	7161	1964	1014	10139
Anagha-Ezikpe road (right-turn)	1367	257	78	1702
Anagha-Ezikpe road (left-turn)	2506	446	127	3079

B. Modelling of Isolated Signalized Intersection

Assumptions

a. There was a 70:30 directional split where the traffic phase suggests straight and turning movement.
b. There was a 25 m turning radius for left turning traffic, and 90 m turning radius (since there is none in actual sense) for right turning traffic.
c. The approaches were on a level profile; no positive or negative grades.

Saturation Flow

$$S_0 = 2080 - 42\delta_g G + 100(W - 3.25)$$
$$S_1 = \frac{(S_0 - 140\delta_n)}{\left(1 + \frac{1.5f}{r}\right)}$$

where: S_0 = the basic saturation flow of the lane allowing for width and grade, δ_g= set to zero if ground profile is level or downgrade; set to one if an upgrade, G = upgrade expressed as percentage, W = lane width in metres, S_1 = predicted saturation flow for lane allowing for all geometric variables and turn information, δ_n = set to one if a kerbside lane, otherwise set to zero, f= proportion of turning traffic, r= radius of turn in metres.

1) Ikot-Ekpene/Umuahia (North) PHASE A:

$$S_0 = 2080 - 42\times0\times0 + 100(2.75 - 3.25) = 2030\text{pcu/hr}$$
$$S_1 = \frac{(2030 - 140\times1.0)}{\left(1 + \frac{1.5\times0.7}{\infty}\right)} = 1890 pcu/hr$$

2) Ikot-Ekpene/Umuahia (North) PHASE C:

$$S_0 = 2080 - 42\times0\times0 + 100(2.75 - 3.25) = 2030\text{pcu/hr}$$
$$S_1 = \frac{(2030 - 140\times0)}{\left(1 + \frac{1.5\times0.3}{25}\right)} = 1994 pcu/hr$$

3) Ikot-Ekpene/Umuahia (South) PHASE B: For traffic moving straight

$$S_0 = 2080 - 42\times0\times0 + 100(5.5 - 3.25) = 2305\text{pcu/hr}$$
$$S_1 = \frac{(2305 - 140\times1.0)}{\left(1 + \frac{1.5\times0.7}{\infty}\right)} = 2165 pcu/hr$$

4) Ikot-Ekpene/Umuahia (South) PHASE B: For traffic turning right

$$S_0 = 2080 - 42\times0\times0 + 100(5.5 - 3.25) = 2305\text{pcu/hr}$$
$$S_1 = \frac{(2305 - 140\times1.0)}{\left(1 + \frac{1.5\times0.3}{90}\right)} = 2154 pcu/hr$$

Total for the entire PHASE B = (3) + (4) = 2165 + 2154 = 4319 pcu/hr.

5) Anagha-Ezikpe road PHASE D:

$$S_0 = 2080 - 42\times0\times0 + 100(5 - 3.25) = 2255\text{pcu/hr}$$
$$S_1 = \frac{(2255 - 140\times1.0)}{\left(1 + \frac{1.5\times1.0}{90}\right)} = 2080 pcu/hr$$

6) Anagha-Ezikpe road PHASE E:

$$S_0 = 2080 - 42\times0\times0 + 100(5 - 3.25) = 2255\text{pcu/hr}$$
$$S_1 = \frac{(2255 - 140\times0)}{\left(1 + \frac{1.5\times1.0}{25}\right)} = 2127 pcu/hr$$

The saturation flow, s and demand (arrival) flow, q are tabulated as in Table VIII.

TABLE VIII
ARRIVAL AND SATURATION FLOWS FOR ALL TRAFFIC STREAMS

STREAM	Arrival Flow, q (PCU/hr)	Saturation Flow, s (PCU/hr)	Ratio of Flows (q:s)
A	6526	1890	3.453
B	2797	1994	1.403
C	10139	4319	2.348
D	1702	2080	0.818
E	3079	2127	1.448

From Table VIII, it could be seen that arrival flow surpasses the saturation flow, greatly; saturation flow being the number of vehicles that could cross the stop line in one hour, if the signal display remains green. It is safe to conclude that the traffic signals do not efficiently solve the problem of traffic delays, considering the fact that traffic signals adopt a time-based assignment of right-of-way. If we assume that for each hour, a particular stream is given right-of-way, following the definition of saturation flow; the signals would not be able to allow an uninterrupted flow for over one-third of the vehicle queued behind the stop line.

IX. Conclusion and Recommendation

In the light of the literature reviewed, and mixed methods adopted; this research work makes the following assertions:

1. The Ikot-Ekpene/Umuahia road is a federal trunk 'A' road, designed to provide mobility function; the very many developments generating trips, and the several intersections along the route, impedes the delivery of its design function.
2. At peak times; traffic volume increases immensely, speed, maneuverability, convenience, and comfort decreases, while travel time, interruption and traffic control intrusion increases. Therefore, the MOE, which suggests the extent to which the road delivers the needs/expectations of the road users, has negative outcomes.
3. At peak times, the road operates under LOS E; but as traffic flow dwindles, the LOS improves to C or D.
4. While it is possible for left turning traffic to safely and conveniently complete their maneuvers, because the entire width of Anagha-Ezikpe road (approx. 22 m, including kerbed-median set back by 4 m) introduced an arbitrary stop line, creating an ample turning radius; no turning radius was provided for the two right turning movements (absolutely 90º). Recall that the saturation flow model relies on radius of turning; this therefore, reduced the saturation flow values.
5. The lane width of the Ikot-Ekpene/Umuahia road is too small; a total of 11 m. This suggests that for traffic originating from the south arm, 5.5 m was provided; to cater for both straight and turning movements (though the stage sequence suggests they both run as a single phase). For traffic originating from the north arm; 2.75 m was effective width provided for each of the two traffic movements. This undermines the ability of traffic signals to discharge backlog of traffic upon gaining right-of-way; recall that the saturation flow model relies on lane width also.
6. If the Ratio of Flow and Capacity (RFC) taken as ratio of the arrival and saturation flows is something to go by; then the intersection is running under the state of "overcapacity".
7. The cause of the issue here is not entirely aged time plan; because the traffic signals were installed only about two years ago. However, poor road geometric design elements were appreciated as the primary cause of the delay. Secondly, the installation of the traffic signals was not duly justified considering the prevalent traffic volume.

The conclusions above would surely be of importance to the planning authorities in Abia State; to ensure that the untold delays along this route would be ameliorated. Secondly, this paper could form the bedrock of further research into the performance evaluation of priority-controlled intersections; possibly at priority-controlled intersections with higher demand flow. Further research would aid in generalizing the findings herein.

A better control of traffic would be achieved by installing a traffic rotary as an alternative measure in accordance with [6]. According [5], when the major street approaches dominate, as the case with the study intersection here; roundabout delay is lower than signal delay, particularly at the upper volume limit for single-lane approaches and when there are a relatively high proportion of left turns. However, when volumes have a 50:50 split between major and minor routes, the delay savings of roundabouts against traffic signals are especially notable on two-lane approaches with high left turn proportions (see Fig. 8).

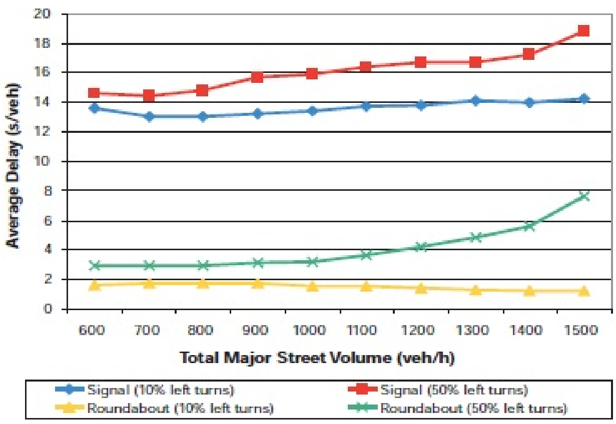

Fig. 8 Average delay per vehicle at major road of intersection [5]

Fig. 8 shows that at the major road of an intersection, with 10% left turns; the delay with roundabout is lower than that occurring with traffic signals. Conversely, at the major road of an intersection, with 50% left turns; the delay with roundabout is also lower than that occurring with traffic signals. There is, therefore, good evidence to suggest that a roundabout would perform better than traffic signals at the study intersection. However, roundabouts introduce geometric delays by virtue of the fact that the traffic island is designed to deflect travel path, and reduce travel speed; though, the delay here is arbitrary (road users often do not notice it), compared with the obvious delay of the traffic signals. Reference [3] suggested that below the threshold of 40,000 veh/day, roundabouts are better control measures; beyond this threshold, signalization could be a secondary measure.

Secondly, the roadway geometry of the lanes upstream of the intersection should be reconsidered for possible widening, though this should be a corollary action if the option of installation of Rotary Island is considered. The approaches must be flared for easy turning movements. Where land acquisition is not an issue, the right turning movement could be independent of the entire roundabout configuration; as with flower roundabouts [13]; see Fig. 9.

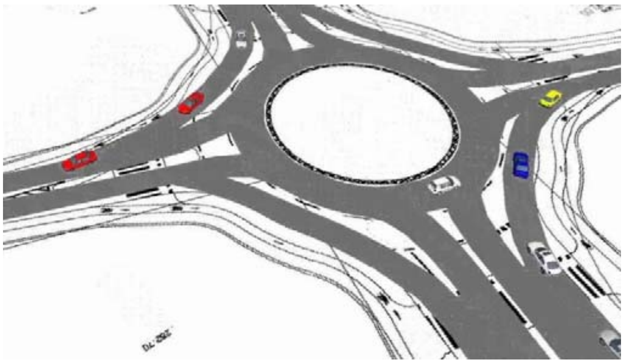

Fig. 9 Typical flower roundabout (showing segregated right-turn)

The issue of highway function would remain silent because there is little or nothing that can be done to salvage the situation.

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