A Performance Analysis of a Two Way Stop Control (TWSC) Intersection under Mixed Traffic Conditions

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Abstract- Intersections are road traffic infrastructure on highways installed to help settle directional movement that could result in conflict while vehicular trips are made. Evaluation of the challenges faced by different automobile users at the Araromi junction (A three Leg at-grade Intersection) located in Akure is the main objective of this paper. To achieve this objective, traffic flow data were collected on the spot by video recording and then the data were manually counted. While, the highway Capacity manual 2010 methodology was adopted to analyse The entry flow rates, Potential Capacities, Movement Capacities, Movement Control Delay, Approach Intersection Control and 95th Percentile Quene Length of the intersection. Findings shows that an average entry flow rate of 357 pc/h occurs for all the legs of the intersection, the North bound left turning movement of the intersection was not within the allowable limit, the average potential capacity by lane for the intersection is 445 pc/h, and the average movement capacity by lane 473 Pc/h, the various legs of the intersection has a level of service of 'A' and 'C' except the left turning minor street movement that has an 'F' LOS. Due to the influence of high traffic flow around the intersection, the analysis of the real-time traffic flow results reveals the need to diverge the high right turning movement into other route to cater for low left turning movement causing delay and poor LOS and a need to introduce Signal on the intersection in other to improve on her functionality.

Keywords: Entry Flow Rate, Turning Movement, Potential Capacity, Movement Capacity

1. Introduction

Congestion on the road network is a situation that occurs on a road transport system as a result of increased traffic, which in effect causes slow speed, increase queues, longer travel time and increased automobile fuel consumption and environmental pollution [1, 2]. As peak hourly demand on the road network increases this causes capacity to reduce thereby bottleneck are formed around intersections, these hourly demand affects driving operations around road traffic intersections causing a delay when the level of service of the intersection becomes poor [3]. An increase in commuters' delays at intersections reduces the level of service of the road user'. In Nigeria, some intersections are known to be very busy with several mixed traffic, the delay witnessed at these intersections at peak periods differs one from another, for multilane roads, at peak periods, lane discipline is a big problem causing the left turn movement to be hindered. This further creates a bottleneck on the road and subsequently reduces the road traffic capacity. Some previous studies had considered different variables such as delay, traffic density, queue length and volume to capacity ratio (V/C) for studying the performance of an Intersection. The measure of service quality that highlights the operational traffic characteristics and their perception by road users is known as the Level of Service (LOS). Measurement of this in Akure, Nigeria for various intersections has been carried out in the past by [4, 5, 6], however, most of the research cited has not worked on the analysis of a three-leg Two Way Stop Control (TWSC) intersection located at the heart of the city of Akure. The entry flow rate, existing flow rate, the Level of Service (LOS), and Capacity of this Araromi junction using the Highway Capacity Manual 2010 (HCM) method was the major objective of this research work. Intersection study is mostly appreciated in appraising the competence and efficiency of the control measure used in the distribution of traffic in an intersection.

2. Literature Review

Most prior research had considered different variable quantities to appraise the performance of a traffic intersection such as the waiting time of the vehicle in queue per vehicle to be serviced by the intersection [7], the minimum response time of vehicles in Queue at an urban signalized intersection [8], vehicle to the capacity analysis of an un-signalized junction with mixed traffic circumstances [9] estimation of capacity within an un-signalized junction under mixed traffic flow conditions [10] comparison based on the capacity of both a signalized and an un-signalized intersection under a mixed traffic stream network [11] critical flow analysis of intersection in a mixed traffic condition at a roundabout intersection [6], Microscopic detailed analysis of un-signalized intersections in multiple Traffic flow conditions [12] are various research outputs that had been carried out to study flow at intersections around the world.

2.1 Traffic Parameters in a Two-Way Stop (TWSC) Intersection

Knowledge of the traffic parameters, like speed, the composition of traffic, the issue of gap acceptance, and the number of conflicting points at the microscopic level, are important for the development of the performance appraisal of the TWSC models. The appraised parameters will help to assess the facilities concerning safety. Several studies have focus mainly on microscopic traffic level characteristics in different types of intersection facilities in more developed countries [12]. Some authors have been able to share few related works on various urban roads having both signalized and un-signalized intersections like in a work carried out by [13] in which they focused on road segments based on the drivers' speed choice and his interactions with other road user's. In a related work by [14] a stronger relationship has been observed between speed reported by drivers and the observed speed taken by the use of Rader, this study also find out that the speed of drivers is sometimes based on the behaviour of other drivers, although the drivers been knowledgeable about their speed in a particular place at a time, they seem to have an unfair awareness of the level of speed generally around them. Wolferman, Alhajyaseen, & Nakamura, (2011) find out that speed profiles on vehicular entry point area (i.e Intersection) and position of the vehicle and vehicle speed are sensitive to the driver at the beginning and end of manoeuvre, their work went further to use empirical data of automobile routes that were obtained at a signalized intersection in a city in Japan which produce a stochastic profile of speed from left-and-right turning, free-flowing movement. Doecke, Wolley, & MacKenzie, (2011) developed a guideline for transport authorities after studying the sequence a vehicle takes when it is in collision part with a another vehicle at a road intersection in a rural community. Viti, Hoogendoorn, Van Zuylen, Wilmink, & Van Arem, (2008) realized that vehicle trajectories are few meters away from where the stop sign normally occurs . Xu & Tian, (2008) worked on microscopic data which looked into the turning effect and gap acceptance behaviours of drivers. They observed that the presence of pedestrians in and around intersections has a great impact on the left turning movement of vehicles. Other studies that have worked on the traffic parameters in a two way stop intersection includes [15, 16]. Some other studies have looked into a different type of traffic parameters such as conflicting points, pedestrian trajectories, vehicle trajectories, acceptability of gap in bad weather condition [17] and lane usage in developing countries. The importance of these parameters for geometric design and evaluation of an un-signalized intersection cannot be overemphasis.

2.2 Flow Rate and the Influence on Level of Service (LOS) and Capacity

Traffic Flow occurs mostly at intersections, with many road users including drivers and passengers moving from one place to another and using the intersection as a connecting point for them to manoeuvre from one directional axis to another. Flows are generated from automobile movement from streets and along highways. Flows can also be generated from bicycles' movement on a corridor, it can also be generated due to pedestrians' movement in stations, parks, shopping malls, and traffic flows are generated close to intersections due to pedestrian crossings, these flows occur any time of day, and flows are normally at its peak during the rush hour of the day [18]. Different kinds of flow exist in engineering practices but Traffic flows are typically different from other flows in various engineering areas like pipe flow and flow of electrons. Human decisions are the basics for Traffic flows to occur and to navigate through an intersection. There are guided rules/laws that are influenced by human behaviours to avoid vehicular crashes. Flow rates are expressed and measured in units per unit of time [18]. These units are units of cars, pedestrians, vessels, containers, and aircraft, depending on the flow rate of the transportation mode being considered. Flow rate is measured in units of vehicles per hour. Traffic movement is very intricate and complex and requires sound analysis to be able to determine information about vehicular movement in road traffic facilities. Measurements, modelling, and analysis of traffic flow phenomena are essential when estimating the capacities of transportation facilities and in making decisions for additional development and expansion of transport amenities [19]. When flow measurements and analysis are properly carried out then, the prediction and proper planning of transport facilities for upcoming queues at highways, and a better understanding of traffic flow circulation in space and time are well articulated [20]. Well-analysed flow measurements will help in proper estimation that can help solve problems associated with queue lengths, traffic density, level-of-service, capacity, and accomplishing activities which will help mitigate traffic congestion [21].

The Concept of Gap-Acceptance

Unsignalised intersections are of two (2) sorts, the Two-Way Stop-Controlled (TWSC) and All-Way Stop-Controlled (AWSC) and their operation are almost similar. Unsignalized intersection functions without any form of input or control by the driver except a positive gap or control is available for the drive to utilize (Troutbeck and Brilon, 1992). The behaviour of the drive to accept a gap created for him to enter and continue his movement is known as gap acceptance. For most instances, the oncoming vehicle approaching from the minor road waits for those in the major road to pass before navigating into the major street. The drive will reject small gaps that will cause a crash if accepted. This method, gives the assumptions that the drivers gives precedence to the right-of-way of the vehicle in the traffic flow to those on the major street in the traffic stream. Nevertheless, Brilon and Wu (2002) posited that gap-acceptance system possesses some shortcomings. One of such setback is that it did not consider the drivers behaviour, as touching priority rules. For instance, forced gap can be drivers who drives aggressively, while well-mannered behaved drivers, that intentionally offers gaps distinctively are not captured based on the priority rules. Prasetijo, (2007) observed that mixed traffic situations worsen traffic movement especially when the movement is one formed as a result heterogeneous movement of both vehicular and non-vehicular means of movement. Hence, another method known as the conflict technique is established to cater for short fall due to the gap-acceptance method, this method is recognised as the Additive Conflict Flow (ACF) method. Likewise, Wu (2000) detailed that some of the major parameters used when designing the intersections are the spread of number of lanes, the traffic flow rates, and the number of pedestrian which will use the intersection, and the flaring of the lane that cater for more vehicles. This conflict method helps in the intersection capacity study. It has been shown that it enhances the dependability of the unsignalized intersection processes used to measure the situation surrounding the intersection. Major factors considered when analysing the conflict technique is the occupation time, (tQ,b) which amounts for the time used by a vehicle when it occupy an area with conflict. Brilon and Wu (2002) describe the term (tQ,b,m) and (tQ,b,I) in an alternative manner to mean the time a vehicle occupies the area when known for conflict. Additional considered parameter in conflict technique is known as blocking time of the conflict area as a result of an oncoming vehicle, (tB,a). Some other researchers like Eisenman , Josselyn, & List, (2004); Vaiana, Gallelli, & Capiluppi, (2007); Joewono & Halimshah, (2012) have worked on gap accepatnce theory.

3. Methodology

Operational analysis for intersections based on the National Cooperative Highway Research Program (2010) was adopted. The process involves the capturing of projected peak turning movement of vehicles going through the intersection. It also considered the traffic peak data (i.e peak hour at 15-minute intervals) for measuring results. The collected traffic data should, to the greatest extent possible, reflect the current peak hour traffic conditions. Data for this work were collected 7.00 a.m. to 9.00 a.m. for peak morning time, 11.00 a.m. to 1.00 a.m. for afternoon time, and 3.00 p.m. to 5.00 p.m. for evening peak time. This data collection represents the start of official duty and the close of working hours in the city of Akure, where the data were sourced. On a conventional intersection, traffic volume data were collected by collection systems using field observatory and video footage recording method of traffic movement at each of the traffic leg.

Video footage courage methodology and Field Observation Methodology

For two weeks, real-time video recordings of the entire intersection were made. This was accomplished by mounting the camera on the story building directly opposite the understudied two way stop intersection and photographing all of the intersection legs from an elevated height of about 20 meters, this exercises was proceeded by measuring the traffic flow. The entry flow was measured first, leg after leg of each of the connecting route to the intersection than, booking of captured traffic flow was carried out in a sequential manner for each leg of the connecting road to the intersection this data were obtained from the pre-recorded videotape, after which the turning movement of the decisions of the automobile user's was also booked. The pre-recorded tape was played repeatedly so as to extract data for each leg differently. The inflow movement were extracted leg after leg and then, the existing flow and wavering pattern of decision of the automobile as they were served was booked. Eight trained field observers were paid to collect data at the intersection. Two (2) individuals were placed to collect data per leg, First person was in charge of entry flow and another collects data on the drivers' circulation/weaving decisions within the roundabout. Manually, the result was entered for bicycles, motorcycles, tricycles, passenger car, and articulated automobile into a real-time datasheet. In line with [18],

Flow (Qe) is expressed in pc/h,

Qe = Entry Flow

Pc/h = Passenger Car Unit Per Hour.

A technique used to regulate the inconsistency for demand flow rate during when peak hourly volume is measured is the Peak Hour Factor (PHF) this demand flow rate is what is adopted in analysing the performance of the intersection. Nicholas and Lester, (2002) defined it as flow when the highest peak of traffic occurs against peak flow rate throughout a certain period around the peak hour.

$$PHF = \frac{Hourly\ volume}{peak\ flow\ rate\ (within\ the\ peak\ hour)} \quad 1$$

$$PHF = \frac{V}{4\ .\ V15} \quad 2$$

Thus: PHF = peak-hour factor, V = Hourly Volume (vph) and, V_{15} = Volume during the Peak 15 min of the peak hour (veh/15 min).

Heavy vehicle adjustment factor, (FHV) is another very important factor considered when analysing traffic performance at intersections. This factor connects the fraction of heavy vehicles in the lane waiting to be served. The factor adjusts for delays due to decrease in saturation flow as a result of availability of heavy vehicle in the steam of traffic flow. This further interruption in over-saturation are due mainly as a result of the inconsistences generated by the operational capabilities of the heavy vehicle such as slow movement, time of response from such saturated passenger car equivalent and vehicle occupancy of the passenger's car. Heavy vehicle can be seen as automobile that has more wheels, i.e above four of its tires having contact with the surface of the road surface. Two (2) is the Passenger Car Equivalent (PCE) attached for various weighty vehicle [18]. To achieve demand flow, equation 3 is used:

$$up = \frac{V}{PHF.\ N.\ fHv.\ fp} \quad 3$$

Thus: up is the demand flow centred on equivalent base condition (pc/h/In); while, *V* is demand volume (veh/h); while, *PHF* is Peak Hour Factor; while, *N* number of lane; while, *fHV* is an adjustment factor of heavy vehicle; and finally, *fp* is an modification factor of unexperienced driver population.

Based on the HCM 2010 the heavy modification factor is thus given:

$$fHV = \frac{1}{1+PT.(ET-1)+PR(ER-1)} \quad 4$$

f_{HV} is the heavy vehicle adjustment factor; while P_T is the proportion of trucks and buses; while, P_R is the proportion of recreational vehicles; while, E_T is passenger car equivalent for trucks and buses in the traffic stream; and finally, E_R is PCE for recreational vehicles in the traffic stream.

4. Result and Discussion

The analysis of the two way stop control intersection based on Highway Capacity Manure methodology follows a process or better still, a set laid down rules after which the result for the entry flow rates, existing flow rates, Level of Service (LOS), control delay and capacity obtained where presented and informed discussion made.

Entry flow for each leg for a period of two hours subdivided into 15 minute periods in the morning, afternoon and evening before conversion into traffic flow rate of the TWSC intersection are presented in table 1, for the mixed traffic that made the approach of the intersection in the morning, afternoon and evening. It was observed that the morning flow rate were more than those of the afternoon and evening flow rate.

Table 1. *Vehicle flow from Araromi axis Left Turn (WB)*

	Morning Session				Afternoon Session				Evening Session			
Time	**Bikes**	**Cars**	**Buses**	**Truck**	**Bikes**	**Cars**	**Buses**	**Truck**	**Bikes**	**Cars**	**Buses**	**Truck**
00-14	55	46	4	0	24	28	0	0	40	30	2	0
15-29	70	69	2	0	30	18	0	1	47	48	2	1
30-44	88	70	3	0	19	22	1	0	21	33	2	0
45-00	114	87	7	0	30	18	2	0	44	33	2	1
00-14	89	80	3	1	29	25	1	0	41	34	3	0
15-29	67	76	2	0	44	21	1	0	51	26	2	1
30-44	63	61	3	1	51	19	2	0	45	33	1	2
45-00	59	43	1	1	73	37	0	0	41	30	0	1
	605	532	25	3	300	188	7	1	330	267	14	6

It was observed that the maximum flow occurs in the orning peak period for all the legs of the TWSC studied for this work. The figure 1 presents, average aggregate flow rate of the traffic that occurs at the intersection during one hour period. In order to verify the variability of the data set for the entry flow decision of the drivers via the TWSC intersection, the entry flow was plotted against the existing flow, this gives a strong R^2 of 0.9333 after the plot the graph in figure 2 shows this.

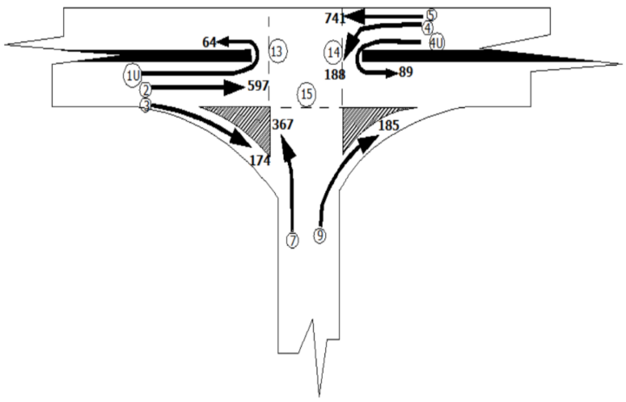

Fig 1. *Flow rate of the traffic at Araromi Intersection.*

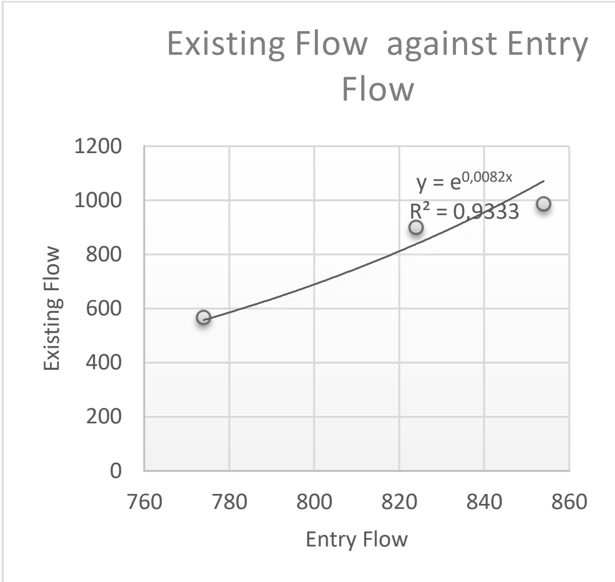

Fig 2. *Existing flow against Entry flow.*

It was likewise observed that the rate for Conflicting flow (V_c), Potential capacity (C_p), Movement capacity (C_m), Movement control delay (d), Approach intersection control (da) and 95th percentile queen length (Q_{95}) for the TWSC analysed are presented in table 2. From the result obtained, V_c, 7 which represent the northbound left turning has the highest conflicting flow, it also has the lowest potential capacity and movement capacity. The level of service of the turning is 'F' signifying poor movement control delay, its 95th percentile queen length is the highest, meaning that road user's trying to make movement through that turning are delayed more than it is necessary and the lane is operating at a very weak capacity. While it was observed that the V_c, 1u has the best conflicting flow of 541, potential capacity of 798, movement capacity of (Cm) 798, level of service 'A' with a good movement control delay of 9.9, it has the best approach intersection control of 0.76, and a Q_{95} percentile quene length of 0.3, which happens to be the best operating in the TWSC intersection considered for this analysis. Generally, the outcomes show that, although most minor movement are functioning at a very low to a restrained delays conditions, the minor movement towards the right turning movement to the Northbound (9) operates at a LOS C while the minor turning in the Left-turning movement (7) experiences high delays and operates at LOS F.

Table 2. *Tabular form of the Araromi TWSC intersection analysis.*

s/ no	No m	Conflicting flow rate	No m	Potential Capacities	Nom	Movement Capacities	No m	Movement Control Delay	No m	Approach Intersection Control	Nom	95th Percentile Queue Length
1	V_c, 4	771	C_p, 4	511	C_m,4	500	d1 u	9.9 A	d_a, EB	0.76	Q_{95},1 u	0.3
2	V_c, 9	386	C_p, 9	528	C_m,9	517	d4 +4	17.09 C	d_a, WB	4.65	Q_{95},4 +4u	2.63
3	V_c, 1u	541	C_p, 1u	798	C_m,1 u	798	d9	15.79 C	d_a, NB	599.67	Q_{95}, 9	1.6
4	V_c, 4u	438	C_p, 4u	910	C_m,4 u	821	d7	893.92 F			Q_{95}, 7	33.7
5	V_c,i ,7	809	C_p,i ,7	320	C_m,4 +4u	571						
6	V_c,i i,7	851	C_p,i i,7	348	C_m,7	70						
7	V_c, 7	1660	C_p, 7	145	C_m,i, 7	159						
8				445	C_m,ii, 7	342						
9					C_T	130						

Nom= Nomenclature, V_c=Conflicting flow, C_p = Potential Capacities, C_m= Movement Capacity, d = Movement Control Delay, d_a = Approach Intersection Control, Q_{95} = 95th Percentile Queue Length

5. Conclusion and Recommendations

The main focus of this work is aimed at the analysing a Two Way Stop Control (TWSC) Intersection under Mixed Traffic Conditions without the negative impeding forces of pedestrian, the study has shown that although two of the legs of the intersections is still functioning well, one of them had futile servicing output due to over-saturations. It is however, observed that the minor movement of northbound traffic right turn has been flowing well due to less impediment on the through movement of the west bound and the u-turning of the east bound movement. To improve on the quality of traffic flow on the minor leg impeded movement caused as a result of high flow from the major east bound movement, alternative junction should be created through which the heavy traffic on the minor lag can be eased. Such junctions as the stadium junctions in the metropolis which can help in its linkage can be improved on to cater for this excessive movement. The reasons why these junction is not utilised is because of the narrow nature of the linking route toward that junction. Another thing that could ease the over loaded traffic is by the provision of a functional signal in which the right calculations would have been assign to the waiting time from both the major and minor intersection. Although, this will increases the service time of the very good and functional legs but will also increase the service delay for the movement in the left turn direction of the minor leg. The Constraint faced by this work is in the area of using computerised tools for data collections because they are the recent tools/equipment best for traffic data collections. Example is the automated traffic count equipment. Traffic flow congestion and analysis prediction is the future for simulating traffic congestion with the help of Artificial Neural Network (ANN).

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Conflict of Interest

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