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An Evaluation of the Operation of a Fixed-Time Signalization Scheme for a Four Leg Intersection in Ilorin Metropolis, Nigeria

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Abstract: The study reports the assessment of the performance of the signalisation scheme at an urban intersection with the purpose of reviewing for better and effective management of the junction delays. Maraba intersection in Ilorin metropolis, Nigeria, is a 4-legged traffic warden controlled intersection in a typical urban centre of a developing economy with the traffic operating at LOS F at each of the legs. As a result of the congestion at the intersection and in a bid to ameliorate the frustration experienced by motorists at the intersection, a fixed-time traffic signalization was installed at the intersection to replace the manual traffic warden controlled signalization. It was however noticed that the congestion experienced at the intersection has become worse despite the introduction of the fixed-time signalization. A 4-phase fixed-time traffic signalization was therefore proposed to replace the present 5-phase signalization, which if implemented will improve the level of service to D. It was consequently recommended that to achieve the new level of service, the intersection should be redesigned by increasing the number of lanes from the existing 2 to 3 for two of the legs while the only approach with a single lane should be increased to 2 lanes.

Keywords: Critical flow ratio, fixed time signalization, intersection congestion, traffic warden controlled

INTRODUCTION

The prevalent method of controlling traffic at intersections in both medium and small size urban cities, such as a state capital in developing countries like Nigeria is the use of human traffic wardens whose operations have been characterised and found to be comparable to the automatic signalization for Minna, Niger State (Ndoke, 2006) and cost-effective for Ilorin, Kwara State (Adeleke and Jimoh, 2011). In the case of the latter, only 3 of the 37 intersections studied were not traffic warden controlled. However, a major handicap with the traffic warden controlled signalization, especially at multi-legged intersections, is the introduction of many signal phases when it is most convenient to assign exclusive separate movement phases to each traffic leg and the turning manoeuvres; which ultimately would result to higher number of phases than the bench marked number for optimised efficiency (Federal Highway Administration, 2009).

There are three distinct movement patterns that are probable at each leg of an intersection, the right turning-, the through-and the left turning traffic (RT, TT and LT). It is only the LT and TT traffic that significantly contribute to safety challenges at the intersections as a result of conflicts of movement at the space sharing intersection. The RT movements are free from interference from the other two movements (TT and LT) for a right hand side driving practice. Besides the human element and bias often exhibi table by the traffic wardens, in-effectiveness in operation and unsafe control at the intersections are also possible '(Adeleke, 2010). Hence in recent times, automatic traffic signalization control was introduced by the traffic managers at the major intersections on the first and second priority arterials in Ilorin, Nigeria. Maraba intersection was among the intersections considered where traffic congestion must be ameliorated to ensure the desirable socio economic working of the urban city.

It was however observed by the commuters (including the authors) who frequently ply the routes that the introduction of the traffic signal at Maraba intersection has not improved the traffic flow or the operational level of service at the intersection. The commuters continue to be burdened with the growing congestion. Consequently, the study was carried out to evaluate the level of service, identify the militating problems at the intersection with the view of designing improvement strategies for a better service from the signalization.
The objectives of the study were:

- Establishment of operating characteristics of the traffic signalization at Maraba intersection, such as the signal timing/phases, etc.
- Identification of critical lane groups based on the prevailing flow ratios
- Designing an alternative for more effective and efficient traffic control at the intersection

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Table 1: Traffic volume-amilegbe approach

Day	Left turn movement					Through movement					Right turn movement				
	Car	Bus	Luxurious bus	Truck	Motor cycle	Car	Bus	Luxurious bus	Truck	Motor cycle	Car	Bus	Luxurious bus	Truck	Motor cycle
Monday	5891	1191	12	0	1527	851	20	0	60	645	1782	31	0	18	1636
Tuesday	5900	1391	0	154	1418	856	22	0	16	623	2226	21	0	10	1667
Wednesday	5899	1279	0	148	1420	880	18	0	24	614	2039	19	0	14	1684
Thursday	5721	1191	6	150	1423	799	14	0	14	741	1984	22	0	24	1383
Friday	5734	1220	0	194	1486	609	21	0	40	595	2165	27	0	16	1571
Saturday	5619	1039	15	146	1375	874	20	0	22	581	2218	24	0	42	1477
Sunday	5405	1130	3	104	1551	966	22	0	60	628	2495	38	9	36	1278

Left turn movement: Amilegbe-Sango; Through movement: Amilegbe-Sabo Oke; Right turn movement: Amilegbe-Post office

Table 2: Traffic volume-sango

Day	Left turn movement					Through movement					Right turn movement				
	Car	Bus	Luxurious bus	Truck	Motor cycle	Car	Bus	Luxurious bus	Truck	Motor cycle	Car	Bus	Luxurious bus	Truck	Motor cycle
Monday	434	17	0	33	461	4753	257	0	148	1384	4896	1261	0	298	2187
Tuesday	400	12	0	16	86	4897	293	9	180	1424	4949	1082	3	106	1809
Wednesday	411	6	0	14	98	5149	356	0	138	1345	4656	1199	15	250	1870
Thursday	403	10	0	14	89	5030	254	0	118	1368	4840	1287	0	204	1994
Friday	263	9	0	16	70	4787	274	0	110	1213	5075	1046	0	144	2008
Saturday	397	28	0	6	88	4570	208	0	110	1223	4929	1163	0	346	1887
Sunday	598	6	3	0	110	6133	155	6	100	869	4225	1125	12	152	1674

Left turn movement: Sango-Sabo Oke; Through movement: Sango-Post Office; Right turn movement: Sango-Amilegbe

Table 3: Traffic volume-sabo oke approach

Day	Left turn movement					Through movement					Right turn movement				
	Car	Bus	Luxurious bus	Truck	Motor cycle	Car	Bus	Luxurious bus	Truck	Motor cycle	Car	Bus	Luxurious bus	Truck	Motor cycle
Monday	160	2	0	0	77	1179	59	0	52	607	1896	62	0	16	288
Tuesday	192	9	0	0	84	1194	52	0	40	617	1672	61	0	22	307
Wednesday	157	8	0	0	84	1205	67	9	70	548	1576	59	0	22	265
Thursday	0	0	0	0	0	1159	49	0	36	639	1816	48	0	14	306
Friday	148	6	0	0	94	1204	72	9	80	580	1583	54	0	4	277
Saturday	1455	34	0	38	827	4309	102	0	168	731	185	0	0	0	116
Sunday	345	8	3	0	123	891	48	0	56	589	680	21	0	42	335

Left turn movement: Sabo Oke-Post office; Through movement: Sabo Oke-Amilegbe; Right turn movement: Sabo Oke-Sango

Table 4: Traffic volume-post office approach

Day	Left turn movement					Through movement					Right turn movement				
	Car	Bus	Luxurious bus	Truck	Motor cycle	Car	Bus	Luxurious bus	Truck	Motor cycle	Car	Bus	Luxurious bus	Truck	Motor cycle
Monday	1441	36	0	38	1018	3785	106	3	136	870	149	0	0	0	100
Tuesday	1386	36	0	38	1040	3770	179	3	118	958	137	3	0	2	111
Wednesday	1354	33	0	28	820	4129	108	0	128	925	178	5	0	0	117
Thursday	1249	30	0	32	821	3329	88	0	74	1198	172	0	0	0	79
Friday	1268	42	0	20	1040	4261	119	0	116	845	141	0	0	0	145
Saturday	285	8	0	2	94	1265	53	0	34	604	1392	57	0	26	382
Sunday	1980	44	0	2	187	5508	264	0	100	804	437	18	0	12	209

Left turn movement: Post office-Amilegbe; Through movement: Post Office-Sango; Right turn movement: Post Office-Sabo Oke

Table 5: Peak hour traffic volume, timing and movement at Maraba

Approach	Day and time		Vehicle movement pattern			Total hourly volume (pcu/hr)
			LT	RT	TT	
Amilegbe	Tue	8-9 am	829	450	164	1443
Sabo oke	Sat	10-11 am	202	42	519	763
Post office	Sun	6-7 pm	220	60	619	986
Sango	Mon	10-11 am	68	823	689	1580

LT: Left turn traffic; RT: Right turn traffic; TT: Through traffic

MATERIALS AND METHODS

Project area description: Maraba intersection is located on the first priority arterial (Spencer *et al*., 1982) and as modified by Adeleke (2010) because it connects the township with a number of priority services of educational institutions (e.g., Kwara State Polytechnics), health institution (University of Ilorin Teaching Hospital (UITH)) and the Nigerian National Petroleum Corporation (NNPC) petroleum depot, Okeoyi. Ilorin metropolis is a typical medium size urban, administrative and political headquarters of Kwara State, one of the 36 states in a developing economy of Nigeria. The intersection is four-legged with three of the approaches dualised. The approaches include Post office, Sango, Amilegbe and Sabo Oke; Sabo Oke being the only approach not

Table 6: Saturation flow rate computation

Approach	So	N	f_w	f_{HV}	f_g	f_p	f_{bb}	f_a	f_{RT}	f_{LT}	S
Amilegbe	1900	2	1	0.982	0.99	1	1	0.99	0.70	0.97	2483
Post office	1900	2	1	0.998	0.99	1	1	0.99	0.94	0.99	3431
Sabo oke	1900	1	1	0.977	0.99	1	1	0.99	0.95	0.99	1711
Sango	1900	2	1	0.98	0.99	1	1	0.99	0.56	1	2044

dualised. The intersection is located in a business district area and adjoined by a public transit park for the intra-and inter-city journeys from Ilorin to the northern part of the nation.

Data collection and analysis: Observatory method of data collection was used to determine the following characteristics:

- Prevailing Level of Service (LOS) at the intersection
- Existing signal phasing, cycle length and identification of critical lane groups
- New signal phase design parameters
- Checks to ascertain the appropriateness of the designed signal timing in relation to the HCM specified LOS criteria.

Traffic count and analysis: A 12 h (7 am to 7 pm) classified traffic count, junction origin and destination (O&D) survey and signal phasing studies were conducted for 7 consecutive days in the month of July 2011 with 3 observers at each approach leg. The acquired data were used for the determination of the prevailing traffic volume trend, peak hour timings and flow rate, movement patterns and the traffic signalization characteristics. The outcome is summarised in Table 1-4 for Amilegbe, Sango, Sabo Oke and Post Office legs respectively. Five different vehicle (carrier) types were observed at the intersection; motorcycles, passenger cars, mini/midi buses (12-18 passengers capacity), buses and heavy goods trucks. The traffic movement scenario at a peak period for a typical day of the week and corresponding time of occurrence were analysed and summarised in Table 5. The maximum hourly volumes, as well as the flow movement scenarios were considered and used to derive the critical values of the flow ratio (v/s ratio) for the lane groups in each signal phase and for each approach. The critical lane groups were subsequently identified and used to evaluate the adequacy or otherwise of the existing signal phasing scheme. The data were also employed to design an improvement of traffic control at the intersection. Figure 1 is the schematic diagram of the intersection and the traffic movement patterns at a typical daily peak hour on the intersection.

The saturation flow rate for each of the approaches was obtained using the Highway Capacity Manual model shown in Eq. (1) (Highway Capacity Manual, 2000). The results are summarised in Table 6.

$$S = S_O\, N\, f_w\, f_{HV}\, f_g\, f_p\, f_{bb}\, f_a\, f_{RT}\, f_{LT} \quad (1)$$

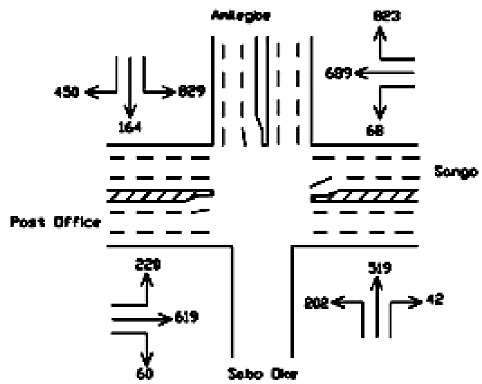

Fig. 1:Intersection layout and critical volumes

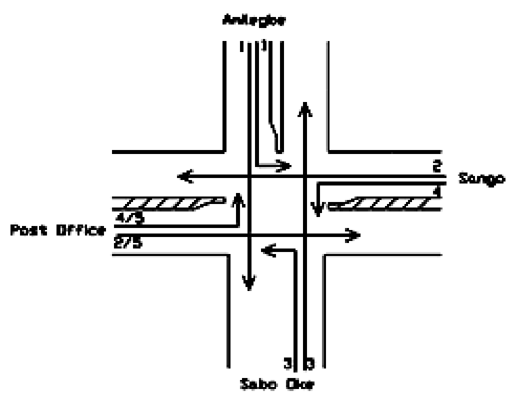

Fig. 2: Existing phase diagran

where,

- S = Total saturation flow rate for lane group (vphg)
- S_o = Ideal saturation flow rate per lane (pcphgpl), usually taken to be 1900 pcphgpl
- N = Number of lanes in the lane group
- f_w = Adjustment factor for lane group
- f_{HV} = Adjustment factor for heavy vehicle presence
- f_g = Adjustment factor for grade
- f_p = Adjustment factor for parking conditions
- f_{bb} = Adjustment factor for local bus blockage
- f_a = Adjustment factor for area type
- f_{RT} = Adjustment factor for right turning vehicles
- f_{LT} = Adjustment factor for left turning vehicles

Determination of critical lane groups and existing signal phasing: During any green signal phase, several lane groups on one or more approaches are permitted to

Table 7: Signal phase, actual capacity and group lanes of maraba intersection ilorin

Phase	Movt	Critical volume (max hourly volume)(v)	Saturation flow rate(s)	Flow ratio (v/s)	Flow ratio for critical lane group$(v/s)_{cr}$	Existing green time	g/C	c = sg/C capacity of lane group	Remarks
1	Left turning movt from amilegbe approach	829	2483	0.334	0.334	45	0.243	604	Not OK/ over saturated
	Through traffic from amilegbe	164	2483	0.066				604	
2	Through traffic from sango	689	2044	0.337	0.337	40	0.216	442	Not OK/ over saturated
	Through traffic from post office	619	3431	0.180				742	
3	LT from sabo Oke	202	1711	0.118	0.303	40	0.216	370	Not OK/ over saturated
	Through traffic from sabo oke	519	1711	0.303				370	
4	LT from post office	220	3431	0.064	0.064	20	0.108	371	OK/ under saturated
	LT from sango	68	2044	0.033				221	
5	LT from post office	220	3431	0.064	0.180	40	0.216	742	OK/ under saturated
	Through from post office	619	3431	0.18				742	

move, the lane group with the most intense traffic is considered as the critical lane. The critical lane groups obtained for the study by comparing the flow ratio (v/s) of each lane group, (McShane *et al*., 1998) during a typical peak period are summarised in Table 7.

There were five signal phases at the intersection as displayed in Fig. 2 and shown in Table 7. The actual capacity (c) of each lane group was compared with the corresponding critical volume to determine whether or not the capacity of the lane group can accommodate the maximum hourly volume (Table 6). The comparison shows that:

- In Phase 1, the left turn movement has a volume greater than the capacity of the lane group
- Phase 2, all the movements have higher traffic volume than the actual capacity
- Phase 3, the capacity is inadequate for the through traffic flow

Evaluation of existing signal timings at the intersection: The signalised intersection has a Cycle length (C) of 185 sec. The critical lane group flow ratio $(v/s)_{cr}$ in each phase was identified, summed up and used for the evaluation of the operational efficiency of the traffic signalization. If the sum of the critical lane group, $\sum (v/s)_{cr}$ is greater than 1.00, then the intersection is deficient in providing sufficient capacity for the anticipated or existing critical lane group flows (McShane *et al*., 1998); either in the facility geometry, phase plan or cycle length specified. The flow ratios for the critical lane groups gave a summation of 1.218 confirming the inadequacy of the signalised control at the Maraba intersection. Since $\sum v/s_{cri}$ value of 1.218 › 1.0, the geometry is inadequate. A more efficient phase plan and addition of lanes to critical lane groups would be necessary to remedy the situation.

Table 8: Experienced delay and LOS at the intersection for a cycle of operation

Phase	g	c	X	d_1	d_2	PF	d (sec)	LOS
1	45	604	1.37	105	177	1	282	F
2	40	442	1.56	86	263	1	349	F
3	40	370	1.40	82	196	1	278	F
4	20	371	0.59	79	191	1	270	F
5	40	742	0.83	69	87	1	156	F

Determining existing level of service: In order to determine the LOS at the intersection, the control delay (d) at the intersection was computed using Eq. (2) to (4) (Highway Capacity Manual, 1994). The results are shown in Table 8.

$$d = (d_1 * PF) + d_2 + d_3 \tag{2}$$

$$d_1 = \frac{\left[0.5 * C\left(1-\frac{g}{C}\right)^2\right]}{1-\left(\frac{g}{C}\right)\left[Min(X,1.0)\right]} \tag{3}$$

and

$$d_2 = 900T\left[(X-1)+\sqrt{(X-1)^2+\frac{8kIX}{cT}}\right] \tag{4}$$

where,

d_1 = Average delay per vehicle due to uniform arrivals in sec/veh
d_2 = Average delay per vehicle due to random arrivals in seconds
d_3 = Residual delay, sec/veh, accounts for oversaturation queues that may have existed prior to the analysis period

Table 9: Start-up lost time for cycle 1

Cycle 1		
Vehicles in platoon	vehicle headway (sec)	vehicle headway-1.86
1	2.30	0.44
2	2.08	0.22
3	2.30	0.44
4	2.12	0.26

Start up lost time: 1.36 sec

Table 10: Observed clearance lost time for various cycles

Cycle	1	2	3	4	5	6	7	8	9	10
Clearance lost time (sec)	1.20	1.24	1.25	1.51	1.36	1.54	1.85	1.50	1.36	1.26

C = Cycle length in seconds
g = Effective green time for lane group in seconds
X = Volume Capacity (v/c) ratio for lane group
T = Duration of analysis period in h
K = Delay adjustment factor that is dependent on signal control mode
I = Upstream filtering/metering adjustment factor
c = lane group capacity, in veh/hr
PF = progression factor

For pre-timed control and for situation where there is no initial queue at the beginning of the analysis period, PF = 1.0, K = 0.5, i = 1.0, $d_3 = 0$.

Determination of signalization operational start-up and clearance lost times: The necessary signal design and operational properties include the saturation headway, start-up lost time and clearance lost times which were determined for the study intersection. The saturation headway (h) was determined by observing the time headway (h) of 10 vehicles in the traffic queue. It was however noticed that the observed headways did not become constant after the first four or five vehicles as expected for a traffic platoon at a signalised intersection. The headway was therefore observed over 10 cycles of signal operation and the average headway of 1.86 sec for all the vehicles in the 10 cycles adopted as the saturation headway. This value of (h) was used to compute the start-up lost time from the headway of the first four vehicles on each platoon of the 10 cycles. The resulting start-up lost time for cycle 1 is shown in Table 9 while those for other cycles were similarly determined. The average start-up lost time (l_1) for all the 10 cycles gave a value of 2.54 sec as shown in Eq. (5):

Average Start up lost time for the 10 cycles =

$$(1.36+2.19+5.56+3.84+2.68+1.22+1.15+2.57+2.27+2.52)/10 \quad (5)$$
$$=25.36/10$$
$$=2.54 \text{ sec}$$

Observed clearance lost time is shown in Table 10. The average observed clearance lost time (l_2) is 1.41 sec. Thus the total lost time (L) is given as:

Table 11: Summary of the proposed and existing saturation flows

Approach	Existing saturation flow (pcphgl)	Proposed saturation flow (pcphgl)
Sango	2044	3066
Amilegbe	2483	3725
Post office	3431	3431
Sabo oke	1711	3422

L = 2.54+1.41 = 3.95 sec, approximately 4 sec

DISCUSSION OF RESULTS AND THE NEED FOR A REDESIGN

Observations: It was obvious from the preceding portions of the paper that the traffic signal scheme at Maraba junction, Ilorin is not efficient. There was in operation a five signal phasing scheme. The volume capacity ratio was greater than 1 for three of the phases and with all the phases experiencing level of service F. The frustration being experienced by commuters at the junction seems justified. It can therefore be speculated that the plan of the signal abnitio was not driven by the traffic operational characteristics. Hence, improvement strategies must be examined in any or all of the three sub components of a transportation system; the vehicles (carrier), the fixed facility and the operational characteristics (traffic control). The geometry of the fixed facility and operation (traffic control) aspects were considered together in the analysis in order to maximise the benefits derivable from the design.

Evaluation of existing geometry of maraba intersection: Sango approach with a road width of 10.73 m has 2 lanes in use. Amilegbe approach with a road width of 10.33 m has 2 lanes in use. The Post Office approach with a width of 9.5 m has 2 lanes in use while Sabo Oke, with a width of 7.3 m has 1 lane in use. From earlier analysis, it was found that $\sum v/s_{cri} > 1$ for the intersection. A suitable geometric design was therefore proposed so as to have a $\sum v/s_{cri} < 1$ for all the phases. A better phasing plan and optimum cycle length were also tried so as to handle the demand flows and reduce the delays, respectively.

This involved the addition of one lane to three of the approaches (i.e., Sango approach, Amilegbe approach and Sabo Oke approach) with critical lane groups as follows: Sango approach-3 lanes; Amilegbe approach-3 lanes; Sabo Oke approach-2 lanes. Post Office approach maintains 2 lanes because of the high density of physical development, the cost of demolition of which would be enormous. The saturation flow of the proposed geometric design was computed Eq. (1) and results is summarised in Table 11.

Design of proposed phase plan: A 4-phase plan was proposed to replace the existing 5-phase plan with the analysis as shown in Table 12.

From Table 12, the sum of the critical flow ratios for the new phase plan is given by:

Table 12: Signal phase, actual capacity and group lanes

Phase	Movt	Critical volume (max hourly volume)(v)	Saturation flow rate(s)	Flow ratio (v/s)	Flow ratio for critical lane group$(v/s)_{cr}$	Proposed green time	g/C	C = sg/C capacity oflane group	Remarks
1	Through traffic from sango	689	3066	0.225	0.225	24	0.279	855	OK/ under saturated
	Through traffic from post office	619	3431	0.180				957	
2	Through traffic from amilegbe	164	3725	0.044	0.152	16	0.186	692	OK/ under saturated
	Through traffic from sabo oke	519	3422	0.152				636	
3	LT from amilegbe	829	3725	0.223	0.223	23	0.267	994	OK/ under saturated
	LT from sabo oke	202	3422	0.059				913	
4	LT from post office	220	3431	0.064	0.064	7	0.081	277	OK/ under saturated
	LT from sango	68	3066	0.022				248	

Y = 0.225 + 0.152 + 0.223 + 0.064 = 0.664.
Since = 0.664 ‹ 1, it implies that the proposed intersection geometry is adequate.

Determination of optimum cycle length and signal settings: The main consideration in selecting cycle length should be that the least delay is caused to the traffic passing through the intersection. The optimum cycle length (C_o) proposed is obtained using Eq. (6) (Kadiyali, 2005):

$$C_o = (1.5L+5) /1-Y \text{ sec} \quad (6)$$

where,

C_o = Optimum cycle length (sec)
L = Total lost time per cycle (sec)
Y = $y_1 + y_2 + y_n$

and y_1, y_2,...,y_n are the critical flow ratio for phases 1,2,...,n, thus with L = 16 sec and Y = 0.664:

$$C_o = (1.5*16+5)/1-0.664 = 86 \text{ sec}$$

The critical v/c ratio for the intersection (X_c) for proposed phase is given as:

$$X_c = \sum(v/s)_{cri}*(C_o/C_o-L) \quad (7)$$

where,

C_o = Optimum cycle length
L = Total lost time

Thus X_c = 0.664*86/(86-16) = 0.82.

Allocation of green time to each phase is obtained from Eq. (8) and the result shown in Table 13.

$$g = v/s_{cri}*C/ X_c \quad (8)$$

Table 13: Summary of timings of proposed signalization scheme

Phase	1	2	3	4
Green time (sec)	24	16	23	7
Total lost time (sec)	16			
Cycle length (sec)	86			

Table 14: Level of service in terms of delay for proposed phase plan

Phase	v/s_{cr}	v	g	c	X	d_1	d_2	PF	d (sec)	LOS
1	0.225	689	24	855	0.81	28.9	8	1	37	D
2	0.152	519	16	636	0.82	33.6	11.3	1	44.9	D
3	0.223	829	23	994	0.83	29.6	8	1	37.6	D
4	0.064	220	7	277	0.79	38.77	20	1	59	E

Cycle Length, Co = g1 + g2 + g3 + g4 + L = 86 sec
= 24 + 16 + 23 + 7 + 16 = 86 sec

Table 13 gives the summary of the proposed design parameters.

Appraisal of appropriateness of the proposed signal phasing: Comparison of the road capacity (c) with the critical maximum hourly flow (v) in each phase movements in Table 14 shows that the proposed phase plan is better than the earlier or existing operation. The new level of service is D (Table 14) as against the F now existing (Table 8).

CONCLUSION AND RECOMMENDATIONS

The automatic traffic signal scheme operating at Maraba intersection, one of the intersections on the first priority arterial in Ilorin, Nigeria was evaluated with following conclusions and recommendation:

- The signalised traffic control operate at a five phasing scheme with a cycle length, average start up and lost time per phase of 120, 2.54 and 4.0 sec, respectively
- The existing traffic signal operation is inadequate because the junction delays at all the four approaches indicated LOS F at peak period

- The sum of the existing critical flow ratio in each of the five phases is greater than one which implied that the intersection geometry is inadequate
- There was the strong need to redesign the junction for a more efficient traffic control at the intersection.

Consequently,

- A 4-phase traffic signal control scheme with an optimum cycle length of 86 sec should be used at the intersection for an enhanced LOS D to operate
- The addition of one lane each to Amilegbe, Sango and Sabo-Oke approaches is recommended while
- Further studies should be carried out on the signalization schemes in use in other intersections in the metropolis.

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