INVESTIGATIONS INTO THE OPERATIONAL PERFORMANCE OF IBRAHIM TAIWO-CIVIC CENTER SIGNALIZED INTERSECTION, KANO STATE

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Abstract: The study is to investigate the operational performance of Ibrahim Taiwo-Civic Center Signalized Intersection and this was achieved through determination of operational traffic volume, establishment of performance parameters and lastly suggesting appropriate measures that would improve the general performance of the intersection under study. Observatory manual method was used to collect the relevant data and Highway Capacity Manual 2000 equations were used to analyze the set data's. After analyzing the relevant data, the following conclusions were drawn; Ibrahim Taiwo approach possessed the highest value of traffic flow followed by Isyaka Rabiu and lastly Civic Center which tends to have the lowest value. But regarding the control delay, Civic Center approach possessed the highest value of 185 secs followed by Ibrahim Taiwo which possessed 65 secs and Isyaka Rabiu having the lowest value of 48 secs. These results clearly shows that the efficiency and smooth flow of traffic is always associated with adequacy of intersection geometric layout.

Keywords: Signalized intersection, operational performance, traffic volume, congestion, delay

Introduction

In recent urban transportation systems, signalized intersections are one of the essential elements that facilitate smooth flow of traffic at junctions and it allows the passage of heavy traffic with relatively low frictions (Kumar and Ranjitha, 2013). However, during peak hour period the carrying capacity of the facility may be inadequate due to increase in traffic demand by the motorists and pedestrian. With regards to these effects, the facility needs to be examining thoroughly in order to devise a better way of improving its performance. The main objective of transportation engineering is basically to provide a system that could operate at a condition satisfactorily to the users (Garber and Hoel, 2010).

Urban traffic congestion is currently the challenge in most cities in the world due to rapid increase in economic and social development. Our country Nigeria is one of developing state in the world and has been facing such difficulties for years. Generally, transportation system is affected by economic development which results in increase of vehicles on roads. This and other factors increase road congestion, especially during peak hours. Despite the intensive road network expansion and upgrade of intersection control systems in Kano state by state government, traffic congestion still remains the major problem in the city particularly at intersections. The Intersection under study is among the busiest Intersections located in the Central Business District (CBD) of Kano Metropolis. At peak hours of the day, the Intersection usually experienced traffic gridlock where road users are always faced with difficulties such as excessive delay and subsequent reduction in its general performance. As such there is need to investigate the operational performance of the intersection using the current traffic flow. Hence the expected results obtained could be used to determine the operational parameters of the selected intersection.

The aim of this study is to investigate the operational performance of Ibrahim Taiwo/Civic Centre Signalized intersection, Kano State. And the following objectives were drawn;

i) To determine the operational traffic volume for the selected intersection.
ii) To establish the performance parameters of the intersection under study.
iii) To suggest the appropriate improvement measures if necessary.

Traffic congestion

As network of traffic is fully operational and usage keeps increasing in a geometric nature, thereby characterized by slower moving vehicles, longer travel times, increased queuing among others this phenomenon is called traffic congestion (Abdulhalim and Prasetijo, 2013). When the demand of traffic is increasing, the interactions between moving vehicles slows the speed of the traffic stream and therefore congestion will occur. As travel demand increases, the capacity of the intersections will consequently reduce thereby leading to the formation of traffic gridlock (Abojaradeh, 2014).

Capacity

The maximum hourly rate at which vehicular or pedestrian traffic negotiate a transverse point or uniform section of a roadway under prevailing roadway, traffic and control conditions is defined as a capacity of a roadway system (HCM, 2000). Capacity can be described as a situation where by a prevailing roadway, traffic and control conditions are reasonably efficient and constant for a given section of roadway. A change observed in the capacity of a facility will therefore lead to a change in the prevailing condition. The analysis of a signalized intersection capacity could be carried out solely by putting uniform traffic, roadway and control conditions into cognizance.

Saturation flow

Saturation flow rate of a traffic stream simply refers to the number of vehicles in traffic that enters an intersection approach during which the traffic signal indicates green for that approach and flow of vehicles continue without interruption (HCM, 2000).

Lost time

There are two types of lost time commonly experienced at a particular signalized intersection.

i) Start-up lost time
ii) Clearance lost time

i) **Start-up lost time**: Start-up lost time can be defined as the total incremental headways observed in the front lines vehicles. This can be represented in a mathematical expression as;

$$L_i = \sum t_i$$

Where: L_i = the start-up lost time (sec); t_i = the incremental headway for the i^{th} vehicles (sec)

ii) **Clearance lost time:** This is the period during which conflicting movements of traffic occur between the last vehicle entering an intersection from one approach and the onset of traffic signal while indicating green.

Delay

Highway Capacity Manual (2010) described delay as an additional time of travel usually experienced by drivers on a specific journey. And any delay associated or being influenced by the presence of traffic signal and conflicting traffic is said to be a control delay. There are certain elements that are responsible for this type of delay and these are effective-green time, lane group-capacity, cycle length and lane group-volume.

Level of service

According to Polson Area Transportation Plan (2010), level of service for a given intersection is a measure of drivers perception to parameters like travel time, number of stops, total number of stopped delay and delay caused by other vehicles at an intersection approach. These parameters however were developed by traffic engineers. A scale was provided to give a clear situation of perception of the drivers operating at a particular intersection. Level of service gave rise to a scale which helps in comparing one intersection with another and provides a platform for understanding irregularities while operating at an intersection. This scale shows a complete range of operating conditions. The scale ranges from A to F and is based on the ability of an intersection to accommodate the number of traffic using the facility (Polson Area Transportation Plan, 2010). Table 1 represents the signalized intersection level of service developed by control delay.

Table 1: Signalized intersection level of service

Level of Service	Control delay per vehicle (sec.)
A	< 10
B	10-20
C	20-35
D	35-50
E	50-80
F	> 80

Source: The Transportation Research Board's Highway Capacity Manual (2000)

Table 2: Conversion factors

Vehicle Categories	Equivalent Value in Passenger Car Unit (PCU) for Signalised Intersections
Passenger Car	1.0
Light goods vehicle	1.0
Truck	3.0
Bus	3.0
Auto-rick shaw/Tricycle	0.75
Motor cycle,Moped,scooter	0.75
Pedal Cycle	0.5

Source: Highway Capacity Manual (2000)

Passenger car equivalents for signalised intersections

According to Highway Capacity Manual 2000, the conversion factors used for signalised intersections are fully described in Table 2.

Table 2 shows the conversion factors of a signalised intersection. In order to take care of the effects of truck and buses, conversion factor is needed to convert the heterogenous traffic stream to homogenous vehicular traffic at a given intersection under prevailing traffic and roadway condition (Highway Capacity Manual 2000).

Materials and Method

Description of the study area

The intersection under study is Y-legged with dual carriageway on each approach. It is however situated within the Central Business District of Kano Metropolis and it connects with two major arterial roads i.e. Ibrahim Taiwo and Civic Center Road (Figs. 1 – 3). These roads are very sensitive to the movement of people and ease of doing business as important places like Kwari Market, Isyaka Rabiu and Sons, Nigerian Railway Corporation, Gidan Murtala, Temporary site of Yusuf Maitama Sule University among others were connected with this facility.

Fig. 1: Civic center approach

Fig. 2: Isyaka Rabiu approach

Fig. 3: Ibrahim Taiwo approach

Data collection

Collection of traffic data at intersection

An observatory manual method was used throughout the exercise and relevant data were obtained to determine the operating characteristics of the intersection under study. Meanwhile, the operating elements to be considered are current traffic volume, level of service and average control delay. For statistical analysis, the basic counting periods are usually the 24 h day, 16 h day, 12 h day and 1 h day (Kolo, 2012). For the purpose of this study, two peak hour period per day i.e. morning and evening were adopted after conducting a vehicular counting exercise for a period of one week.

However, this effort was considered in order to identify the probable peak hour period of the facility. During the survey, some suitable tools were used such as stop watch, digital camera, pencil and tally forms. After conducting the survey, the available data observed were then converted to passenger car equivalents using appropriate conversions factor in Table 2.

According to Highway Capacity Manual (2000), saturation flow rate, capacity and control delay of signalized intersection could be obtained using the following equations;

$S = S_O N F_w F_{HV} F_g F_p F_{bb} F_a F_{RT} F_{LT}$ ……1

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 condition; 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

Capacity;

$c = sg/C$ 2

Where: c = capacity; s = saturation flow; g = allocation of green time

Delay;

$d = d_1 (PF) + d_2 + d_3$ ……3

$$d_1 = \frac{0.5\,C(1-g/C)^2}{1-[\min(1, X)\,g/C]} \quad \text{……} 4$$

$d_2 = 900T\,[(X-1) + \sqrt{(X-1)^2 + 8kIX/cT}$ …….. 5

Where: d = control delay per vehicle (s/veh); d_1 = uniform control delay assuming uniform arrivals (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; PF = uniform delay progression adjustment factor; C =Cycle length in seconds; G = Effective green time for lane group in seconds; X = volume capacity (v/c) ratio for lane group; K = Delay adjustment factor that is dependent on signal control mode; I = Upstream filtering/metering adjustment factor; T = Duration of analysis period in h; c = Lane group capacity

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, T = 0.25 h

After considering the relevant equations from HCM 2000, the characteristics of the intersection is of utmost important and should be established such that performance indicators could also be computed (Table 3).

Table 3: The Characteristics of Ibrahim Taiwo-Civic Center signalized intersection

Arm	Posted speed limit (km/hr)	Cycle time (sec)	No. of lanes	Amber time (sec)	Green period (sec)
Isyaka Rabiu	30	174 sec	3	4 sec	50
Ibrahim Taiwo	30	174 sec	3	4 sec	50
Civic Center	30	174 sec	2	4 sec	50

Results and Discussions

After conducting preliminary observations and traffic volume count for the period of one week, two peak hour's period was chosen to be critical and found worthy for the analysis. On each day, 9-10am and 4-5pm was observed to be the rush hour period of this selected route of concern. The results are clearly shown in Tables 4 – 12.

Table 4: Traffic volume for Civic Center Approach

Day	Left-turning traffic (PCU/hr)					Right-turning traffic(PCU/hr)				
	Tricycle	Car	Bus	L. Bus	Truck	Tricycle	Car	Bus	L. Bus	Truck
Monday	4709	3801	36	06	12	1838	1606	21	03	08
Tuesday	4679	3954	51	03	09	2033	1343	17	01	05
Wednesday	5762	4029	39	02	18	2247	1426	26	02	09
Thursday	5484	3880	22	00	13	1752	1223	32	05	04
Friday	3115	2455	14	01	11	1424	997	18	00	03
Saturday	4363	3882	32	04	17	1706	1966	37	03	10
Sunday	3901	3111	19	00	09	1529	1012	23	00	06

Table 5: Traffic volume for Isyaka Rabiu approach

Day	Left-turning traffic (PCU/hr)					Through-traffic(PCU/hr)				
	Tricycle	Car	Bus	L. Bus	Truck	Tricycle	Car	Bus	L. Bus	Truck
Monday	787	547	14	01	00	6615	5251	2718	06	06
Tuesday	624	613	09	00	00	6367	5590	1457	05	02
Wednesday	653	497	07	02	01	7224	6112	2555	03	07
Thursday	526	502	11	00	02	7011	6110	2842	01	11
Friday	412	396	08	00	00	5997	4972	1979	00	05
Saturday	803	467	18	00	00	6789	5487	1750	04	10
Sunday	368	404	07	01	00	4032	3798	1504	02	05

Table 6: Traffic volume for Isyaka Rabiu approach

Day	Left-turning traffic (PCU/hr)					Through traffic (PCU/hr)					Right-turning traffic (PCU/hr)				
	Tricy.	Car	Bus	L.Bus	Truck	Tricy.	Car	Bus	L.Bus	Truck	Tricy.	Car	Bus	L.Bus	Truck
Mon.	79	18	06	00	00	8487	7443	3268	03	16	6718	2332	103	01	16
Tue.	62	23	03	00	00	8524	7661	3483	02	11	6457	1927	82	00	13
Wed.	94	17	04	00	00	9560	8112	3415	04	18	5114	1609	116	03	22
Thur.	106	12	03	00	00	8526	7421	2982	00	13	5993	1213	109	00	17
Fri.	47	09	00	00	00	7421	5989	2114	00	08	4405	737	87	00	09
Sat.	128	26	04	00	00	8311	7230	3567	05	19	6892	876	95	02	21
Sun.	39	14	00	00	00	6326	4948	1322	01	07	4788	552	61	00	07

LT: Left-turn traffic; TT through traffic; RT: Right-turn Traffic

Traffic data for signalized intersection

Tables 4 – 6 above present the traffic volume data for the three approaches of Ibrahim Taiwo-Civic Center Intersection.

Table 7: Peak hour traffic volume, timing and movement pattern at Isyaka Rabiu Approach (A)

Day	Time (hr)	LT	TT	Total hourly volume (PCU/hour)
Monday	9-10am	250	936	1186
	4-5pm	315	1035	1350
Tuesday	9-10am	316	1006	1322
	4-5pm	301	1110	1411
Wednesday	9-10am	251	929	1180
	4-5pm	313	1012	1325
Thursday	9-10am	262	784	1046
	4-5pm	243	902	1145
Friday	9-10am	156	730	886
	4-5pm	189	991	1180
Saturday	9-10am	219	775	994
	4-5pm	205	806	1011
Monday	9-10am	441	660	1101
	4-5pm	397	1013	1410

LT: Left-turn traffic; TT through traffic

Table 8: Peak hour traffic volume, timing and movement pattern at Ibrahim Taiwo Approach

Day	Time (hr)	LT	RT	TT	Total hourly volume (PCU/hour)
Monday	9-10am	126	783	1856	2765
	4-5pm	134	473	1787	2394
Tuesday	9-10am	52	677	1579	2308
	4-5pm	72	761	1685	2518
Wednesday	9-10am	34	710	1747	2491
	4-5pm	41	811	1810	2662
Thursday	9-10am	19	734	1488	2241
	4-5pm	29	794	1573	2396
Friday	9-10am	62	705	1685	2452
	4-5pm	59	691	1761	2511
Saturday	9-10am	54	751	1844	2649
	4-5pm	71	814	1824	2709
Monday	9-10am	36	770	1917	2723
	4-5pm	83	823	1942	2848

Table 9: Peak hour traffic volume, timing and movement pattern at Civic Center Approach

Day	Time (hr)	LT	RT	Total hourly volume (PCU/hour)
Monday	9-10am	747	108	855
	4-5pm	891	205	1096
Tuesday	9-10am	740	112	852
	4-5pm	782	159	941
Wednesday	9-10am	754	110	864
	4-5pm	842	186	1028
Thursday	9-10am	680	124	804
	4-5pm	721	141	862
Friday	9-10am	699	138	837
	4-5pm	721	201	922
Saturday	9-10am	687	80	767
	4-5pm	694	92	786
Monday	9-10am	742	75	817
	4-5pm	821	122	943

From the results obtained in Table 11, Civic Center approach is operating at LOS F followed by Ibrahim Taiwo operates at LOS E and Isyaka Rabiu which operate at LOS D, respectively. These results clearly indicate that during peak hour period, most of the motorists that are constantly plying the road experienced difficulties such as forced flow of traffic, low speed and excessive delay.

Table 10: Computation of saturation flow (Ibrahim Taiwo Road by Civic Center Intersection)

Approach	S_O	N	F_W	F_{HV}	Fg	F_P	F_{bb}	F_a	F_{RT}	F_{LT}	S (pcu/hr)
Isyaka Rabiu	1900	3	1	1	0.99	1	1	0.99	0.85	0.95	4511
Civic Center	1900	2	1	0.96	0.99	1	1	0.99	0.85	0.95	2887
Obasanjo Bridge	1900	3	1	1	0.99	1	1	0.99	0.85	0.95	4511

Table 11: Computation of experienced delay and level of service at the intersection

Phase	g	C	X	d_1	d_2	PF	D	LOS
1	50	1504	0.74	44.28	3.31	1	47.59	D
2	50	1504	1.29	50.03	135.62	1	185.65	F
3	50	962	0.93	48.34	16.36	1	64.70	E

Table 12 Computation of capacity and group lanes of Ibrahim Taiwo-Civic Center intersection

Phase	Movement	Critical volume (max hourly volume) (v)	Saturation flow rate (s)	Flow ratio (v/s)	Flow ratio for critical lane group (v/s)	Existing green time (g)	g/C	c= sg/C capacity of lane group	Degree of Saturation (v/c)	Remarks
1	Through traffic from Isyaka Rabiu	1110	4511	0.246	0.246	50	0.333	1504	0.738	
	Left turn traffic from Isyaka Rabiu	397	4511	0.088						OK/Under saturated
	Right turn traffic from civic center	205	2887	0.071						
2	Through traffic from Ibrahim Taiwo	1942	4511	0.431	0.431	50	0.333	1504	1.291	
	Right turn traffic from Ibrahim taiwo	823	4511	0.182						NOT OK/ Over saturated
	Through traffic from Isyaka Rabiu	1110	4511	0.246						
3	Left turn traffic from civic center	891	2887	0.309	0.309	50	0.333	962	0.926	
	Right turn traffic from civic center	205	2887	0.071						OK/Under saturated
	Right turn traffic from Ibrahim taiwo	823	4511	0.182						

Based on the results obtained, it shows that Ibrahim Taiwo by Civic Center intersection is operating at a critical condition, more especially at peak hour period.

The intersection under study possessed an average cycle length of 174 sec and its critical lane group (v/s) for the overall phases was determined to be 0.986. These results show that the operational efficiency of the intersection is adequate. According to McShane *et al*. (1998) signalized intersection is said to be deficient if it fails to provide sufficient capacity for existing or anticipated critical lane group's flow i.e. if the sum of v/s is greater than 1.0.

The actual capacity of each lane group was compared with the corresponding critical volume in order to determine whether or not the capacity of the lane group can accommodate the maximum hourly volume. Table 12 shows that:

- Phase I, the through movement, left turn traffic and Right turn has a volume of less than the capacity of the lane groups, and hence implies that it's under saturated (OK).
- Phase II, the through movement has a volume greater than the actual capacity of the lane. But the Right and through traffic are all OK.
- Phase III, the Left turn, Right turn are all within the capacity of the lane.

Conclusions and Recommendations

Considering the present volume of traffic during peak hour period for the three approaches, it was concluded that Ibrahim Taiwo possessed the highest value followed by Isyaka Rabiu and lastly Civic Center which tends to possessed the lowest. Phase I and Phase III of the intersection approach operate satisfactorily with 0.738 and 0.926 as respective values of degree of saturation (v/c). But Phase II has value greater than 1 and this result shows that the performance of phase II is not encouraging. This inefficiency of the existing phase is associated with geometric problems of the intersection layout. It was also concluded that the delay of 185 secs experienced at Civic Center approach is high followed by Ibrahim Taiwo which possessed 65 secs. Meanwhile, Isyaka Rabiu approach got the lowest value i.e. 48 secs. These results show that the efficiency and smooth flow of traffic is decreasing with increasing value of delay on each respective approach.

Since the delay observed at three approaches of the intersection is not encouraging, the Civic Center possessed the highest value of 185 secs and operational Level of Service F. Meanwhile, regarding the outcomes of the results; it is recommended to add an additional lane on Civic center approach. According to Manual on Uniform Traffic Control Devices (2007), amber period could be suitably set from 2 to 6 secs. Considering the current performance of this intersection, the amber period for Ibrahim Taiwo and Isyaka Rabiu approaches can be increase to 6 secs which ultimately will improve its performance.

As a result of inefficiencies surrounding the use of manual method, it is strongly recommended to implore more sophisticated method in order to improve and have a reliable data. For further studies, more control systems and operational parameters should also be considered.

Conflict of Interest

Authors declare that there is no conflict of interest.

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