Design of A Composite Traffic Control System at Kpakungu Roundabout Minna, Niger State.

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Abstract

A composite traffic control method is proposed to control traffic and ease congestion especially during peak periods at Kpakungu roundabout in Minna, Niger state. Reconnaissance survey of the roundabout was carried out to note predominant directions of traffic flow from each approach to the roundabout; manual counting of traffic for five working days was done between 7:00 am to 12 noon and 3:00 – 7:00 pm daily. The result of the survey shows that congestion occurs at the roundabout between 7:45 - 9:30 am and between 5:00 - 6:30 pm every day. Results also show that the peak hourly traffic flow rate occurs between 8:00 and 9:00 am, and 5:00 to 6:00 pm daily. The result of the traffic count was then forecasted for 2-years using data on annual vehicle registration in Minna for 2011 to 2015 obtained from the Niger State Board of Internal Revenue Service. The Webster method of signal timing was used to design traffic signals that will optimally allocate right of way time to conflicting traffic streams. A 5–phase signalization of 90 and 97 seconds cycle lengths were proposed for morning and evening peak periods, respectively.

Keywords: Congestion, Peak periods, Traffic count, Traffic signals.

Introduction

A road is a thoroughfare, route or way on land between two places that has been paved or otherwise improved to allow travel by means of some conveyance including horse, cart, bicycle or motor vehicle (Gupta and Gupta, 2007). The basic function of a road is the movement of people, goods and services from one place to another (Gurcharan and Jagdish, 1991). A road can be said to be effective only when it performs this function in a manner that is safe, quick and comfortable (F.H.A, 2009; Forbes, 1999).

A highway system consists of different facilities. These facilities include freeway segments, intersections, ramps and other highway elements. Highway and traffic engineers are frequently engaged in evaluating the performance of these various highway facilities and proffering solutions where there are problems, especially at intersections (Martin, 2003).

An intersection is an area shared by two or more roads, whose main function is to provide for the change of route directions (Garber and Hoel, 2012). Intersections vary in complexity from a simple intersection, which has only two roads crossing at a right angle to each other, to a more complex intersection, at which three or more roads cross within the same area. Drivers therefore, have to make a quick decision at an intersection on the alternative routes they wish to take (Jaap *et al*., 2013). This decision, which is not required at non-intersection areas of the highway, is part of the reason why intersections tend to have a high potential for crashes (Bhardmus, 2013). The overall traffic flow on any highway depends to a great extent on the performance of the intersections.

Conflict points are present at intersections, which if not taking care of result in crashes, delays, and congestions. Hence highway engineers usually look for ways of minimizing or removing the conflicts which arise at intersections. Methods usually employed to control traffic, and hence remove or minimise conflicts at intersections in order of increasing hierarchy are (Maurice, 2005):

i.) Basic rule of the road, that is, first come first serve.
ii.) Use of yield and stop signs usually employed on minor roads.
iii.) Round-about which eliminates crossing conflicts.
iv.) Traffic signals or use of traffic wardens.
v.) Interchange.

The current method used in controlling traffic at Kpakungu intersection is a roundabout which works on the principle of circulation and entry flows so that motorists yield the right of way to traffic on their left hand. This method of control has proven to be grossly inadequate, especially during peak periods, the need for an improvement. Security and police men are usually deployed to control traffic during peak periods. This is to enhance free flow of traffic at Kpakungu roundabout. As these measures have yielded little dividend, additional measure proposed for traffic control at the roundabout is the introduction of traffic signals. This proposed method, known as a composite traffic control mechanism employs two or more traffic control methods (Backfrieder and Ostermayer, 2014). It involves the use of roundabout with traffic signals.

The study is aimed at designing a composite traffic control to enhance free flow vehicles at Kpakungu roundabout in Minna, Nigeria.

The objectives are to determine (i) the peak period (ii) reduce/eliminate the delay experience by motorists and (iii) eliminate conflict at the intersection.

Methodology

The following methods were adopted for the study:

i.) Traffic flow determination.
ii.) Geometric measurement.
iii.) Congestion study.
iv.) Traffic count.
v.) Signal Timing.

Traffic flow determination.

Reconnaissance survey of the Kpakungu roundabout to determine the predominant direction of traffic flow for each of its four approaches. Each approach was divided to lane groups based on the predominant direction of flow for traffic using that lane, shown in Fig. 1 is the lane group A to H. The saturation flow (S_i) and start-up lost time (L_i) for each lane group was then estimated using the procedure outlined in Highway Capacity Manual (HCM, 2000). The steps followed to determine the saturation flow and start up lost time for each lane group are summarized below:

i.) Queue is allowed to occur at the lane group whose saturation flow is to be determined i.e., vehicles on the lane group whose saturation flow is to be determined are not flowing.
ii.) When the queue in the lane group begins to move, the time taken for each successive car on the queue to cross the yield line of the roundabout at that approach to the roundabout is determined with a stop watch and recorded. This gives the vehicle headway (h_i).
iii.) The average of the relatively constant time when successive car cross the yield line as recorded from step (ii) is determined and taken as the saturation headway (h).
iv.) Saturation flow for the lane group is calculated using Equation 7-3 of HCM, (2000).

$$S = \frac{3600}{h} \qquad (1)$$

where
S = saturation flow (pcu/hour)
h = saturation headway.

v.) The startup lost time for each lane group is calculated using equation 2

$$L=\sum_{i=1}^{n} hi - h \qquad (2)$$

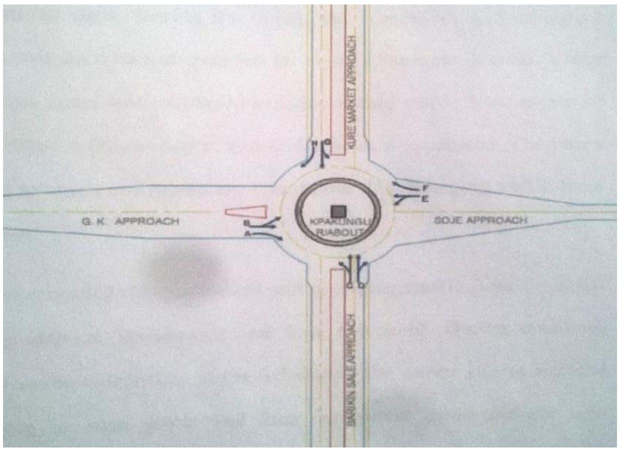

Fig. 1: Kpakungu roundabout showing the adopted lane groups.

Geometric measurement

The geometric features (approach and exit dimension are measured directly and recorded with the aid of a steel tape as early as 5.30am, in the morning before the heavy flow of traffic for safety reasons.

Congestion Study

Congestion study of the roundabout was carried out by physical inspection of the roundabout during peak periods. During the inspection, the approach where the congestion occurred was identified, the time period when the congestion occurred was recorded and the cause of the congestion also noted.

Traffic Count

Traffic count was conducted simultaneously on all the four approaches to the roundabout for five consecutive working days as that situation demand. During the count, the continuous and diverging traffic for each approach was counted and recorded for every 15-minute interval. Video camera was mounted on camera stand, employed to video record the traffic flow at two of the approaches to the roundabout (Kure market and Gidan-kwano approach). The video record was later watched to count the continuous and diverging traffic from each of the two approaches. (Grenard and Wei, 2008)

Traffic was grouped into seven categories as established by (Salter, 1990). Table 1 shows the seven groups and the type of vehicle belonging to each group and their equivalent passenger car unit conversion factor.

Traffic count for each day was carried out in two sessions namely morning and afternoon sessions. Morning session was from 7am to 12 noon while afternoon session was from 3 to 7 pm (Ayeni, 2015).

Table 1: Equivalent Passenger Car Unit for Vehicle Groups.

Vehicle Grouping	Type of Vehicle	Conversion Factor
One	Cars	1
Two	Motorcycles	0.5
Three	Tricycles	0.75
Four	Pickup and Buses	1.5
Five	2-3 axle configuration Buses	2.8
Six	2-3 axle Configuration Tipper and Trucks	2.8
Seven	3-5 axle combination vehicles	3

Source: Salter, 1990

Signal Timing

The method adopted for signal timing for this work is the Webster method of signal timing. The sequence of design process is summarized below.

i.) The data obtained from Traffic count for each day was converted to equivalent passenger car unit (PCU) using the conversion factor shown in Table 1 and the average PCU for the five days calculated.

ii.) The data of the annual number of new vehicle registered in Minna for the past five years (2011- 2015) was obtained from the office of the Niger State Board of Internal Revenue Services. The 8 % growth rate in vehicular registration as determined from the obtained data and was used to forecast the future traffic volume to use the Kpakungu roundabout after fifteen years with proper maintenance which is the design life of the traffic signal (Qu, 2008).

iii.) From the result obtained in step two above, the hourly period having the highest traffic flow for both morning and afternoon session of traffic count was identified and the peak hour factor (PHF) for the peak hours calculated using Equation 3.

$$\text{P.H.F} = \frac{\text{peak hour volume}}{4\ x\ \text{peak 15} - \text{minute volume during peak hour}} \quad (3)$$

iv.) The traffic signal design volume of traffic for each lane group is calculated using Equation 4.

$$\text{Design traffic volume} = \frac{\text{forcasted design traffic volume for approach}}{\text{peak hour factor}} \quad (4)$$

v.) A signal phasing sequence for signal timing was developed. The phasing system is such that gives the best possible alternative to achieving the aim and objectives of the system.

vi.) Webster equation (Webster, 1964) of signal timing reproduced as Equation 5 was then used to calculate the optimum cycle length and to allocate effective green time for each phase accordingly.

$$C_o = \frac{1.5L + 5}{1 - \sum_{i=1}^{n} yi} \quad (5)$$

where C_o = Optimum cycle length (seconds)

L = Total lost time per cycle (seconds)

y_i = maximum value of the ratios of approach flows to saturation flows for all lane groups using phase i.

Results

Saturation Flow (S_i) and Startup Lost Time (L_{1i})

The saturation flow result for lane groups A, B, C, D, G and H are presented in Table 2. The saturation flow for lane group E and F are not determined using the procedure outlined in signal timing because of low traffic flow from that approach. Instead, the result obtained for lane groups A and B is assumed for lane groups F and E respectively.

Table 2: Saturation flow and lost time for each lane group

	Headway (secs)	Headway (secs)	Headway (secs)	Headway (secs)	Headway (secs)	Headway (secs)
Vehicle	A	B	C	D	G	H
1	2.50	2.49	2.40	2.35	2.00	2.05
2	2.38	2.12	2.00	2.01	1.98	1.90
3	1.98	1.78	1.93	1.85	1.59	1.81
4	1.75	1.62	1.81	1.70	1.50	1.70
5	1.61	1.52	1.75	1.60	1.48	1.58
6	1.59	1.49	1.68	1.55	1.46	1.57
7	1.48	1.58	1.65	1.50	1.45	1.56
Saturation headway(h_i)	1.50	1.59	1.69	1.55	1.46	1.57
Startup lost time(L_{1i})	2.00	2.30	1.40	3.60	2.60	1.20
Number of lanes	1	1	1	2	2	1
S_i (pcu/hr)	2264	2400	2130	4646	4900	2293

Signal Phasing

The adopted signal phasing sequence for traffic signal design is presented in Fig. 2. Fig. 2 shows the lane groups belonging to each phase.

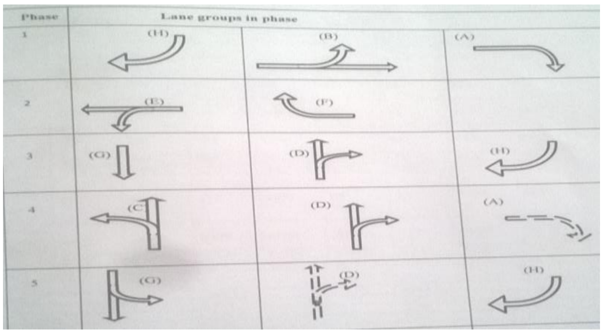

Fig. 2: Signal Phasing Sequence

Signal Timing Calculation

The calculations for allocating the green time for each session morning and afternoon sessions are presented in Table 3.

(i) Afternoon Session Signal Timing Calculation. The Peak Hour is between 5:00 – 6:00pm

Table 3: Afternoon session signal timing design data

Period	A	B	C	D	E	F	G	H
5:00 – 5:15pm	140	201	189	275	9	5	379	247
5:16 – 5:30pm	175	200	172	257	12	3	343	233
5:31 – 5:45pm	180	204	165	216	12	8	353	247
5:45 – 6:00pm	169	193	175	229	11	5	342	239
Total	664	798	701	977	44	21	1417	966
PHF	0.92	0.98	0.93	0.89	0.92	0.66	0.94	0.98
Traffic signal (Qi) design volume	723	814	753	1097	48	32	1508	986
Saturation flow (Si) pcu/hr	2264	2400	2130	4646	2264	2400	4900	2293
Yi	0.319	0.339	0.353	0.236	0.0212	0.013	0.307	0.43
L_{1i}	2.3	2	1.4	3.6	2	2.3	2.6	1.2

Phase	Max yi	Max L_{1i}
1	0.43	2.3
2	0.0212	2.3
3	0.43	3.6
4	0.353	3.6
5	0.43	2.6
	$\sum yi = 1.664$	$\sum L_{1i}$ =14.40

Optimum Cycle (c_o) length from Webster Equation :

$C_o \; = C_o = \frac{1.5L+5}{1-\sum_{i=1}^{n} yi}$

Sum of startup lost time $\sum L_{1i} = 14.40$ seconds = 14 seconds

Sum of clearance interval between phases (L_2) = 20seconds

Total lost time per cycle (L) = $L_1 + L_2$

= 14 +20

= 34 seconds.

$C_0 = \underline{(1.5\times34) + 51} - 1.66 \qquad = \frac{56}{0.66}$

= 84.84 seconds

C_o = 85seconds

Total Effective green time = $C_0 - L$

= 85 - 34

= 51 secs

Actual Effective green time for each phase (Gai) with 3.0 taken as adopted yellow interval for all lane groups

$G_{ai} = \frac{Yi}{\sum Yi} + l_{1i} \; - 3.0$

$G_{a1} = \frac{0.430}{1.660} \times 51 \;+\; 2.3 \;-3.0 \;=$ 12.51secs

$G_{a2} = \frac{0.0212}{1.660} \times 51 \;+\; 2.3 - 3.0 \;= 0.50$secs

$G_{a3} = \frac{0.430}{1.660} \times 51 \;+\; 3.6 - 3.0 \;=$ 13.81secs

$G_{a4} = \frac{0.353}{1.660} \times 51 \;+\; 3.6 - 3.0 \;=$ 11.45secs

$G_{a5} = \frac{0.430}{1.660} \times 51 \;+\; 2.60 \;- 3.0 \;=$ 12.81secs

5 seconds of green time is allocated to phase 2. This increases the total effective green time to 56 seconds and cycle length to 90 seconds. The phase diagram is presented in Fig. 3 and 4

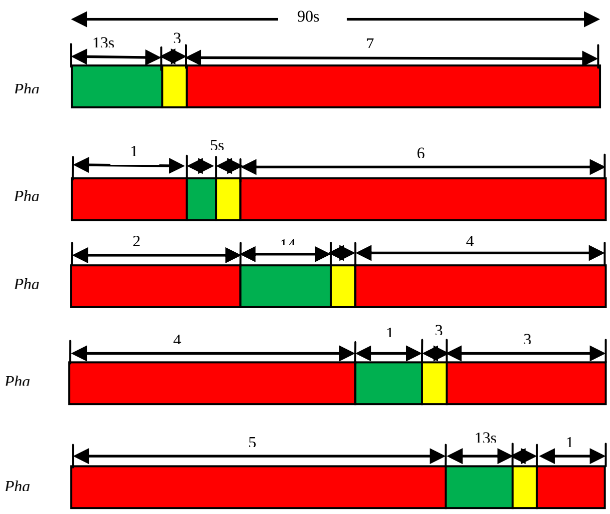

Fig. 3: Afternoon session signal phase diagram

Morning Session Signal Timing Calculation

The calculations for the morning session signal timing are presented in Table 4.

Peak hour: 8am - 9am.

Table 4: Morning session signal timing design data

Period	A	B	C	D	E	F	G	H
8:00 - 8:15am	172	267	183	296	9	6	274	194
8:16 – 8:30am	183	290	187	282	11	8	215	217
8:31– 8:45am	158	274	180	237	9	6	236	208
8:46 – 9:00am	168	274	177	289	12	5	279	204
Total	681	1105	727	1104	41	25	1001	823
PHF	0.93	0.95	0.97	0.93	0.85	0.78	0.91	0.95
Traffic signal (Qi) design volume	723	1163	750	1187	48	33	1100	866
Saturati on flow (Si) pcu/hr	2264	2400	2130	4646	2264	2400	4900	2293

Yi	0.323	0.485	0.352	0.255	0.021	0.014	0.225	0.378
Li	2.3	2	1.4	3.6	2	2.3	2.6	1.2

Phase	Max yi	$MaxL_{gi}$
1	0.485	2.3
2	0.021	2.3
3	0.378	3.6
4	0.352	3.6
5	0.378	2.6
	Σyi = 1.614	Σli = 14.40

$$\text{Optimum cycle length } (C_0) = \frac{1.5L + 5}{1 - \Sigma yi}$$

Sum of startup lost time Li = 14.40seconds = 14 seconds
Sum of clearance interval between phases = 20 seconds
$L = L_1 + L_2 = 14 + 20 = 34$ seconds

$$C_o = \frac{(1.5 \times 34) + 5}{1 - 1.614} = \frac{56}{0.614}$$

= 91.21 seconds $\quad C_o = 92$ sec
Effective Green time = C – L
$G_{te} = 92 - 34 = 58$ seconds.
Actual green time for each phase with 3.0 sec adopted as the yellow interval for all lane groups.

$$G_{ai} = \frac{Yi}{\Sigma Yi} + l_{1i} - 3.0$$

$$G_{a1} = \frac{0.485}{1.614} \times 58 + 2.30 - 3.0 = 16.73\text{secs}$$

$$G_{a2} = \frac{0.021}{1.614} \times 58 + 2.30 - 3.0 = 0.55\text{secs}$$

$$G_{a3} = \frac{0.378}{1.614} \times 58 + 3.60 - 3.0 = 14.18\text{secs}$$

$$G_{a4} = \frac{0.352}{1.614} \times 58 + 3.60 - 3.0 = 13.25\text{secs}$$

$$G_{a5} = \frac{0.378}{1.614} \times 58 + 2.60 - 3.0 = 13.18\text{secs}$$

The actual green time for phase 2 is put at 5.0 seconds. Hence the total cycle length increases to 97 seconds. The Phase diagram is presented in Fig. 4.

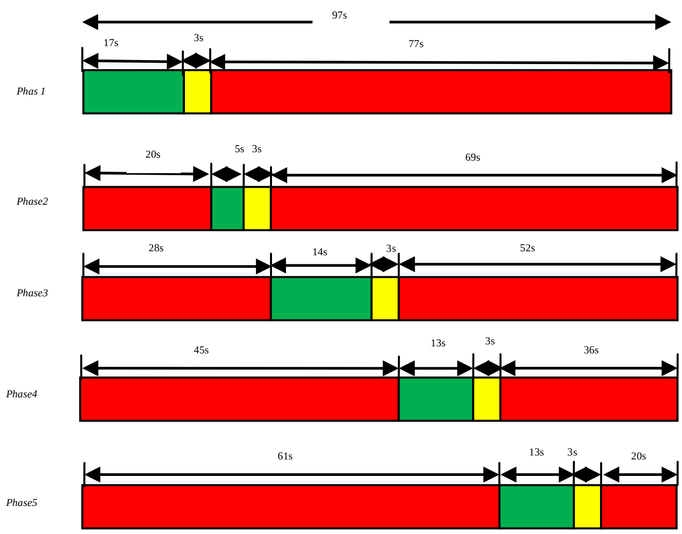

Fig. 4: Morning session signal phase diagram

Discussion of Results

The traffic survey carried out at the Kpakungu roundabout shows that the Gidan kwano approach to the roundabout experiences more congestion than other approaches. The congestion occurs especially during peak periods (7:45 - 9:00am and 5:00 - 6:30pm). The congestion at the approach was attributed to the following factors.

i.) The approach is not as wide as the other approaches.

ii.) Presence of more pedestrian crossing activities at that approach making drivers to reduce their speed.

iii.) Parking activities of commercial and non-commercial vehicles which reduce the effective space available for traffic which ultimately make drivers to reduce their speed to compensate for the small available space

iv.) Presence of speed bumps which makes traffic to flow at lower speed.

The above listed factors have caused a significant decrease in the capacity of that road segment thereby making demand to exceed capacity during peak periods ultimately causing congestion.

A five phase traffic signal was designed with phase one having lane groups H, B and A having exclusive right of way simultaneously when the signal lamps for those lane groups will indicate green and that of the other lane groups showing red. Phase two has lane groups E and F having exclusive right of way while lane group A has a permitted right of way (signal lamp shows yellow indicating that traffic going that direction can move if the intersection is clear of conflicting traffic). Phase three has exclusive right of way for lane groups G, D (continuous and right-turn traffic only) and H. Phase four gives exclusive right of way for lane groups C and D while lane group A has a permitted right of way. Phase five gives exclusive right of way to lane groups G and H while lane group D has a permitted right of way.

During the traffic signal design, a clearance interval of 4 seconds each between phases 1 and 2, 2 and 3, 3 and 4, 4 and 5 and 1 is adopted for design for safety reasons so that traffic can clear the roundabout completely before conflicting traffic streams in the next phase are released. A yellow interval of 3 seconds was also adopted for design.

Conclusions

The composite control mechanism provides a method of controlling traffic at the Kpakungu roundabout that is safe, economical and environmentally friendly. Other advantages of the composite traffic intersection include:

i.) The design is relatively cheaper to implement as there will be no need to redesign or reconstruct any new fixed facility at the intersection, just the installation of traffic signals which is relatively cheap.

ii.) It will help to eliminate pollution at the intersection coming from the exhaust of vehicles since there will be no more congestion.

iii.) Also frustrations experienced by drivers during off-peak periods which are experienced in pre-timed traffic intersections could be eliminated by switching off the traffic lights during the off-peak periods and motorist resulting to the normal roundabout rules.

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