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## Predictive modeling of entry flow at rotary intersections in Akure, a developing city and capital of Ondo state, Nigeria

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### Abstract

Predictive models for entry flow at rotary intersections in Akure - a developing city in Nigeria- have been developed. Data were collected at the intersections critical to traffic flow in the study area using a cine camera placed at a vantage point from the road sections during peak and off-peak periods in week days. Entry flow ( $q_e$ ) was modelled as a function of circulating flow ( $q_c$ ), delay ( $d_a$ ), headway ( $h$ ) and geometric features of the intersections. The data were fitted to a multiple linear regression equation to obtain the generalized flow models for peak and off peak periods. The equations obtained were validated using empirical data other than those used to calibrate the model. The adjusted  $R^2$  values obtained during the peak and off peak periods were 95.8% and 87.7% respectively, indicating that the independent variables (circulating flow, delay and headway) made significant contributions in predicting the entry flow. The models developed can be used to evaluate entry flow at rotary intersections in the study area and other cities in developing countries with similar traffic characteristics for which such models are scarce, thereby facilitating planning and design of effective traffic control mechanisms.

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### Introduction

Traffic congestion on major roads consequent upon existing bottlenecks at intersections is a major problem especially in metropolitan areas. Intersections are the most critical points from capacity, congestion and safety viewpoints for the operation of an urban road network and have implications on the socio economic workings of a city.

Roundabouts (rotary intersections) that provide traffic control without the use of stop signs or traffic signals—have gained popularity to reduce conflict points, accidents severity, traffic speeds, traffic delay, air pollution, fuel consumption, and construction costs at intersections. When constructed where geometric and traffic conditions are appropriate, they can potentially provide advantages over conventional intersections in terms of capacity reduced, delay, queue length, emissions, increased safety, and aesthetics. A roundabout brings together conflicting traffic streams, allows the streams to safely merge and traverse the roundabout, and exit the streams to their desired directions. The geometric elements of a roundabout also provide guidance to drivers approaching, entering, and traveling through it.

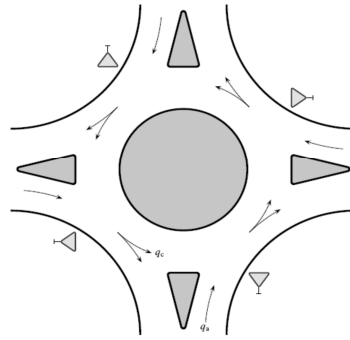
Research on traffic flow prediction at rotary intersections have been focused mainly on cities in developed countries (Kimber, 1980; Troutbeck, 1993; Brilon et.al, 1997), where the traffic situation is very different from those in developing countries; hence this study is intended to formulate predictive traffic flow models for rotary intersections in Akure, Nigeria—a developing city to bring about effective traffic management. It is expected that the developed models would also be applicable to other developing cities with similar traffic characteristics.

In this paper, a brief literature survey is given in Section 1 followed by a description of the methodology for the study in Section 2. The developed models are presented in Section 3 and relevant conclusions drawn.

### 1. Brief literature review

At a roundabout as shown in Figure 1, vehicles circulating around the central island do so in a counterclockwise manner while approaching flows ( $q_a$ ) give priority to circulating flows ( $q_c$ ) (TRB, 2000). This ensures an uninterrupted flow in the circulating roadway. Circulating and approaching flows merge immediately at the entrance to the circulating roadway.

To evaluate the performance of a roundabout, three measures are typically used namely: degree of saturation, delay, and queue length. In all cases, a capacity estimate must be obtained for an entry to the roundabout before a specific performance measure can be computed. Several attempts have been carried out on entry capacity of roundabout and allied models. Some of them are described below.



**Figure 1 - Direction of movement at a typical roundabout. Source: TRB (2000).**

Kimber (1980) who conducted studies in the UK and developed an empirical linear regression equation 1 and equation 2 for single and double lane entry respectively; which was based on a large number of observations at roundabouts operating at-capacity. This equation directly relate capacity to the roundabout geometry.

$$\begin{aligned} Q_e &= k(F - f_c Q_c), & f_c Q_c &\leq F \\ Q_e &= 0, & f_c Q_c &> F \end{aligned} \quad (1)$$

For Double lane entry:

$$Q_e = 2424 - 0.7159Q_c \quad (2)$$

where:  $Q_e$  is entry capacity, vehicles/hour;  $Q_c$  is circulating flow, passenger car equivalent/hour; and  $k, F, f_c$  are constants derived from the geometry of the roundabout.

Troutbeck (1991) presented an Australian capacity formula given as:

$$Q_e = \frac{3600 \alpha q_c e^{-\gamma(T-\Delta)}}{1 - e^{\gamma T_0}} \quad (3)$$

in which decay parameter  $\gamma$  is defined by

$$\gamma = \frac{\alpha q_c}{1 - \Delta q_c} \quad (4)$$

where:  $Q_e$  is entering capacity (vehicles/hour),  $\alpha$  is proportion of free vehicles,  $q_c$  is circulating flow (vehicles/seconds),  $T$  is critical gap (seconds),  $T_0$  is follow up time (sec), and  $\Delta$  is minimum headway in circulating stream (seconds).

Stuwe (1992) studied eleven German roundabouts and developed the following exponential regression Equation 5 to estimate roundabout entry capacity.

$$C = A e^{\left(-\frac{B V_c}{10,000}\right)} \quad (5)$$

where:  $C$  is entry capacity (vehicles/hour);  $V_c$  is circulating flow (vehicles/hour); and  $A, B$  are parameters dependent on the number of circulating and entry lanes.

Troutbeck (1993) conducted studies for the Australian Road Research Board and developed an analytical equation based on gap acceptance characteristics observed and measured at roundabouts operating below capacity. Critical gap and follow-up times were related to roundabout geometry and capacity was then determined using the Equation 6.

$$Q_e = \frac{\alpha Q_c e^{-\gamma(t_c - t_m)}}{1 - e^{-\gamma t_f}} \quad (6)$$

where:  $Q_e$  is entry capacity (vehicles/hour);  $Q_c$  is circulating flow (vehicles/hour);  $\alpha$  is proportion of non-bunched (free) vehicles in the circulating streams;  $\lambda$  is model parameter;  $t_c$  is critical gap in seconds;  $t_f$  is minimum headway in circulating streams in seconds; and  $t_m$  is follow-up time, s.

Owolabi and Adebisi (1993) also developed models for headway data for single lane-traffic flows at some points along Zaria-Sokoto Road, Nigeria. The study was particularly designed to reflect the traffic situation in developing countries like Nigeria where motorcycles constitutes a reasonable proportion of traffic on urban roads. From the Kolmogorov-Smirnov (KS) goodness of fit test results, the composite exponential model was found to be a sound descriptor of observed headways for flows ranging from 170 vph to 750 vph; while the shifted negative exponential model was found to be a sound headway model only for low flows. The approximate relationship for cases where motorcycles were included in the observations was:

$$a = 1.07x10^{-3}q - 0.06 \quad (7)$$

where:  $a$  is the proportion of free vehicles;  $q$  is traffic flow expressed in vehicles per hour, while that for data not involving motorcycles was given as:

$$a = 4.510^{-4}q + 0.13 \quad (8)$$

Brilon et al. (1997), developed the capacity curve for the urban compact roundabout based on the capacity curves for roundabouts in Germany with single-lane entries and a single-lane circulatory roadway given as:

$$q_{e,max} = 1218 - 0.74q_c^* \quad (9)$$

where:  $q_{e,max}$  = entry capacity (passenger car equivalent/hour),  $q_c^*$  = circulating flow (passenger car equivalent/hour)

Polus and Shmueli (1999) developed an exponential regression model in equation based on their studies of six small to medium-sized roundabouts in Israel. The model yielded an exponential reduction in entry capacity with an increase in circulating flow and a significant increase in entry capacity with an increase in outside diameter as shown in equation 10.

$$C = 394D^{0.31} e^{-(0.00095V_c)} \quad (10)$$

where:  $C$  = entry capacity, vph;  $D$  = outside diameter; and  $V_c$  = circulating flow, vph.

The Highway Capacity Manual (TRB, 2000) presented a methodology for estimating roundabout capacity based on gap acceptance. The capacity model presented in Equation 10 is applicable only to single-lane roundabouts with a circulating volume less than 1,200 vph.

$$C_{ex} = \frac{V_{cx} e^{-V_{cx} t_c / 3600}}{1 - e^{-V_{cx} t_f / 3600}} \tag{11}$$

where:  $C_{ex}$  = entry capacity for the entry x in passenger car units/hour;  $v_{cx}$  = conflicting flow in front of entry x in passenger car units/hour;  $t_c$ = critical headway in seconds; and  $t_f$ = follow-up time in seconds.

The Highway Capacity Manual (TRB, 2000) also gives the capacity of the critical lane of a multilane roundabout entry as follows:

$$C_{crit} = 1230 e^{(-0.0009 V_c)} 2.13 \tag{12}$$

where:  $C_{crit}$  is capacity of the critical lane on the approach in vehicles/hour; and  $V_c$  is Conflicting flow in vehicles/hour.

The capacity of the non-critical lane is assumed to be the same as that of the critical one. The multilane capacity model has two parameters that can be calibrated: the coefficient in front of the exponential term i.e. 1230 and the coefficient within the exponential term i.e. -0.0009. The coefficient in front of the exponential term is equivalent to the follow-up time and can be readily measured in the field.

### 2. The study area

Akure the capital city of Ondo State with a population of 387,087 according to 2006 census, is one of the fastest growing urban settlements in the South Western region of Nigeria. It is located on latitude 7° 20'N and longitude 5° 15'E. The existing land use is characterized by a medium density of structure within the inner core areas. Akure is composed mainly of residential areas forming over 90% of the developed area but additional activities such as warehousing; manufacturing, workshops and other commercial activities are commonly located within the residential neighborhoods. Over the years, the number of vehicles on its roads had increased greatly due to increasing socioeconomic activities. Increase in infra-structural facilities such as housing, electricity, water supply and transportation caused rural –urban migration that imposed serious strains on existing transport infrastructure brought about various traffic problems. The natural pattern of development is linear along its main roads; Oyemekun-Oba Adesida road and Arakale-Oda road. These roads connect other street roads from Aiyedun, Isolo, Araromi, Oke-Ijebu, Elerinla, Fanibi, Isikan and Adegbola residential areas.

In Akure metropolis, unsignalized intersections are the most common forms of intersection where it is controlled by Stop and Yield signs. The traffic composition in the metropolis is mixed comprising of motorcycles, taxis, minibuses, Lorries and trucks (trailers); however, the traffic composition of Akure is dominated by taxis, motorcycles (Okadas) and minibuses (Owolabi, 2009). Figure 2 is the map of Ondo State showing the study area.



Figure 2 - The map of Ondo State showing the study area. Source: Ogunmodede (2006).

### 3. Methodology

Field studies were conducted at two rotary intersections namely Olukayode (RN1) and Alafiatayo (RN2) shown in figure 3, being critical to traffic flow in the study area. Traffic parameters were metered using cine camera placed at an elevated vantage point from the road section during the morning and evening peak periods between 7:30-8:30 am and 4:30-5:30 pm respectively and off-peak period between 11:30 am-12:30 pm during week days. Data on speed ( $V_s$ ), density ( $K$ ), traffic volume ( $q$ ), headway ( $h$ ), and delay ( $d_a$ ) were meticulously extracted from the cine camera by replaying it. Speed was measured by taking the travel time as vehicles traversed a short measured distance along the intersection approaches. Density was measured by counting the number of vehicles occupying a given section of the roadway while replaying the cine-camera. The headways were measured between the vehicles while replaying the cine-camera. The control delay was measured by taking note of how long a vehicle waited at a particular approach before having the right-of-way. The entry flow ( $q_e$ ) was expressed as a function of roadway characteristics and geometric features and was fitted to a multiple linear regression using the Statistical Package for Social Scientist (SPSS 16) to obtain the calibrated model equations for selected intersections in the metropolis; the model equations were validated using field data.

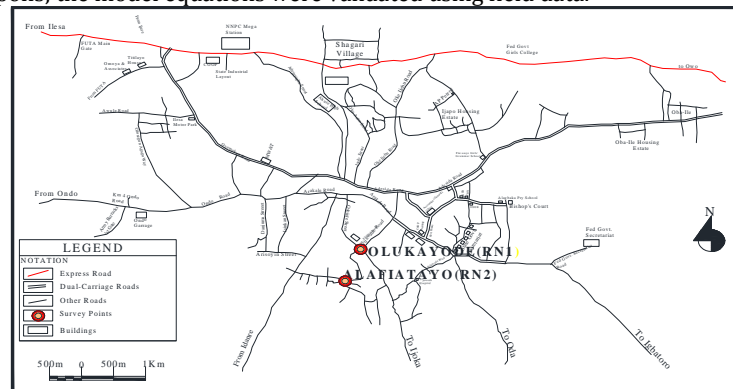


Figure 3 - Street Guide Map of Akure Showing the Survey Points. Source: Ministry of Lands and Housing (2010).

#### 4. Results and discussion

The descriptive statistics of traffic data for the rotary intersections studied during peak and off peak periods are shown in Table 1 and Table 2. In the tables,  $q_e$  is the entry flow in Vehicles/hour,  $q_c$  is the circulating flow (Vehicles/hour),  $d_a$  is the average delay in seconds and  $h$  is the headway in seconds.

**Table 1 - Descriptive statistics of traffic data during peak periods**

Traffic Characteristics	Mean	Median	Mode	Kurtosis	Skewness	Standard Deviation	Variance	Coefficient of Variance
$q_e$	994.17	990	1056	-0.15	0.010	71.61	5127.38	0.072
$q_c$	967.83	976	976	2.42	-0.99	88.88	7900.27	0.092
H	3.78	3.68	3.64	2.77	1.30	0.39	0.15	0.10
$d_a$	23.81	24	24	-0.13	0.02	3.27	10.70	0.14

**Table 2 - Descriptive statistics of traffic data during off peak periods**

Traffic Characteristics	Mean	Median	Mode	Kurtosis	Skewness	Standard Deviation	Variance	Coefficient of Variance
$q_e$	635.83	634	632	1.10	0.24	64.66	4181.08	0.10
$q_c$	639	640	640	8.11	1.56	81.81	6693.11	0.13
H	5.83	5.81	5.08	1.37	1.00	0.81	0.65	0.14
$d_a$	20.19	20	20	-0.48	0.16	4.65	21.64	0.23

For Rotary Intersection:

$$q_e = f\left(\frac{q_c \cdot d_a \cdot w_l \cdot w_e \cdot w_c \cdot n_e}{h}\right) \tag{13}$$

where:  $w_l$  is average entry lane width,  $w_e$  is entry width,  $d_c$  is central island diameter,  $w_c$  is circulating road width and  $n_e$  is the number of entry lanes. Taking the log of both sides gives:

$$\log q_e = \log\left(\frac{q_c d_a w_l w_e w_c n_e}{h}\right) = \log q_c + \log d_a + \log(w_l w_e w_c n_e) - \log h \tag{14}$$

Note:  $\log q_e$ ,  $\log q_c$ ,  $\log d_a$ , and  $-\log h$  are hereafter referred to as  $Q_e$ ,  $Q_c$ ,  $D_a$  and  $H$  respectively. Average entry lane width( $w_l$ ),total entry width( $w_e$ ),circulating road width( $w_c$ ),no. of entry lane( $n_e$ ), and number of circulating lanes( $n_c$ ) are constant; hence they fizzle into the constant term  $a_0$  in the regression equation. Multiple linear regression gives:

$$Q_e = a_0 + a_1 Q_c + a_2 D_a + a_3 H \tag{15}$$

Table 3 and Table 4 give the summary of regression coefficients for the rotary intersection during the peak and off-peak period respectively.

**Table 3 - Summary of coefficients for rotary intersection during peak period**

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95% Confidence Interval for B		Correlations		
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part
1	(Constant)	2.532	.045		45.283	.000	1.951	2.129			
	H	-.505	.019	-.608	-26.824	.000	-.542	-.468	-.930	-.890	-.397
	Qc	.279	.014	.447	20.285	.000	.252	.306	.892	.828	.300
	Da	-.020	.010	-.031	-2.007	.046	-.039	.000	.194	-.145	-.030

Dependent Variable:  $Q_e$

For Rotary intersection during peak period, substituting the regression coefficients in Table 1 into equation 15 gives:

$$Q_e = 2.532 + 0.279Q_c - 0.020D_a - 0.505H \tag{16}$$

$$\therefore \log q_e = \log 10^{2.040} + \log q_c^{0.279} + \log d_a^{-0.020} + \log h^{-0.505} \tag{17}$$

$$q_e = 10^{2.532} \cdot q_c^{0.279} \cdot d_a^{-0.020} \cdot h^{-0.505} \tag{18}$$

Therefore, the model for rotary intersection during peak period is given as:

$$q_e = 340.41q_c^{0.279} \cdot d_a^{-0.02} \cdot h^{-0.505} \tag{19}$$

Similarly, the regression coefficients were substituted to obtain the model equations during the off-peak periods.

The model for Rotary Intersection during Off-Peak Period is given as:

$$q_e = 131.52 \cdot q_c^{0.401} \cdot d_a^{-0.037} \cdot h^{-0.517} \tag{20}$$

**Table 4 - Summary of coefficients for rotary intersection during off peak period**

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95% Confidence Interval for B		Correlations		
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part
1	(Constant)	2.119	.076		23.576	.000	1.638	1.940			
	H	-.517	.028	-.698	-18.772	.000	-.571	-.462	-.820	-.890	-.674
	Qc	.401	.031	.470	12.624	.000	.326	.447	.638	.796	.453
	Da	-.037	.013	-.100	-2.764	.007	-.064	-.010	-.098	-.277	-.099

Dependent Variable:  $Q_e$

Equations 19 and 20 above show that circulating flow ( $q_c$ ), delay ( $d_a$ ) and headway ( $h$ ) made significant contributions in predicting entry flow ( $q_e$ ).  $d_a$  and  $h$  made negative impact on the model while  $q_c$  made a positive contribution. Thus, increase in  $q_c$  will lead to increase in the value of  $q_e$ . Table 5 shows summary of the model parameters from statistical analysis output.

From the output summary shown above the adjusted  $R^2$  values indicate that: The percentages of independent variables that are explained at RN1 and RN2 are 0.958 and 0.877 respectively. The developed models were validated using empirical data other than those used to calibrate the model in the first place, by comparing the predicted and observed flows. The standard residuals are within -3 and +3 which is an acceptable range. Hence there is a relatively good level of association between the observed and predicted values.

**Table 5 - Summary of the model parameters**

Intersection	R	R <sup>2</sup>	Adj R <sup>2</sup>	SEE	Source	SS	df	MS	F	Sig.
Rotary Peak Period	0.979	0.959	0.958	0.00916	Regression	0.367	3	0.122	1.460E3	0.000
					Residual Error	0.016	188	0.000		
					Total	0.383	191			
Rotary Off-Peak Period	0.939	0.881	0.877	0.01597	Regression	0.174	3	0.058	227.643	0.000
					Residual Error	0.023	92	0.000		
					Total	0.198	95			

**Conclusion**

This study formulated entry capacity equation for a single-lane rotary intersection during the peak and off-peak periods using data obtained from Akure in Nigeria. Traffic parameters such as circulating flow ( $q_c$ ), delay ( $d_a$ ) and headway ( $h$ ) made significant contributions in predicting entry flow ( $q_e$ ). However, both  $d_a$  and  $h$  made a negative impact on the model while  $q_c$  made positive contributions. Thus, increase in  $q_c$  will lead to increase in the value of  $q_e$ . This simple relationship is capable of providing accurate predictions of roundabout entry capacity. The generalized flow equations can be used to evaluate entry flow and used for planning and design of effective control mechanisms at intersections in the study area and in other cities with similar traffic characteristics

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