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A Model for Predicting Capacity of Right-turn Traffic at Closely Spaced Unsignalised Junctions

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Abstract
Right-turn traffic at closely spaced un-signalised junctions is associated with delay and the resulting queuing since it cuts through main stream traffic. Through traffic volumes and spacing between junctions have significant bearing on the capacity and delay for right-turns. No relationship has been developed in the literature to predict capacity of right-turn traffic considering through traffic volume, right-turn traffic volumes and spacing between closely spaced junctions. In this study, model for predicting right-turning capacity of two successive unsignalised close junctions was developed. Traffic volume data from six paired junctions with intermediate spacing ranging between 30.0m and 185.0m on selected major roads in Kawempe Division of Kampala City were collected by video recording entered in Microsoft Excel and analysed using the RStudio modelling software. The critical right-turning traffic volume that yielded maximum queue length on the observed junctions was 230 vehicles per hour irrespective of the spacing between junctions. A model to predict right-turning capacity between two successive unsignalised junctions basing on spacing between them, traffic volume discharged and merging traffic was proposed. The study recommends the use of aerial data collection methods, extending observation time and inclusion of geometric characteristics in modelling
Key words*: Right-turn Capacity, modelling, unsignalised junction, Negative binomial regression, Rstudio.*

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I. Introduction

Traffic congestion is one of the major liabilities of modern life since it increases travel time and operating cost in terms of fuel consumption (Mohan and Ramachandra 2012). World over, traffic congestion occurs mostly at junctions during rush hours (Shamsher and Nayeem 2013). A trigger situation develops from bottlenecks whenever a queue spills into adjacent junctions thus interrupting the flow. Increasing urban road traffic congestion in major cities in the world significantly undermines that mobility of people who work there to earn a living (Lindley 1987). Control measures are usually put in place in form of policy regulations and design standards such as stop signs, flow limitation and traffic lights among others to check on the stagnation of traffic flow (MoWT 2010). However, these measures have proven to be expensive to maintain since they are always not applied adequately. While construction of additional facilities increases capacity, dynamic traffic growth together with improvement in traffic flow may generate more traffic and the condition at a particular junction gets worse. Consequently, predicting the right capacity to take up threshold traffic for a specified period of time is difficult (William 1969).

Junctions are necessary to allow vehicles to have access to and exit from the main road without or with less delay (Troutbeck 1986). It is almost impossible to avoid the existence of two consecutive junctions along highways due to changes in land-use over time (Mohan and Ramachandra 2012). More so, at-grade intersections involve non-motorized traffic sharing road space with traffic which limits safety, speed and capacity hence a high propensity of collisions. Good junction design should allow traffic flow from one route to another or through traffic movement on the main route and intersecting route with minimum delay and maximum safety (AASHTO 2001; MoWT 2010). Accidents usually occur at such junctions due to traffic conflict resulting from inadequate capacity in terms of demand and supply at either downstream or upstream junctions, respectively. Therefore, there is need to re-examine the performance of closely spaced junctions especially the delay and capacity of right turns off the minor roads.

Models have been developed in the literature to predict right-turn capacity at junctions basing on the demand and supply treating each junction independently(Spek et al. 2006; Kyte, et al. 1996; Daganzo 1997);. This has not addressed the problem of stagnation since the volume of conflicting traffic on the upstream junction cannot be linked to the ones on the downstream junction. Determination of minimum spacing between two successive junctions that allows maximum flow is necessary for safety, operational comfort and reduction in delays.

Therefore, this study attempted to develop a model to predict right-turn capacity on paired closely spaced un-signalised junctions while studying downstream and upstream traffic partners in combination.

1.1 Objectives

The main objective of this research was to develop a model to predict delay and capacity of right-turn traffic at closely spaced un-signalised junctions in Kampala Capital City. The specific objectives of this research included the following;

i. To determine the critical right turning traffic volumes at junction that yields maximum queue for a given spacing between two successive closely spaced un-signalised junctions.
ii. To develop a model to predict capacity of right-turn traffic based on conflicting traffic volume at the junction and spacing between two successive un-signalised junctions.
iii. To develop a model to predict average right-turn delay at the junction based on traffic and geometrical factors.

II. Materials And Methods

Geometric data; intermediate distance between junction, number of lanes, shoulder width were obtained physically from study locations and traffic data; number of vehicles turning right (VRD), discharging through junctions (VDC) and merging with right-turning traffic (VDM) were obtained from Video recordings on Tuesdays and Thursdays for three hours between 16:00 hours and 19:00 hours and, two hours were selected from the videos (off peak to peak) for analysis. Results were tabulated in in *Microsoft Excel* and analysed using *Rstudio* Software programme. This enabled the researcher to develop relationships which resulted into the model formulation.

2.1Data Processing

Traffic counts for right-turning ,discharged through and merging traffic volume were recorded every 15 minutes for two hours from peak to off peak as illustrated in Figure 1.The value of traffic volumes were entered in Microsoft Excel sheet. Eight intervals were considered at each junction making a total of eight observations. Upstream and downstream junctions were combined to make 16 observations. When all six junctions were aggregated a total of 96 observations were used in model estimation.

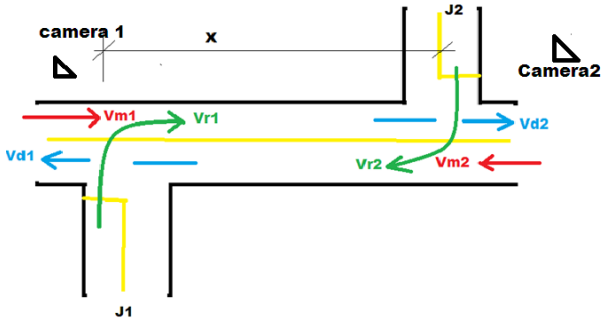


Figure 1: Data extracted from video recording

III. Model hypothesis

3.1 Model Formulation

Raw data for the right-turning (V_r), discharged through (V_d), merging (V_m) and queue length traffic volumes (Fig1) were extracted from field and prepared in Microsoft Excel sheet in tabula form. The collected data from upstream and downstream junctions were combined and the relationships between variables were explored using graphical representations (Addison and Heydecker 2008; Miles and Shevlin 2008). The plots enabled the researcher to determine the forms for estimating the models and consequently development of model equations for this study

The capacity of vehicles to join the main road from minor roads is influenced by spacing (s), V_r, V_d and V_m between successive junction pairs. The results were used for model development using *Rstudio* software since relationships are non-linear model. Equation 1 capacity was proposed for right-turning model since traffic arrives at the junction in a uniform pattern and departs in discrete pattern (Daganzo, 1997).

$$Y = exp(\beta_o + \beta_1 X_1 + \cdots \ldots \ldots \beta_n X_n) \quad (1)$$

Where: Y = dependent variable, β_o = intercept, β_1, β_n = coefficients of independent variables
X_1, X_n = independent variables

3.2 Model Validation

Right–turning capacity model was confirmed by goodness of fit tests on the predicted model to select the best model (Akaike, H. 1973; Lambert 1996; Kutner 2005). The likelihood ratio tests in the *R software* (RCore Team. 2014), were also employed in selection of the best predicted model. The model with the lowest AIC values was a better fit of the data. The likelihood ratio statistic was used to compare models for goodness of fit and computed as Equation 2.

$$G2 = 2[LL(F) - LL(R)] \quad (2)$$

Where: G2 = likelihood ratio statistic which follows a chi-square distribution and LL(F) and LL(R) are log-likelihood statistics for full and reduced models, respectively. Equation (2) was used to compare different model specifications for goodness of fit and implemented using the ANOVA procedure in R software. The ρ^2 analogous to R^2 in ordinary least squares regression that is used to show how much variability in the data is explained by the model was computed using Equation (3).

$$\rho^2 = 1 - \frac{LL(\beta)}{LL(O)} \quad (3)$$

Where: LL(β) and LL(0) = residual and null deviations, respectively. ANOVA was conducted using the likelihood ratio of negative binomial models to select the best model among the prediction (R Core Team 2014). Finally, the significance test for the variables used in prediction was used in selecting the best model.

IV. Results and discussion

4.1 Results

4.1.1 Exploratory Data Analysis

Relationships between variables were explored using graphical representations shown in Figure3. It was noted that both $V_r - V_d$ and $V_r - Q$ plots in Figure 3(a and b) possess more scatter without any definite trends. This suggests that both discharged through traffic and queue length between two successive junctions are not correlated to right-turning volumes. However, this is not as expected because discharged traffic through successive junctions decreased with increase in right-turn traffic that impeded the vehicles from upstream junctions to pass through downstream junction and vice versa (Addison and Heydecker, 2008; Miles and Shevlin, 2008). On the other hand, queue length should grow as right-turning volumes increase. Further examination of Figure 3 shows two trends that explain lack of correlation between any two variables. From Figure 3(a), Vr increases in the direction indicated by arrow *B* and decreases in direction shown by arrow *A*. A similar behavior is observed in Figure 3(b) where V_r increases in the direction shown by arrow *D* and reduces in the direction shown by arrow *C*.

This shows that the size of Q in the direction of V_d mediates the effect of the discharged traffic through the junctions and conflicting traffic volume (right turning traffic volume, V_r). This was explained by studies by (Mwesige et al. 2016; Miles and Shevlin 2008). It was suggested that a variable mediates the relationship between the explanatory and response variables if the explanatory and mediator variables are correlated, which in turn affects the response variable. This can be explained by Figure 4 since by definition arriving traffic is calculated by equation 4

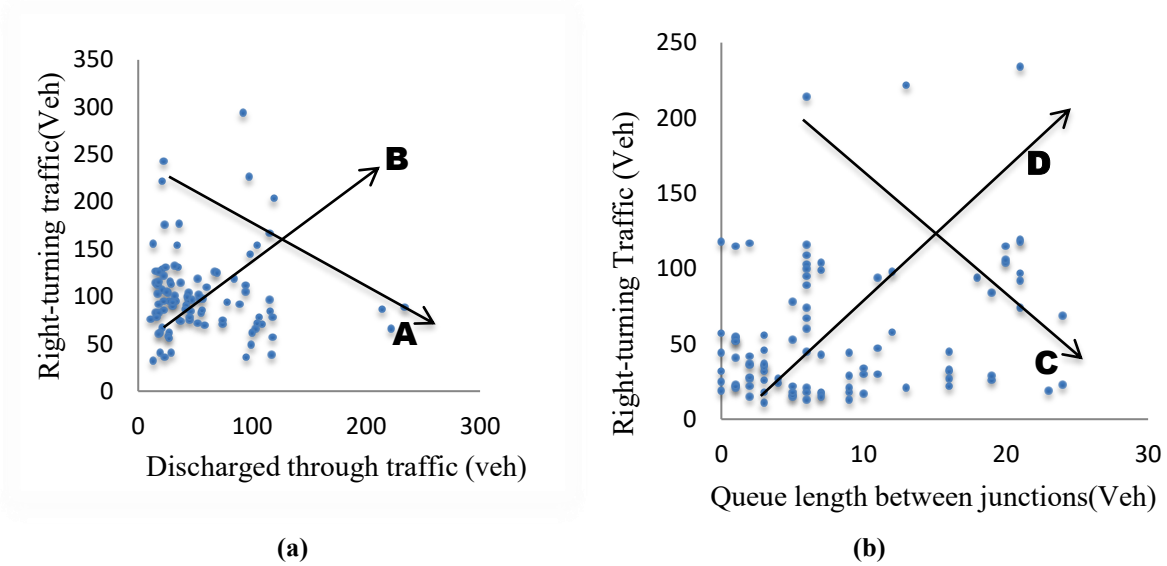
$$V_a = V_d + Q_i - Q_{i-1} \quad (4)$$

V_a= Arriving Traffic.,V_d = Discharged Through Traffic, Q_i= Queue length in current interval, $Q_{(i-1)}$= Queue length in previous interval

Right-turning against Queue length traffic volume (V_r) Figure 3(b) shows that capacity between a pair of junctions is not constant. There is no flattening-off at certain durations which would imply stationary traffic at full capacity for the spacing between a pair of junctions. While this should reflect the capacity, there appears to be no transition point. However, this inconsistency can be described by the differing distances between the junctions where the data were aggregated for all junction pairs irrespective of the distance between junctions because isolation of traffic data obtained from the field for each particular junction pair would not be enough to give the aggregate flow behavior. This would result in straight forward constructs for the relationship which would be true for a particular distance but a true representation of general traffic scenarios that is complex in nature (Hongler and Filliger 2002).

These results are consistent with the idea that temporary daytrips of flow, such as at merges, can be sustained for a shorter time as traffic flow increases. Flow breakdown is often presumed to be initiated by a single driver momentarily slowing, to avoid a conflict or simply because of some change in road geometry. Xi et al.(2015) found that the probability of flow breakdown increases with the local transient flow. They also suggested that apparent periodicity of shock waves may arise from some 'regenerative' process or relaxation from smoother flow just ahead of a shock wave to more turbulent flow downstream

(Addison and Heydecker 2008) reported that jam density is not a property of moving traffic. This is because a vehicle behind a stationary queue lacks the freedom to increase a gap by moving slower than the vehicle in front. However, this may have little impact on a typical motorway queue where only a fraction of vehicles is stopped at any time.



(a) **(b)**

Figure 3: Scatter plots of the observed data: (a) $V_r - V_d$ and (b) V_r– Q **(Author's contribution)**

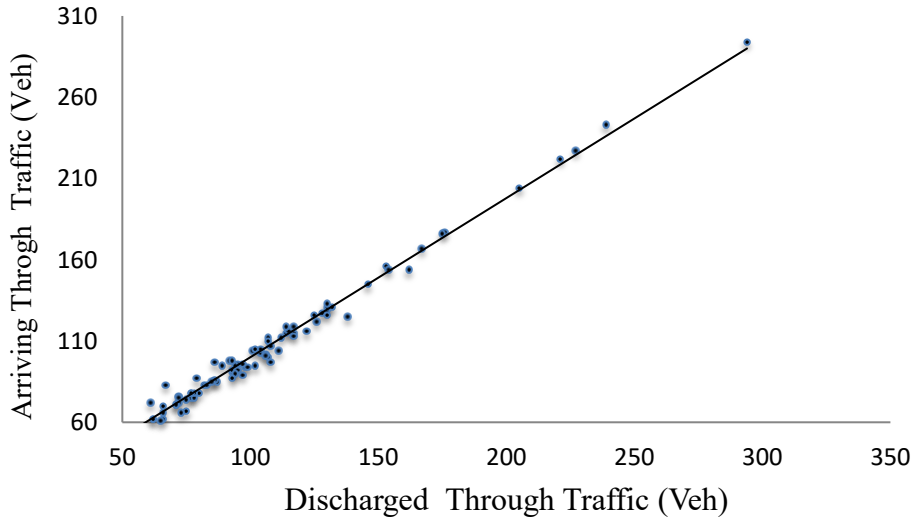


Figure 4: Exploring flow interrelationships for model development (Author's Contribution)

4.1.2 Hypothesis for Model Development

It is usually observed that the Queue (vehicles) at two successive junctions tends to be reproduced whenever the same traffic volume is observed. Based on this observation, it seems reasonable to postulate that, right-turn capacity is associated with traffic flow into the junction, queue length, and spacing between junctions. The specific relationship between them resulted in the concept of traffic flow-density diagrams that describe the associations. Over the years, the concept originating from among others Gazis (2002); Daganzo (1997); Button (1993); Greenshields (1935), resulted in the well-known speed- flow-density diagrams for hypothetical analysis

4.1.3 Model Estimation

Negative non-binomial Sub set regression models were developed using *Rstudio* software. Predicted models are presented in Equations 5, 6 and 7 respective predictor variables. The vehicles arrive at the intersection at discreet times and wait to be served and queuing occurs as arrival rate rise above the rate at which vehicles can be served or released out of the conflicting lane. This is basically why the researcher selected non-linear model forms.(Daganzo, 1997)

$$VRD = exp(\beta_o + \beta_1 S + \beta_2 VTT + \beta_3 VTTS) \quad (5)$$

$$VRD = exp(\beta_o + \beta_1 S + \beta_2 VDC + \beta_3 VCM) \quad (6)$$

$$VRD = exp(\beta_o + \beta_1 S + \beta_2 SS + \beta_3 VTT + \beta_4 VTTS) \quad (7)$$

Table 2 summaries the descriptive statistical output obtained from *Rstudio* software that was used to analyze the predicted models for right-turning capacity. It was from these statistical values that the best model was selected and presented. Considering (AIC) values, variability of the data predictors, two log likelihood, dispersion parameters at 95 % confidence level model Equation (5) whose predictor variables were significant with ρ^2 = 0.113, AIC = 941.24 and two log likelihood = -928.761 was selected as the best and is presented as Equation 7

$$VRD = exp(2.484 + 0.002678S + 0.001274VTT - 0.00002846VTTS) \quad (7)$$

Where; VRD = Right-turning traffic volume (Veh), S = Spacing between two junctions (m), VTT= Sum of discharged through and merging through traffic volume (Veh), VTTS= Square of sum of discharged through and merging through traffic (Veh^2).

4.2 Model Validation

Data was collected on a different of junctions pairs and resulted ploted .The graph obtained from the predicted data had $R^2 = 1$ as shown in Figure 5. Therefore the predicted model had good corrliation. The relation between Right turning capacity and predicted variables of spacing, sum of merging through traffic and square of sum of merging through traffic in both directions had good corrlation thus the model can be employed in predictig the right turn capacity volumes on any paired junctions that are close to one another.

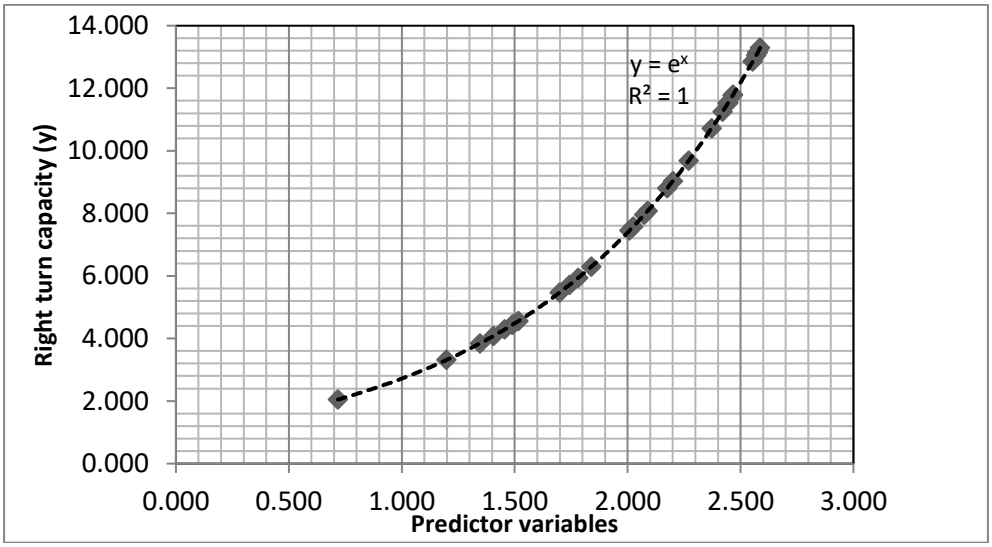


Figure 5: Graph of Right turn Capacity (y) against predictor variables (x) (Author's Contribution)

Table 2: Summary of Right –Turning Capacity model parameter outputs

	Model 1			**Model 2**			**Model 3**		
Description									
Model variables	Coefficient	Standard Error	Z-value	Coefficient	Standard Error	Z-value	Coefficient	Standard Error	Z-value
VRD									
Intercept	2.484	4.873x10^{-1}	5.096***	2.302	5.261x10^{-1}	4.375***	2.894	3.577x10^{-1}	8.090***
VDC	-	-	-				9.9x10^{-3}	3.57x10^{-3}	2.773**
VDM	-	-	-				1.105x10^{-2}	3.476x10^{-3}	3.178**
VCM	-	-	-				-1.214x10^{-4}	3.713x10^{-5}	-3.271*
QC	-	-	-				-	-	-
S	2.678x10^{-3}	1.352x10^{-3}	1.981*	1.273x10^{-2}	8.85x10^{-3}	1.439	2.059x10^{-3}	1.395x10^{-3}	1.476

SS	-	-	-	-4.87x10^{-5}	4.074x10^{-5}	-1.195	-	-	-
VTT	1.274x10^{-3}	4.668x10^{-3}	2.729**	1.164x10^{-2}	4.663x10^{-3}	2.496*	-	-	-
VTTS	-2.846x10^{-5}	1.045x10^{-5}	-2.723**	-2.784x10^{-5}	1.037x10^{-5}	-2.684**	-	-	-
Statistics									
Two log likelihood			-928.761	-931.238			-929.655		
Dispersion parameter			2.3088	2.3462			2.364		
Null deviance [LL(O)]			114.60	116.37			117.21		
Residual deviance [LL(β)]			101.65	101.62			101.45		
Akaike Information criteria (AIC),			941.24	941.65			940.76		
$\rho^2 = 1 - \frac{LL(\beta)}{LL(O)}$			0.113	0.127			0.134		
Confidence level			95	95			95		
No. of parameters			03	04			04		
Sample Size			96	96			96		

***Significance level at 0.001.
**Significance level at 0.01.
*Significance level at 0.05.
Significance level at 0.1

4.2 Discussion

Sensitivity analysis of explanatory variables conducted for equation 7, the peak right-turn volume occurs at 230Vph for through traffic volumes in two directions and starts to decrease at higher two directional through traffic volumes irrespective of spacing between the successive junctions. This shows that the conflicting factors for right-turn capacity is through traffic on the major road in two directions and spacing as illustrated in Figure 5. The specified spacing provided by the (MoWT 2010) of 50m and 100m is only applicable when junctions receive 48vehicles/hour and 64vehicles/hour respectively. That is why it is important for highway design engineer to determine the right-turn volumes during locating junctions along the major roads.

This study confirmed that the crossing of two traffic streams was consistent. A priority traffic stream (major stream) and a non-priority traffic stream (minor stream) of the volume are involved in right-turning movement. Vehicles from the major stream can cross the conflict area without any delay. On the other hand, Vehicles from the minor stream are only allowed to enter the conflict area, if the next vehicle from the major stream is still tc seconds away (tc is the critical gap), otherwise they have to wait. Moreover, vehicles from the minor stream can only enter the intersection tf seconds after the departure of the previous vehicle (tfis the follow-up time) (Grossmann et al. 1991; Catchpole and Plank 1986; Troutbeck 1986; McDonald and Armitage 1978; Siegloch 1973)

Right-turn volume increased with increase in spacing for a given sum of discharged and merging traffic volume (VTT) [Figure 6]. However, the right-turn capacity decreased as right-turn volumes and merging traffic volumes (VTT) increased beyond 200 Vehicles per hour, irrespective of the spacing between the two successive unsignalised junctions. This shows that the merging effect has great influence on the right-turn volume and should be regulated for proper junction performance.(Kyte, et al. 1996; Qu et al. 2014; Tanner 1962)

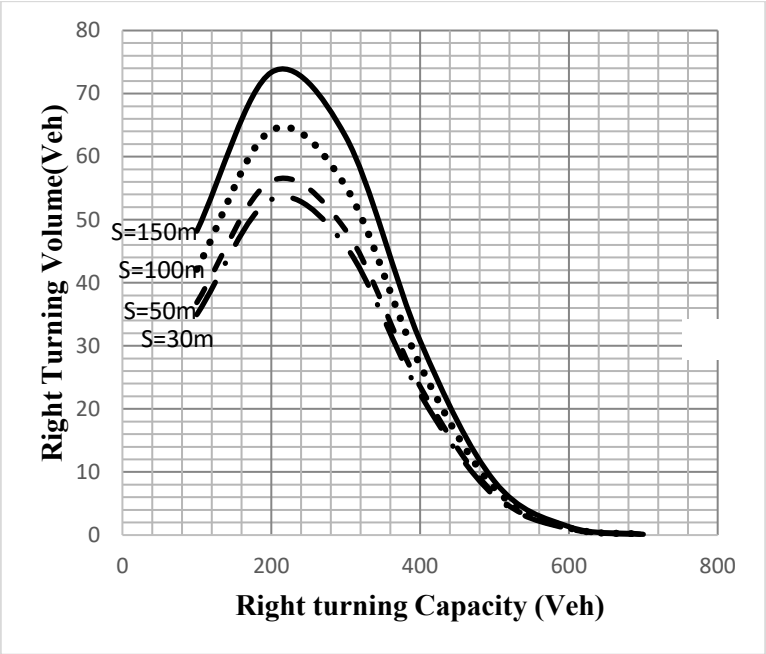
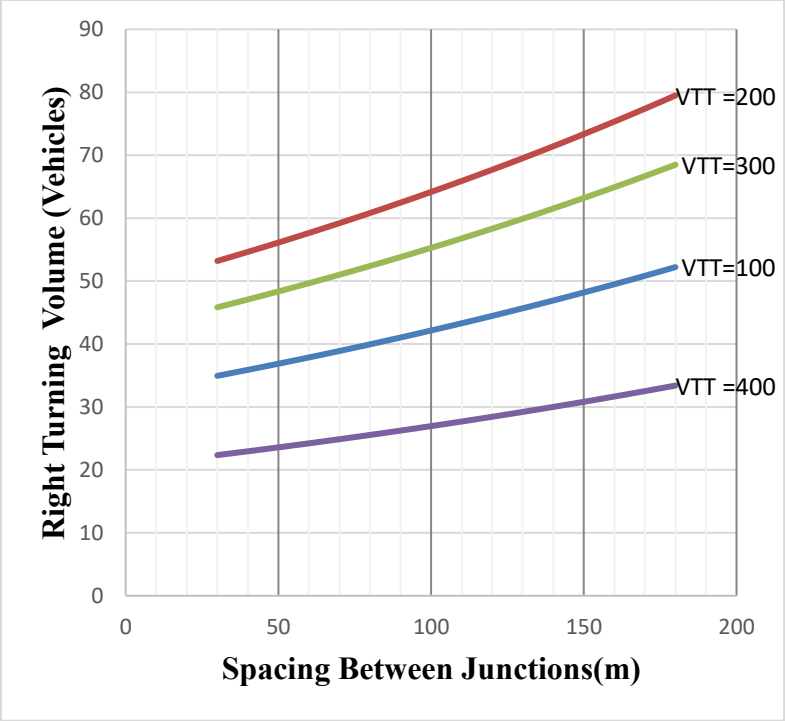


Figure 5 Right-turning volume against capacity (Author's Contribution)



VTT = sum of discharged and merging traffic volume (Veh)

Figure 6 Right-turning volume against spacing between junctions(Author's Contribution)

V. Conclusion

The study suggested a new negative binomial regression model for predicting right-turn capacity and was found to depend on spacing, discharged through and merging traffic volumes and The critical right-turn traffic volume that resulted into traffic stagnation for spacing of 30, 50,100 and 150m between the studied junctions was found to be 230 vehicles per hour with in two-hour traffic operation time. The study recommended increasing traffic operation time beyond two (2) hours, reducing observation time intervals to less than 15 minutes and the use of aerial data collection methods such as aerial photography using drones in future research. Geometry and gradient of successive junctions should be explored in future research to explain how they affect the right-turning movements of vehicles joining the main road.

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