

Effect of Traffic and Geometric Characteristics of Rural Two Lane Roads on Traffic Safety: a case study of Ilesha-Akure-Owo road, South-West, Nigeria

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Abstract— Road safety engineering involves identifying influencing factors causing traffic crashes through accident data, carrying out detailed accident studies at different locations and implementing relevant remedial measures. This study was carried out to establish relationship between traffic accident characteristics (frequency and severity) and traffic and road design characteristics on a two-lane highway. Statistical models applied in traffic accident modeling are Poisson regression, Negative Binomial regression (NB), and Zero-Inflated Negative Binomial regression (ZINB).; Traffic flow and road geometry related variables were the independent variables of the models. Using Ilesha-Akure-Owo highway, South-West, Nigeria accident prediction models were developed on the basis of accident data obtained from Federal Road Safety Commission (FRSC) during a 4-year monitoring period extending between 2012 and 2015. Curve radius (CR), lane width (LW), shoulder factor (SF), access road (CHAR), average annual daily traffic (AADT), percentage heavy good vehicle (HGV) and traffic sign posted (TSP) were the identified effective factors on crash occurrence probability. Finally, a comparison of the three models developed proved the efficiency of ZINB models against traditional Poisson and NB models.

Keywords— Traffic accidents, Single carriageway, accident prediction model, road geometric characteristics

1 INTRODUCTION

In Nigeria today, roads play very crucial roles on the economic and social activities, because it is the most popular mode of transportation that exists within the country. It is the only modal class of transportation that connects all the area within the country, and it is the cheapest. This also accounts for why approximately 80 percent of freight and passenger traffic are moved through the highway/roadway network systems in Nigeria (Wang, 2002). Traffic engineers continue to emphasize the identification of causal factors for crashes on individual sections and on different functional classes of highways as an area of emphasis. Generally road safety issues do not receive explicit consideration in the design stage, road safety engineering have been introduced as a mean for assuring that crash occurrence measures aimed to eliminate or reduce the safety problems are fully considered.

In this paper, we deal with research that have been conducted for identifying the effective factors on frequency and severity of accidents on single carriageway and use crash data of Ilesha-Akure-Owo highways, South-West, Nigeria as a case study. Data on road accidents was obtained from the Federal Road Safety Commission, while results on traffic and geometric characteristics were obtained on site in conjunction with Pavement Evaluation Unit, Federal Ministry of Works, Kaduna, using GIS was used for accurate record of time and place of accidents and assistance of police reports.

2 LITERATURE REVIEW

2.1 ROAD DESIGN AND TRAFFIC RELATED FACTORS

The traffic flow and road geometry related factors was used in this research as independent variables of models. Such variables are observed in studies of many other researchers particularly in the area of modeling crashes occurred on freeways and urban or rural highways (Delen *et al*, 2006). Lee & Mannering, (2002) applied pavement condition or quality, Chang, (2005) and Hauer, (2001) adopted driver behavior and weather condition related variables as independent variables in their models.

In this study, traffic volume (AADT), percentage heavy good vehicle (HGV), traffic sign posted (TSP), and speed (SPD) are applied as traffic flow related variables. Malyshkina & Mannering, (2009) applied the average daily traffic (ADT) or annual average daily traffic (AADT) in modeling as traffic flow related variable and also consider number of lanes in each side, Chang & Wang (2006) used and applied ADT or AADT per lane as road geometry related variables. Delen *et al* (2006) and Ma *et al*, (2008) in modeling variables used average daily truck traffic (ADTT) or percentage of trucks to account for the role of heavy vehicles in frequency and severity of highway accidents or variables of average daily passenger car traffic and average daily truck traffic or percentage of trucks separately for detachment of the role of passenger cars and heavy vehicles in accident occurrence.

Anastasopoulos & Mannering, (2009) however used the average degree of curvature of horizontal curves, and gradient or length of vertical curves in traffic crash modelling. In each segment of highway have been applied in modeling in Hauer (2001). A limited access road is where traffic from local or distributor road is limited or controlled, and have less interference on highway traffic flow. Lee & Mannering, (2002), Chang, (2005), and Milton *et al*, (2008) applied variables of number of access roads, number of interchanges, at-

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grade intersections or ramps in specified distances of freeways or highways.

2.2 HUMAN RELATED FACTORS

Human related factors in road traffic accidents are all factors related to drivers and other road users, it includes driver behaviour, visual and auditory acuity, decision making ability and reaction time. Drug and alcohol use while driving is an obvious predictor of road traffic accident, road traffic injury and death (Adogu and Asuzu, 2009).

Human factors have the largest influence on the occurrence of accident events and include, the age of the road users, driver skills, attention, fatigue, experience, use of intoxicative substances and use of cellular-telephones (Petridou and Moustaki, 2000; Ogden, 2007). The contributions of human factors are too manifold and too complex to be controlled directly by the road infrastructure decision makers (Lum and Reagan, 2005). In order to control human factors, law- enforcement actions would be needed, e.g. stop-and-search operations by road safety (FRSC) officials.

2.3 POISSON REGRESSION MODEL

Poisson regression is one of the most suitable techniques for crash prediction modeling because highway crashes are discrete rare events and crash counts are non-negative integer variables. Poisson regression models also provide an easy linkage between crash occurrence and the concept of probability. This is because the number of crashes in a given space-time region can be considered as a random variable with probabilities that are Poisson distributed. Shankar *et al*, (2005) cited the general form of crash models derived using a Poisson regression model that *i*-th observation of dependent variable y_i is modeled as a random Poisson variables with mean λ_i

$$P(y_i) = \frac{e^{-\lambda_i} \lambda_i^{y_i}}{y_i!}$$

2.4 NEGATIVE BINOMIAL REGRESSION MODEL

A weakness of the Poisson approach is the unduly restrictive assumption that the mean and the variance of crash distribution are equal. In most crash data, however, it is seen that the variance is greater than the mean, giving rise to the over-dispersion phenomenon. To address this problem, the Negative Binomial model, a variant of the Poisson, has often been proposed for crash prediction modeling. The Negative Binomial model allows for additional variance representing the effect of omitted variables. In a study for Indiana, Brown *et al*. (2000) developed crash prediction models for crash rates on road segments based on geometric and access control characteristics.

The *i*-th observation of dependent variable y_i has the following probability distribution function:

$$P(y_i) = \frac{\Gamma(y_i + r)}{y_i! \Gamma(r)} \left[\frac{\mu_i}{\mu_i + r} \right]^{y_i} \left[\frac{r}{\mu_i + r} \right]^r$$

The conditional mean of for the vector of observed independent variables, x_i is given by:

$$E(y_i / x_i) = \mu_i = e^{x_i/\beta}$$

2.5 ZERO-INFLATED NEGATIVE BINOMIAL (ZINB) REGRESSION MODEL

The other problem, which accident data often encounter, is preponderance of excess zero data. In other words, number of zero data is more than expected in Poisson and NB models. If one meets with excess zero data while data mining, uses zero-inflated (ZI) distribution for data analysis.

Since Poisson and negative binomial crash frequency models do not account for the distinction that some sections of roadway are truly safe (near zero-accident likelihood) while others are unsafe but happen to have zero crashes observed during the period of observation, they could produce biased coefficient estimates because of the preponderance of zero-crash observations. The zero-inflated family of models were developed by (Miaou & Lum, 2003) and extended by (Shankar *et al*, 2007) and (Ivan & O'Mara, 1997). Zero-inflated count models are appropriate when some observations have no chance of experiencing the event

The particular ZINB regression model considered in this study has the following form:

$$p(Y_i = y_i) = e^{-\theta r_i} \quad \text{if } y_i = 0$$

$$\left(\frac{1 - e^{-\theta r_i}}{1 - e^{-r_i}} \right) \frac{r_i^{y_i} e^{-r_i}}{y_i!} \quad \text{if } y_i = 1, 2, 3, \dots$$

and

$$r_i = v_i \left[e^{x_i/\beta} \right] = v_i \left[e^{\sum_{j=1}^k x_{ij} \beta_j} \right] \quad i = 1, 2, 3, \dots, n$$

where $0 < \theta \leq 1$. (Note that for $\theta > 1$, the probability of observing zeros is deflated rather than inflated.)

3 METHODOLOGY

In this research, the accidents of single carriageway of Ilesha-Akure-Owo road, South-West, Nigeria is modeled by three regression models—Poisson, Negative binomial (NB), and Zero-inflated Negative binomial (ZINB). Two groups model were developed, one for crash frequency and the other for crash severity. Independent variables applied in these models include traffic-related and geometry-related variables. Traffic Flow-related variables include traffic volume, percentage heavy good vehicle and speed and geometry-related variables include lane width, horizontal curves and access roads. Ilesha-Akure-Owo Road, South-West, Nigeria is a very important road linking Osun State to Ondo State in South-West, Nigeria; the 110-kilometre, two lane single carriageway road is heavily trafficked, with significant

proportion of heavy vehicles and horizontal curves in the mix. The route is divided into 55 sections; the main factors that influenced the choice of length of road section were the road features, and road landmarks.

STATA 13.0 was used for statistical computations related to models. After statistical analyses, it is found out which parameters affect traffic accident occurrence and which does not have much part in traffic accident occurrence. Regression analysis was run on the data collected from 2012 – 2015 to build accident prediction model. The study compare Poisson and NB regression models with ZINB regression models, the study use significance of dispersion parameter and likelihood ratio (LR) test as criterions. Vuong statistic is used for model comparison, it is one stage of comparison; the other stage is the use of Akaike Information Criteria (AIC) for goodness-of-fit evaluation of models and their fit comparison, AIC is calculated as:

$$AIC = -2LL + 2k$$

where LL is log-likelihood, k number of parameters and n number of observations. The lower AIC is, the more model fit and model with the least AIC is the fit test one (Hauer, 2001). Results of the second stage of comparison often approve the first stage conclusion

4 DATA

Ilesha–Akure–Owo Road, South-West, Nigeria is used as a case study route for modeling two-lane highway. The 110km road is divided into 55 sections, the data on road traffic accidents (RTA) was obtained from the Federal Road Safety Commission (FRSC), Akure unit between 2012 and 2015. In this research, model are applied to number of accidents cases (crash frequency) and crash severity (Minor, Serious and Fata Injury accidents), highway sections are based on road features, and road landmarks. The traffic flow related variables including sectional traffic volume (AADT), percentage heavy good vehicle (HGV), speed (SPD) and traffic sign post (TSP) and geometric variables including lane width (LW), Curve radius (CR), vertical gradient (VGRAD), deflection angle (Δ), Shoulder factor (SF) and access points (CHAR), are applied as independent variables of models in this investigation. The summary statistics of the independent variables of the models is presented on Table 1.

5 STATISTICAL MODELING

The research intends to explore in this investigation, by modeling the effective factors on frequency and severity of crashes on 2-lane single carriageway. The well-known models of Poisson, Negative binomial (NB), and (ZINB) are applied to developing two groups' model for crash frequency and crash severity. For evaluating significance of independent variables, the statistic for each parameter is also constructed as the ratio of the parameter estimate over its standard error. If the p-value of a parameter is less than needed level of significance (0.05 or less), the corresponding variable is significant and will stay in model, otherwise it is neglected and leaves the model (Ivan & O'Mara, 1997). The calculations were process by STATA, estimated parameters and their

significance evaluation for accidents with crash frequency and crash severity are presented in Table 2, 3 and 4.

6 RESULTS AND DISCUSSION

The crash prediction modeling for the single carriageway yielded results that indicated varying result unlike the other variables, the general results of all the models, are discussed on a variable-by-variable basis using ZINB model, it is the model that takes into consideration sections with zero crash record.

6.1 TRAFFIC FLOW CHARACTERISTICS

Traffic Volume "AADT" turned out to be a significant variable in all the crash models: Higher AADT is associated with higher crash frequency. If AADT increases by one unit in two-lane road, the crash severity would increase by 6.2% ($e^{\ln(1.0713)}$). The model results also showed that percentage heavy good vehicle "HGV", is an influential factor affecting crashes on single carriageway road. From the model results, it is seen that a percentage number heavy good vehicle is associated with higher crash frequency. One unit increase in HGV, will increase probability of crash severity by 0.92% ($e^{0.01164}$).

It was determined that the traffic Sign Posted "tsp", served to reduce the frequency of crashes, as seen from the model results, as the presence of traffic signs along the highway is expected to engender more cautious driving. TSP plays an important role in safety enhancement, a well-informed driver or one made aware of imminent danger can respond appropriately to avert a potential crash situation. A unit increase in tsp factor, reduces the probability of crash severity on two-lane road by 4.1% ($e^{-0.05439}$).

6.2 GEOMETRIC CHARACTERISTICS

The modeling results showed that the Lane Width variable, LW, was found to be a significant factor in all the crash models for single carriageway. The negative coefficient for the lane width in all the models indicates that wider lane widths are associated with lower crashes. The result is consistent with expectation because wider lanes serve as buffer zones offering more opportunity for errant vehicles to recover or for vehicles to seek temporary refuge to avoid an errant oncoming vehicle and therefore reduce the risk of collision. If LW decreases by one unit in ZINB model, the probability of crash frequency on single carriageway would increase by 2.9% ($e^{-0.03328}$).

The Shoulder factor variable was shown to have a significant influence on crashes at single carriageway road. Increasing quality of shoulder is associated with decreasing crash frequency, as reflected in the negative coefficient. If SF decreases by one unit in ZINB model, the probability of crash frequency on single carriageway would increase by 7.2% ($e^{-0.08309}$). Wider and good paved shoulders enhance safety by providing additional buffer zone where operators of stray vehicles can regain control, recover from error and resume normal travel.

Table 1. Statistical attributes of roadway independent variable

Variables	Single Carriageway (Ilesha-Akure-Owo Road)				
	Mean	SD	Var.	Min.	Max.
Traffic Characteristics					
Average Annual Daily Traffic (AADT)	8159.7	784.1	614890	7344	9156
Percentage Heavy Good Vehicle (HGV)	5.36	1.64	7.69	3.2	7.1
Speed (SPD)	97.67	23.03	530.56	41	122
Traffic Sign Post (TSP)	0.25	0.44	0.19	0	1
Geometric Characteristics					
Curve Radius (CR)	743	567	43.92	712	1329.6
Deflection Angle (Δ)	1.91	0.34	0.05	22	58
Vertical Gradient (VGRAD)	0.46	2.80	7.81	-5.2	5.8
Lane Width (LW)	10.78	0.58	0.33	9.8	11.5
Access Road Points (CHAR)	2.47	0.81	0.66	1	3
Shoulder Factor (SF)	2.24	0.821	2.674	0.46	3.67

Table2. Poisson Model Calibration Results

Variable	Crash Frequency		Crash Severity	
	Coefficient	P-Value	Coefficient	P-Value
Constant	93.91557	0.012	62.16095	0.398
InaadT	9.90121	0.018*	11.071118	0.030*
hgv	1.10341	0.065	.0106112	0.047*
spd	.024308	0.034*	.0084413	0.499
tsp	-.001121	0.586	.0544111	0.046*
Δ	.2612481	0.811	.0027001	0.122
cr	-.0116731	0.017*	-.01174421	0.000*
vgrad	-.4153123	0.061	-.0096330	0.375
lw	-.03491607	0.063	-.0312800	0.034*
char	-.016544	0.000*	-.0235331	0.028*
sf	-.0700031	0.011*	-.0730214	0.013*
LL	-157.11972		-114.41058	
LR chi2(12)	-67.12		-174.59	
Prob>chi2	0.0000		0.0000	
Pseudo R2	0.1760		0.4328	

Table 3. Negative Binomial Model Calibration Results

Variable	Crash Frequency		Crash Severity	
	Coefficient	P-Value	Coefficient	P-Value
Constant	72.17181	0.012	32.1224	0.398
InaadT	8.28054	0.018*	1.311376	0.030*
hgv	.7389483	0.065	.08193	0.047*
spd	.0223778	0.024*	.0047341	0.499
tsp	-.012211	0.586	.1425507	0.016*
Δ	.0630894	0.112	.092374	0.686
cr	-.0664533	0.017*	.0257574	0.000*
vgrad	-.2911084	0.059	.0761125	0.375
lw	-.02300849	0.093	.1632277	0.033*
char	-.0172311	0.000*	.0966114	0.028*
sf	-.0406137	0.011*	.1038098	0.013*
LL	-118.09971		-81.0997	
LR chi2(12)	55.36		58.44	
Prob>chi2	0.0000		0.0000	
Pseudo R2	0.1498		0.2788	

Table 4. Zero Inflated Negative Binomial Model Calibration Results

Variable	Crash Frequency		Crash Severity	
	Coefficient	P-Value	Coefficient	P-Value
Constant	93.91558	0.009	-72.21855	0.398
Inaad	9.873875	0.014*	11.071309	0.030*
hgv	1.10752	0.082	.0116397	0.047*
spd	.021819	0.039*	.0094748	0.499
tsp	-.02172	0.034*	-.0543877	0.034*
Δ	.2812522	0.071	.0047112	0.093
cr	-.0126768	0.043*	-.0137496	0.000*
vgrad	-.4553452	0.099	-.0096915	0.375
lw	-.03791803	0.072	-.0332823	0.033*
char	-.016445	0.000*	-.0245384	0.048*
sf	-.071211	0.036*	-.0830855	0.031*
LL	-121.2433		-84.4106	
LR chi2(12)	58.25		58.44	
Prob>chi2	0.0000		0.0000	

Horizontal Curve result, CR, was a significant factor in the entire single carriageway crash model. The model results suggest that sections with a higher degree of horizontal curves have more crash occurrence. Curve radius (CR) was a significant factor in all the crash models. This finding suggests that sections with lower average curve radius experience more crashes, if CR decreases by one unit in ZINB model, the probability of crash frequency on single carriageway would increase by 1.8% ($e^{-0.01375}$). A wider horizontal curve radius provides smoother transition between tangent section and leads to reduction of centrifugal forces on vehicles negotiating the curve, thereby reducing the risk of overturning.

6.3 MODELS EVALUATION AND COMPARISON

What is considerable after modeling, is not only significant variables issue but goodness-of-fit evaluation and comparison between models *i.e.* not only after modeling we will see which variables have considerable effect on likelihood of crash frequency and crash severity, but model fit and comparison issue is also considered. After receiving results, first Poisson and NB models are compared in terms of data dispersion, so the significance evaluation of dispersion parameter in NB model and LR test is implemented.

Vuong test which is useful in comparing non-nested models (Washington, et al, 2003), it can be compared with z-values. Hence, if V is greater than $V_c = 1.96$ (critical value assuming a 95% confidence level) the test favors the selection of the ZINB model. , V is approximately 2.02, from this we can see that despite zeros in the data, the superiority of the ZINB model over the NB model is statistically confirmed. The other step of comparison is goodness-of-fit evaluation of models and their fit comparison, so (AIC) are employed. The results of comparison in the second stage often approve the first. From Table 5 dataset for two-lane road, Zero Inflated Negative binomial regression model also have the best model data fit, it has the least AIC value of 186.2, compared to Poisson model and Negative Binomial model that give values of 211.5 and 192.8 respectively. The results of goodness-of-fit evaluation of models and their comparison are also presented in the Table 5.

Table 5. Results of model evaluation and comparison for two-lane road

	Poisson	Negative Binomial	Zero Inflated Negative Binomial
alpha	-	6.238(16.59)	1.488(18.03)
AIC	211.5	192.8	182.6
likelihood ratio statistic	67.29	56.43	73.43
Vuong Statistics	-	-	2.02
Goodness of fit	69.03	79.11	80.37

7 CONCLUSIONS

In this research, the four years accident data (2012 – 2015) from FRSC on Ilesha-Owo-Akure road highways were used for the analysis and evaluations; traffic related factors and road geometric characteristics variables used as independent variables of models to scrutinize the impact and effect on traffic crashes. The statistical methodology applied in this research, is employing three well known regression models in modeling highway accidents comprising Poisson, Negative binomial and Zero-inflated Negative binomial regression models.

In this study, two groups model was developed, one for crash frequency and one for crash severity (Minor, serious and fatal injury accidents) and concluded that, the likelihoods of no injury and more severe accidents increase with increase in traffic volume and existence of number of horizontal curves and access roads, also as shoulder factor and speed. The likelihood of reduction in crash severity with lane width increment, but it does not have much effect on likelihood of more severe accidents. The results of research indicate that, the percentage of heavy good vehicle have increasing impact on likelihood on crash frequency and crash severities on two-lane road. After that, the study considered goodness-of-fit evaluation and comparison between models and concluded that, Zero Inflated Negative Binomial (ZINB) regression model is the best and fittest model for crash frequency and crash severity prediction.

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