



Relationship between Road Environment and Road Traffic Crashes in Metropolitan Lagos: A Multiple Linear Regression Analysis

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Abstract

This study investigates the relationship between road environment and road crashes in metropolitan Lagos, Nigeria, to assess the contribution of road factors to crash occurrence. Ten years (2013-2022) crash data was obtained from Federal Road Safety Corps and plotted with ArcGIS tools to determine the black spot before further locational data were collected. Land use, road condition, crash time, road geometry, and traffic calming attributes of the road were assessed using a multiple linear regression model. The study revealed that among the road environment parameters, traffic management had the most significant impact at 18.2%, followed by road condition at 7.98%, road geometry at 8.9%, time at 4.21%, land use at 1.3%, and road type at 1.2%, and all the parameters are significant at 0.05 level of significant. The model revealed that road factors explained 51.4% of the variation in road crash occurrence. The study concludes that the roles of traffic calming/management, road conditions, road geometry, and time in influencing the likelihood of road crashes are critical to achieving safer roads in the metropolitan area of Lagos. It is recommended that traffic calming and improving traffic management strategies be planned to enhance a safer road traffic system.

Keywords: Safer road, Blackspot, Road crashes, Road factor, Multiple Linear Regression, ArcGIS

Introduction

The road environment in many cities and urban areas in low-income countries like Nigeria presents wrong expectations to drivers, which often puts drivers in the critical situation of committing errors or being unable to avert the mistakes. Unexpected road situations without warning or information influence road users' perception and maneuverability of the road environment (Theeuwes, 2021). A safe road is a self-explaining and forgiving road, where the road is recognizable, distinguishable, and interpretable. A black spot is a road environment where the highest number of crash occurrences or severity is recorded than another part of the road segment, in other words, black spots are the unsafe part of the road.

Urban road networks are characteristic by high-density traffic and busy flow, as well as higher pedestrian interactions with the traffic environment, hence there is a need for a smart road (traffic management) to moderate the driver's speed and ensure the safety of all road users (Sloman, 2003). Traffic

management is a measure used to create safe and smart roads that can alter drivers' behavior, especially speeding, and reduce the frequency of collisions and severity (Gallagher, 2021). It promotes self-enforcing roads by the use of road geometry elements to promote speed compliance (USDOT, 2018), thereby reducing police monitoring and enforcement on the road (Gallagher, 2021). It includes intelligent traffic management techniques for altering and controlling speeds.

The safe system approach to road safety is based on providing a safe road transport system where no one will be killed or seriously injured on the road (Job, Truong, & Sakashita, 2022). *The concept of the safer road in the system approach is relevant to creating a road environment that will minimize wrong expectations, distinguish the road from surrounding activities, and provide recognizable and interpretable road information that will eliminate black spots and or make the road smarter.*

This study aims to examine the complex

relationship between road environment characteristics and road crash occurrence to develop measures and policies that will enhance the achievement of a smarter and safer road. It considered road variables such as crash time, road type, land use, road geometry, traffic calming/road safety measures, and road surface conditions. The overall road condition/situation is correlated with the crash occurrence to establish the relationship between the variables.

Literature Review

Road environment parameters are defined by the identified elements of the road, as acknowledged in the definition given by Pembuain, Priyanto, and Suparma (2018) that a road is a land transport infrastructure that includes all parts of the highway, including complementary buildings and equipment, with concern for road surface and geometric conditions in the achievement of safer road.

The causes of road traffic crashes are widely studied, and authors have variedly presented the factors as human, vehicle/mechanical, and environmental/road factors (Aworemi, Abdul-Azeez, and Olabode, 2010; Afolabi and Gbadamosi, 2017; Deme, 2019; Oyesiku, 2020). Some authors distinguished between environmental factors and road factors by drawing a line of distinction between the atmospheric environment and the physical environment while a host of others argue that the physical environment is often influenced by the prevailing atmospheric condition and as such the road and environmental indices are categorized as environmental factors.

Pembuain et al (2018) investigate the effect of road infrastructure formation on the risk of crashes. Elements of the road infrastructure were identified as road geometric, road surface condition, roadside hazard, complementary building of the road, and road equipment. In all the studies reviewed these elements have significant effects on road crashes. To corroborate the work of Pembuain, Mkwata, Eu, & Chong (2022) study the relationship between road pavement condition and road crashes, the review study identified predictors of pavement condition failure as the roughness of road surface, skid resistance, and road rutting. The study established that pavement surface condition has a strong positive relationship with road crashes. And that road crashes injuries and deaths are caused by drivers'

distraction which is indirectly linked to driving discomfort caused by pavement distress.

Scholars have found that bad road infrastructure influences crashes (Osayomi and Areola, 2015; Olusina and Ajanaku, 2017). Conversely, the work of Gbadamosi (2015) and Cantillo Garcés, & Márquez. (2015) has also shown that good road and road types influence the probability of higher road crash occurrence. Further to this discussion Osayomi (2013); Atubi (2012); and Mends-Brew et al. (2018) have also identified the length of road and the presence of traffic management facilities such as federal road safety agencies as predictors of road traffic crashes. Hossain and Zaman (2021) and Srisurin & Chalermpong (2021) have also found that time of the day (crash time) and road geometry (curved roads and conflict points) induce a greater positive risk of fatal crashes,

Umar, Rana, & Lodhi (2022) studied the impact of urban design and the built environment on road traffic crashes in Rawalpindi, Pakistan. Multiple linear and Tobit regression models were used to confirm the variables influencing the frequency of road crash occurrence and density, in the result, the model found that land use classes: commercial, residential, recreational, and open spaces were statistically significant predators of road crashes with positive relationship with hotspot density. In more specific terms, Lin et al., (2022) highlighted some land uses that create roadside attractions that are related to the risk of crashes including gas stations, convenience stores, supermarkets, and retail markets are related to the risk of a crash at intersections.

Several research has investigated the traffic situation in Nigeria and in Lagos state in particular, Bombom et al (2022) in a study of the underlying patterns in road traffic fatality rate in Nigeria between 2005 and 2018, discovered that Lagos state has a 0.52 fatality rate per crash which is the lowest among the state of the federation. The study further established that for 14 years, Lagos was second to Abuja in the number of recorded crashes with 10128 cases. During the period Lagos recorded an average death of 5270 deaths, which is below the mean rate of 8900 per year, and came to a distant 7th position in the ranking of states with road fatality. Olusina and Ajanaku (2017) found that accidents in Lagos are caused by the smoothness of the road, especially the expressway where the largest number of

crashes are recorded. The study added that 3.6% of accidents are caused by pedestrians' refusal to use pedestrian facilities e.g. bridges.

According to LAMATA (2018), Lagos state is small in landmass but has over 20 million urban population, the rate of population increase is higher than the annual urban growth rate of 6%, averagely the population influx into urban Lagos is at 600,000 yearly. Lagos registered over 20,000 vehicles annually and recorded 224 vehicles per kilometer of the road (Olusinal and Ajanaku, 2017) and on average generates over 20 million trips (LASMA, 2013) from Over 10 million commuters daily (Olusinal and Ajanaku, 2017), interestingly 95% of the trips generated are by road transport mode.

The road safety situation in Lagos state has improved through the government attention in the sector which focused on three major areas, namely the development of transport sector policy and strategies; commissioning of urban transport projects and the preparation of Lagos state strategic transport master plan 2010-2020. (LAMATA, 2013). Among so many interventions are, the establishment of Lagos drivers institutes, the establishment of the Lagos State Traffic Management Authority (LASMA), the establishment of urban transport management authority (Lagos Metropolitan Transport Authority LAMATA) and the Bus Rapid Transit (BRT), and road intersection improvement projects that cut across the state.

Central to the Lagos state transport policy and program is the road network efficiency improvement policy, the policy focuses on road construction and rehabilitation. The Lagos state government approached the road network efficiency from two areas, first is the road construction and maintenance by the Lagos State Ministry of Works and Infrastructure and second is the road improvement intervention under the Lagos Urban Transport Project (LUTP). Between 2017 and 2020, 156 roads aggregated to 145.561km were constructed under the ministry supervision, while under the LUTP intervention routine maintenance was carried out on a total of 275km of roads out of the 632km declared road network under the intervention. Other road improvement activities by the intervention include 57 junction improvements, 51.5km of road rehabilitation, and periodic maintenance of 45km of road (Lagos Bureau of Statistics, 2022; LAMATA, 2013). Despite this intervention in road improvement, road factors still contribute greatly to road crashes occurrence,

Methodology

Lagos is a state in south-west Nigeria, located on the latitude 6° 2'N to 6° 4'N and longitude 2° 45' E to 4° 20'E. Lagos state is statutorily divided into 20 local government areas and 37 local development councils, sixteen (16) of the local government areas are in metropolitan Lagos, which accommodates over 85% of the population. A ten-year (2013-2022) Comprehensive Road Traffic Crashes (RTC) data from Lagos State Sector Command of Federal Road Safety Corps were obtained, scanned, cleaned, and processed using ArcGIS, to identify the black spot, before road assessments was conducted to collect data on land use type, road geometric features, traffic management situation and road condition which was not in the secondary data obtained.

Road environment parameters' contribution to crashes is analyzed with a Multiple Linear Regression (MLR) form of ordinary least squares due to two main econometric reasons. First, the predicted variable for this study is numerical and continuous before Principal Component Analysis (PCA). The causes of road crash occurrence have qualitative data derived from the road accident record of the Lagos metropolitan area as provided by the Federal Road Safety Commission (2023). The qualitative data was first analyzed with the aid of PCA to provide index scores for all indicators of the probable causes. Thus, the use of the MLR model is most suitable to produce parsimonious results. PCA procedure which is followed by the specification of multiple linear regression (or OLS) models in the second stage is provided thus:

$$PCI_{score} = \sum_{i=1}^n F_i W_i \dots (1)$$

Where,

PCI_{score} = Probable Cause Index score (or Aggregate Cause Index); F = absolute factor loadings; W set of indicators (overall cause indicators); i = individual observation. The number, n , indicates the quantity of predictor variables within each measure.

Consequently, the respective levels of all the observed predictors are taken into account to formulate an expanded model that explains the relative contribution of each road parameter to causes of road crashes. This procedure is required to provide a holistic and comprehensive understanding of the role of time, road

geometry, road type, land use, road condition, and traffic calming/management to the risk factors of road crashes in the Lagos metropolitan area for the period under review. The equation to this effect is formulated thus:

$$\begin{aligned}
 PCI_i = & \alpha_i + \beta_{1_ITIM_2_i} + \beta_{2_ITIM_3_i} + \beta_{3_IROG_2_i} + \beta_{4_IROG_3_i} + \beta_{5_IROG_4_i} + \beta_{6_IROG_5_i} + \beta_{7_IROG_6_i} + \beta_{8_IROT_2_i} + \beta_{9_IROT_3_i} + \beta_{10_ILAU_2_i} \\
 & + \beta_{11_ILAU_3_i} + \beta_{12_ILAU_4_i} + \beta_{13_ILAU_5_i} + \beta_{14_ILAU_6_i} + \beta_{15_ILAU_7_i} \\
 & + \beta_{16_ROC_2_i} + \beta_{17_ROC_3_i} + \beta_{18_TRM_2_i} + \beta_{19_TRM_3_i} \\
 & + \varepsilon_i \dots (2)
 \end{aligned}$$

Note that some levels of predictors such as *_ITIM_1*, *_IROG_1*, *_IROT_1*, *_ILAU_1*, *_IROC_1*, and *_ITRM_1* are missing in the equation because they are treated automatically by the system (STATA 12.1) as "reference groups".

The equation is further calibrated into the linear equation to account for a percentage of linear prediction of causes by road parameters. The estimates for this analysis activity are obtained via "standardized beta" regression coefficients. The Equation (3) is formulated as thus;

$$\begin{aligned}
 PCI_i = & \alpha_i + \beta_{20}TIM_i + \beta_{21}ROG_i + \beta_{21}ROT_i + \beta_{23}LAU_i + \beta_{24}ROC_i \\
 & + \beta_{25}TRM_i + \varepsilon_i \dots (3)
 \end{aligned}$$

Where,

TIM = Time of the day; *ROG* = Road geometry; *ROT* = Road type; *LAU* = Land Use; *ROC* = Road Condition; *TRM* = Traffic Management; α = model constant; $\beta_1 - \beta_{25}$ = slope coefficients

Result and discussion

In the consideration of the contribution of road parameters to the probable cause of the crashes in Lagos metropolitan areas, an assessment of the components of the dependent variable (probable cause) was first conducted to establish goodness of fit for the component using Principal Component Analysis (PCA) of Factor Analysis tool. The result revealed that 22 out of the 24 risk factors loaded for the probable cause index, and for the human, vehicle, and road index all the factors assessed present strong positive or negative scores. This means that the risk factors are a good measure of the dependent variables. Consequently, the derived indexes (*PCI*, *HFI*, *VFI*, and *RFI*) through PCAs after diligent consideration of suitable

factors on appropriate components are further employed as continuous variables for each of the models (1, 2, and 3) specified in the methodology section.

The result of the contribution of each road parameters (independent variable) predictor is estimated with the assumption that other factors are held constant. The estimation of the influence of time of the day revealed that afternoon and midnight time influenced the probable cause of crash compared to morning time. This result differs partly from the findings of Hossain and Zaman (2021) who found that the probability of time of the day influencing crash is high in the morning and midnight, though the result appears to be statistically insignificant ($F\text{-Stat} = 0.47$; $p\text{-value} = 0.6260$) at both 5 percent and 10 percent level of significant. The time of the day as a predictor of road crashes is not significant ($F\text{-stat} = 0.47$; $p\text{-value} = 0.6260$), this also differs from the earlier studies which show a significant relationship between road crashes and time of the day.

Interpretation of the result of road geometry variables revealed that straight ways ($p\text{-value} = 0.000$), bends ($p\text{-value} = 0.000$), and roundabouts ($p\text{-value} = 0.000$) are predictors of road geometry that significantly influence the probable cause of road traffic crashes in the Lagos metropolitan area. The study further revealed that road bends, straightways, and roundabouts produced a reduced influence on probable causes of crashes than intersections. Overall, road geometry is found to be a significant ($F\text{-Stat} = 37.59$; $p\text{-value} = 0.000$) predictor of probable cause of crashes in the study area. Contrary to an earlier study (Srisurin et al., 2021) which found a positive influence of road geometry on road crashes. The result of this study indicated that road bends, roundabouts, and straightways are more likely to generate a reduced influence, this could be the result of a well-treated road section which helps in moderating driving behavior or more likely that drivers are cautious of the challenges posed by these section of road.

The result of the road type factor revealed that both expressways and highways are more likely to aggravate probable risk factors of road crashes than access roads (street) by approximately 0.56 units and 0.62 units respectively. The result also indicates that the incidence of probable risk factors like sleeping on steering, brake failure, and tire burst increase more when the road is expressway by a point of 0.06 units in the study area. An expressway is a higher-order road, which is expected to have higher traffic carrying capacity, and higher speed or traffic flow than the

highway and access roads, they are trunk A roads that are owned and maintained by the federal government. Earlier studies have shown that more crashes occurred on expressways than the other types of roads (Gbadamosi, 2013). Cantillo et al (2015) attribute 67.6 percent of the crash to arterial roads, while highway and access roads are of lesser proportion. Hence, the result of this study has reinforced the earlier findings that expressway influence causes of crashes, and concludes that road type ($F\text{-stat} = 9.43$; $p\text{-value} = .0001$) is statistically significant at 5 percent and 10 percent levels of significance.

The result of the land use variable shows that residential, industrial, public, mixed-use, and port are less likely to increase probable cause factors than commercial use by approximately 1.10 units, 1.39 units, 0.61 units, 0.50 units, and 0.47 units respectively. This finding revealed that probable road risk factors decrease more with industrial use than any other uses when compared with commercial use by a magnitude of 0.29 units. It is proven further that residential land use ($p\text{-value} = .000$), industrial ($p\text{-value} = .000$), and mixed-use ($p\text{-value} = .019$) are significant at a 5 percent level of significance to reducing the incidence of probable cause factors in the study area while public use ($p\text{-value} = .089$) and port land use ($p\text{-value} = .076$) are statistically significant at 10 percent level of significance. The interpretation of this result shows that land use type other than commercial has a negative influence on probable cause of road crashes, unlike the finding of Umar et al (2022) which revealed a significant positive relationship between land use type and road crashes, similarly, Lin et al., (2022) found a correlation between commercial land use and road crashes. The final interpretation of the findings of this study shows an agreement with earlier findings that land use ($F\text{-stat} = 12.23$; $p\text{-value} = .0000$) is a significant variable in explaining the probable cause of the crash.

The result of road condition shows that fair road status and good road condition positively influence the probable cause of road crashes in the study area than poor road condition by approximately 0.35 units and 0.67 units respectively. This means that a good and fair road condition induces road traffic crashes. This result is surprising going by the theoretical belief that road risk factors should decrease with fair and good road conditions. However, this result reflects the dominant role of human factors among the probable risk indices in the study area such as brake failure, sleeping on the road, route violation, and among others. Of these two

variables, good road condition ($p\text{-value} = 0.005$) appears to be significant at both 5 percent and 10 percent levels of significance. Furthermore, the overall assessment of road condition variables revealed that road condition $F\text{-stat} = 4.86$; $p\text{-value} = .0079$) is a significant predictor of probable cause factors in the study area reinforcing the findings of Mkwata et al (2022).

Traffic calming as a predictor of risk factors revealed that the availability of traffic calming in bad and in good condition reduces the probability of risk factors when compared with locations without traffic calming, though both are significant at 5 percent and 10 percent, traffic calming in good condition is more significant by approximately 1.06 units than with both yes-bad and no traffic calming. Traffic calming and road safety management ($F\text{-stat} = 30.96$; $p\text{-value} = .0000$) is also found to be a statistically significant predictor of risk factors. This finding confirms the work of Osayomi (2013); Atubi (2012); and Mends-Brew et al. (2018) have earlier identified that the presence of traffic management facilities, such as traffic calming and road safety operations on the road reduces the probability of the risk factors.

In conclusion, road factor measured by the identified road parameters is empirically presented as having accounted for 51.4 percent level of variation in probable road crash risk factors (PCI) in the Lagos metropolitan area, when the predictors are considered at categorical levels. And of the road parameters, Traffic Management has the highest percentage impact of 18.2 percent followed by road condition (ROC) at 7.98 percent; road geometry (ROG) with 8.9 percent impact factor; time (TIM) at 4.21 percent; land use (LAU) with 1.3 percent) and road type (ROT) with 1.2 percent. This study confirms the more significant impacts of traffic management, road condition, road geometry, and time on probable risk factors to cause road crashes in the Lagos metropolis.

Further analysis of the risk factors into the broader classification of the causative Factors of human, vehicle, and road environment in the metropolitan area of Lagos presents that the human factor has an impact factor of approximately 45 percent which is followed by road factors representing 26.2 percent and marginal contribution of vehicle factors by 15.5 percent.

Table 1: OLS-based Multiple Regression and Auxiliary Regression Estimation Results of Road Environment Parameters Impact

Model 1 OLS-Based Multiple Regressions Dependent Variable: PCI					OLS-Based Auxiliary Regression (Model 3) Dependent Variable: RCR				
Variable	Coef.	Std. Error	t-value	p-value	Beta	Variable	Beta	t-value	p-value
<u>ITIM_2</u>	.1028	.1062	0.97	0.333		HFI	.4533	-3.67	0.000**
<u>ITIM_3</u>	.0394	.2023	0.19	0.846		VFI	.1545	2.53	0.011**
<u>IROG_2</u>	-1.3641	.1294	-10.54	0.000**		RFI	.2618	6.15	0.000**
<u>IROG_3</u>	-.7776	.1568	-4.96	0.000**					
<u>IROG_4</u>	.0792	.2763	0.29	0.724					
<u>IROG_5</u>	-1.4111	.1666	-8.47	0.000**					
<u>IROT_2</u>	.5594	.1438	3.89	0.000**					
<u>IROT_3</u>	.6189	.3675	1.68	0.092*					
<u>ILAU_2</u>	-1.0993	.1570	-7.00	0.000**					
<u>ILAU_3</u>	-1.3898	.3234	-4.30	0.000**					
<u>ILAU_4</u>	-.6066	.3567	-1.70	0.089*					
<u>ILAU_5</u>	-.5042	.2145	-2.35	0.019**					
<u>ILAU_6</u>	-.4691	.2643	-1.77	0.076*					
<u>IROC_2</u>	.3485	.2171	1.61	0.109					
<u>IROC_3</u>	.6645	.2347	2.83	0.005**					
<u>ITRM_2</u>	-.3008	.1447	-2.08	0.038**					
<u>ITRM_3</u>	-1.3619	.1749	-7.79	0.000**					
<u>cons</u>	1.2197	.2952	4.13	0.000**					
Model 2									
<u>TIM</u>				0.096*	.0421				
<u>ROG</u>				0.000**	-.0890				
<u>ROT</u>				0.639	-				
					.0120				
<u>LAU</u>				0.612	.0129				
<u>ROC</u>				0.000**	.1154				
<u>TRM</u>				0.000**	-.1820				
<u>_CON</u>	.7794	.3048	2.56	0.011**					
		T-test Result							
	F-stat	Prob > F							
<u>TIM</u>	0.47	0.6260							
<u>ROG</u>	37.59	0.0000							
<u>ROT</u>	9.43	0.0001							
<u>LAU</u>	12.23	0.0000							
<u>ROC</u>	4.86	0.0079							
<u>TRM</u>	30.96	0.0000							
Model Fitness Test					Breusch-Pagan / Cook-Weisberg test for heteroskedasticity				
	F-stat	Prob > F			chi2(1)	Prob > chi2			
Model 1	23.17	0.0000			Model 7	0.17	0.6845		
R² (Model 1)	51.41%								
Model 2	31.06	0.0000							
R² (Model 2)	57.91%								
Model 3	15.50	0.0000							
R² (Model 3)	83.10%								
Number of Observations	1,464								

Note: (i) Note that some levels of predictors such as ITIM_1, IROG_1, IROT_1, ILAU_1, IROC_1, and ITRM_1 are “reference groups”. (ii) Dependent

Variables: “PCI” = Probable Cause Index; “RCR” = Road Crash Rate; (iii) Independent Variables: “TIM” = Time of the day; “ROG” = Road Geometry; “ROT” = Road Type; “LAU” = Land Use; “ROC” = Road Condition; “HFI” = Human Factor Index; “VFI” = Vehicle Factor Index; “RFI” = Road Factor Index; (iv) Estimated Parameters: “Coef” = Slope Coefficient; “Std. Error” = Standard Error; “t-value” = test statistics; “p-value” = probability value of estimated coefficient at 5% level of significance. (v) Decimal placement: values of “coef.” and “std. Error” are at four decimal places (4 d.p.); values of “t-value” at 2 d.p and values of p-value at 3 d.p. (vi) * = significance at 10% level; ** = significance at 5% level.

Source: Researcher’s Computation from STATA 12.1 Outputs (2024)

Conclusion

In conclusion, the study revealed that among the road environment parameters, traffic management had the most significant impact at 18.2%, followed by road condition at 7.98%, road geometry at 8.9%, time at 4.21%, land use at 1.3%, and road type at 1.2%. All the parameters are significant at 0.05 level of significant. The model revealed that road environment parameters collectively explained 51.4% of the variation in road crash occurrence. This study reaffirms the critical roles of traffic calming/management, road condition, road geometry, and time in influencing the likelihood of road crashes in Lagos, highlighting the importance of considering traffic calming/management to enhance safer roads in the metropolitan area of Lagos. The study recommends planning and designing traffic calming for the road network, especially the blackspot corridor, and enhancing traffic management strategies to moderate the road traffic system.

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