Article

Towards Promotion of Road Safety: Crash Diagnosis for the Odumasi-Oterkpolu Road, Ghana

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Abstract

Crashes in road curves contribute significantly to road traffic fatalities in developing countries. The crash risks increase when there are multiple vertical and horizontal curves on the road section. In this study, we diagnose the crash-contributing factors along the crash-prone and curvy Odumasi-Oterkpolu road in Ghana and propose countermeasures. Spot speed counts were done using radar guns in addition to manual traffic counts, field inspections, and victim self-reports. Secondary police crash data (from 2015 to 2019) were collected from the Building and Road Research Institute of Ghana. Multiple regression and descriptive analyses were computed to identify crash-contributing factors. Vehicle brake failure and driver inattention were identified as the main driving errors that contribute to crashes in the road curves. Notably, the majority of crashes involved movements in left-turning lanes, in other words towards drivers' left sides. Speed, traffic volume, and the volume of motorcycles and medium trucks had the strongest association with fatalities. Overall, the road lacks street lights, guardrails, road signs, road markings, posted speed limits, and durable pavement. This is the first empirical investigation of the studied road; therefore, the findings and proposed countermeasures will help to improve road design and safety measures.

Keywords: crash diagnosis; traffic survey; curvy roads; horizontal curves; vertical curves; Ghana

Social and Health Sciences
https://unisapressjournals.co.za/index.php/SaHS/index
#11845 | 31 pages

Introduction

Approximately 93% of road fatalities occur in low- and middle-income countries, and the highest death rates of road traffic injuries occur in Africa (World Health Organization, 2018). In sub-Saharan Africa, alarming road traffic fatalities (Alimo et al., 2022) and poor road infrastructure have been reported (Tamakloe et al., 2021). The crash risks increase when there are multiple vertical and horizontal curves on the road section (Zegeer et al., 1991). To provide countermeasures, engineers require a prior crash diagnosis to identify crash contributing factors (Rakotonirainy et al., 2015). The Highway Safety Manual provides a three-step methodology for road facilities' crash diagnosis (American Association of State Highway and Transportation Officials [AASHTO], 2010). This provides engineers with up-to-date information on road infrastructure, crashes, and countermeasures. Crash diagnosis is relevant in promoting safer communities since road curves have different user behaviours, geometric properties, pavement conditions, and environmental conditions (AASHTO, 2010).

Several studies have found a strong association between geometry, condition of road infrastructure, and crash frequency in road curves. In a nationwide road network analysis in the Czech Republic, researchers found that curves with a higher crash risk have lower radii with around 10% of road segments containing at least one dangerous horizontal curve (Bíl et al., 2019). This makes road curves a critical part of road segments that require the utmost attention from traffic safety engineers. Hummer et al. (2010) found that the curve length, traffic volume, lane width, and curve radius are major crash contributing factors. Their review of some previous studies provided 37 potential countermeasures that can be used to reduce the frequency and/or severity of horizontal-curve collisions, particularly on two-lane roads. The significant effects of road traffic signage, drivers' behaviours, and environmental factors on crash frequency in road curves have also been established (Zegeer et al., 1991). Speed estimation among drivers is more accurate when there are warning and speed limit signs (Findley et al., 2012; Milošević & Milić, 1990). Consequently, Torbic et al. (2004) proposed 20 countermeasures to improve the safety of horizontal curves, including traffic control devices, road markings, sight distances, and horizontal alignments.

However, Nama et al. (2016) noted that previous studies largely focused on only horizontal curves. Traversing several vertical curves can affect drivers' attention and behaviour in adjoining horizontal curves. It is imperative to study both vertical and horizontal curves together. In addition, previous crash identification and diagnostic studies in curves exclude the victims' perspectives. Victim self-reports complement police reports (Boufous et al., 2010; Rakotonirainy et al., 2015). In addition, curve crashes have received more attention in developed countries than in low- and middle-income countries. Crash diagnosis is therefore imperative to improve the safety of municipal roads, which are important to the national road network because they are the feeders of regional roads, and all the local freight such as agricultural produce and mining or manufacturing raw materials are transported through them.

As the Decade of Action for Road Safety (2021–2030) seeks to reduce road traffic injuries by 50% in Ghana, dangerous road curves and crashes along curvy roads would require more attention. As far as we are concerned, there is no previous crash diagnosis focused on crash-prone curvy roads or road curves in Ghana. In this study, we adopted a field investigation to diagnose crashes along the Odumasi-Oterkpolu municipal road in Ghana and propose safety measures. In recent years, safety concerns about this road have heightened in Ghana, especially regarding the Asitey curve, which is crash-prone (Bokpe & Adjase-Kodjoe, 2019; Ghanaweb, 2022; Nyabor, 2019). However, there is no scientific field evidence to deal with the incessant crashes. Our study seeks to provide empirical evidence to guide decision-making and engineering. The findings can help improve road designs in Ghana and curve treatments to reduce road traffic injuries.

In this study, we, therefore, seek to (1) identify the crash contributing factors on the road, (2) analyse associations between speed, traffic volume, left-turning and right-turning movements, crash severities (property damage only, hospitalised crashes, and non-hospitalised crashes) and fatal crashes, and (3) discuss countermeasures and treatments for injury prevention and safety control. Given the high incidence of road traffic injuries in Ghana, the findings will be beneficial for traffic engineering and safety decisions towards promoting safer communities.

Methodology

Case Study Road

The studied road is a 25 km single-lane dual carriage municipal road traversing the Oterkpolu Junction and the Odumasi Junction within the Yilo and Lower Manya municipalities in the Eastern Region of Ghana. The Yilo Krobo Municipality covers an estimated area of 805 km^2, which represents 4.2% of the total area of the Eastern Region and a population density of 109 persons per km^2. Similarly, the Lower Manya Krobo municipality covers an area of 1 476 km^2, constituting about 8.1% of the total land area within the Eastern Region. The traffic flow comprises trips generated from the two municipalities, the adjoining Upper Manya Krobo district, and several other rural communities in other neighbouring districts. It serves as the major route for trips from these areas to Accra, Koforidua, and other parts of Ghana. The main occupation in these areas is farming. Trucks that transport agricultural commodities as far as Burkina Faso use this road. In addition, one of Ghana’s major limestone mines is in neighbouring communities and their heavy goods vehicles (HGV) use this route. This road, therefore, has a high traffic demand and heavy load. Figure 1 shows the geographical setting, the target curve, and other geospatial landmarks.

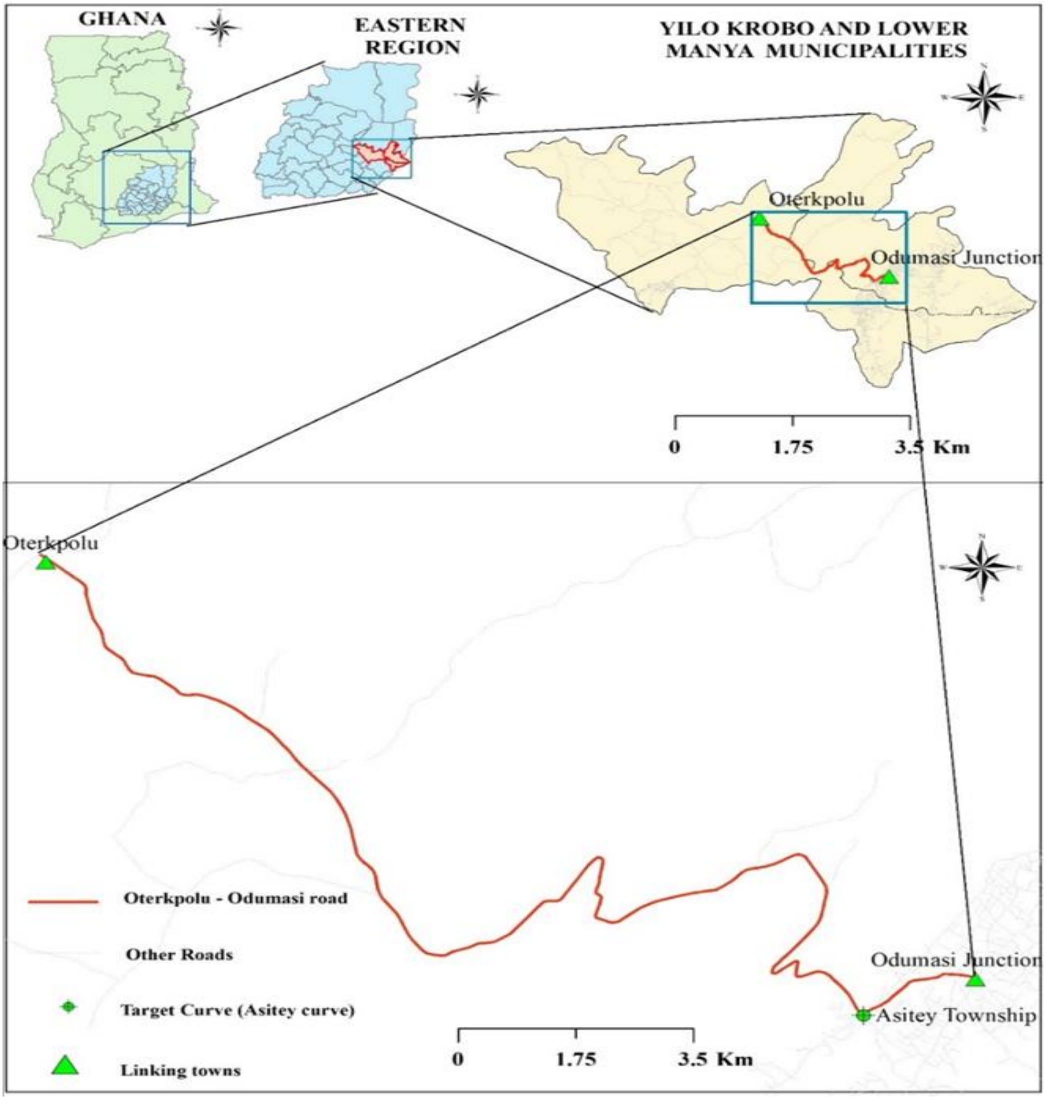

Figure 1: The geographical setting of the study

Crash Data Sourcing and Analysis

This study uses the three-step guideline for crash diagnosis provided by the Highway Safety Manual (AASHTO, 2010). It comprises (1) police crash data analysis, (2) field investigation, traffic survey, and interviews of crash victims, and (3) analysis of crash contributing factors. Police crash reports from 2015 to 2019 were collected from the Building and Road Research Institute (BRRI) of the Centre for Scientific and Industrial Research of Ghana. The BRRI manages the national crash database of Ghana. The data include the number of casualties, crash severity, reported driving errors, collision types, vehicle types involved and vehicle movement or manoeuvre crashes. The crash locations were geolocated using google maps. They were then analysed with heatmaps to present all crash locations and the fatal crash locations. The geometric features of the curves were also collected.

Traffic Survey, Road Inspection and Victim Interviews

Professional engineers conducted a preliminary site inspection on 10 April 2021. This comprised inspection of road signage, road markings, pavement conditions, drainage, sight distance and visibility, lighting, vegetation cover, side barrier conditions, and other road infrastructure. The inspection was conducted on a Saturday because it is the market day in the municipality. Usually, market days offer an extreme form of traffic conditions, which are good for diagnosis. Saturdays are also characterised by several funerals and other cultural activities, which creates a high traffic demand and transport supply imbalances.

Traffic data were collected between 17 and 18 April 2021 by 16 enumerators supervised by professional engineers. Two sets of data were collected simultaneously; vehicle spot speeds and traffic counts. The speed and volume data were collected from designated curves along the road. Speed data were collected using radar guns and the volume data adopted manual counts of vehicles making left-turning movements (Oterkpolu towards Odumasi) and right-turning movements (Odumasi towards Oterkpolu) by enumerators in each direction. These curves were strategically chosen to capture turning tendencies and avoid waste of resources. This is because some curves may have sustained traffic volume owing to the lack of adjoining roads. The data collection lasted for 24 hours (06:00 to 06:00). A four-hour shift system was used for the data collectors; one measuring speed, and another recording, with the third person on standby. They could change roles as often as the lead engineers visited them to ensure that the standard measurement and recording procedures were followed. The average vehicle volumes were also computed including the higher directional distribution and aggregated measure of traffic volume.

In April 2021, we interviewed two victims of past crashes on the road. Victim self-report has several benefits such as helping solicit information, which police reports may not include (Boufous et al., 2010). The interviewees were asked to give accounts of the crashes they experienced. This allows for comprehensive diagnoses of the problem, which some previous researchers did not consider. These reports were recorded and transcribed by us. The transcribed data were sent to the interviewees for confirmation before their inclusion in the final results.

Multiple Regression Analysis

The multiple regression analysis sought to find out how speed, traffic volume, geometric characteristics of the road (left-turning and right-turning movements), and crash severities (property damage only, hospitalised crashes, and non-hospitalised crashes) were associated with fatal crashes. We mixed traffic flow variables with crash severity variables since they have strong interactive effects on crash fatalities. Growth factors were applied to the data to reflect traffic change in class counts on the facility (Transportation Research Board [TRB], 2010). All skewness and kurtosis values (Table 1) were in the normal range (−2 and +2) except for speeds of small, medium, and large buses, light trucks, and trailers which are lightly-tailed (positive kurtosis). Moreover, values of the Shapiro-Wilk test of normality were greater than 0.05, indicating that the data do not significantly deviate from a normal distribution. Overall, 23 outliers were discovered that were retained for analysis upon inspection of variable box plots (Appendix A) and histograms. We also visualised the relationships between the variables by employing several scatterplots (Appendix B). After a visual inspection of individual scatterplots, the relationships appeared linear upon examination and there were no issues with heteroscedasticity (Hair et al., 2010). Plots of the residuals also showed that they were almost normally distributed (Appendix C).

Table 1: Descriptive statistics of variables used in modelling

Vehicle Type	Mean	SD	MAD robust	Skewness	Kurtosis	Shapiro-Wilk*	Min.	Max.
Shared tax speed (LT)	0.92	0.75	0.46	−0.43	−1.81	0.75	0.00	1.77
Medium bus speed (LT)	0.19	0.46	0.00	2.27	3.71	0.46	0.00	1.47
Medium bus speed (Both)	0.23	0.48	0.00	1.92	2.32	0.53	0.00	1.51
Light truck speed (LT)	0.84	0.68	0.53	−0.41	−1.80	0.76	0.00	1.64
Light truck speed (Both)	1.14	0.46	0.14	−2.03	3.03	0.65	0.00	1.58
Private car speed (RT)	1.16	0.54	0.16	−1.74	1.43	0.64	0.00	1.59
Pickup/4WD volume (LT)	0.53	0.61	0.22	0.46	−1.67	0.76	0.00	1.46
Pickup/4WD volume (RT)	0.62	0.51	0.74	0.23	−1.37	0.89	0.00	1.42
Pickup/4WD volume (Both)	1.11	0.60	0.28	−1.32	0.04	0.70	0.00	1.65
Small bus/Van speed (LT)	1.05	0.64	0.29	−1.06	-0.70	0.72	0.00	1.67
Small bus/Van speed (RT)	1.32	0.42	0.12	−2.82	7.53	0.57	0.00	1.70
Large bus speed (RT)	0.06	0.29	0.00	4.89	23.92	0.22	0.00	1.42

Vehicle Type	Mean	SD	MAD robust	Skewness	Kurtosis	Shapiro-Wilk*	Min.	Max.
Heavy truck speed (Both)	0.74	0.62	0.86	−0.16	−1.69	0.83	0.00	1.61
Trailer speed (RT)	0.70	0.73	0.83	0.08	−2.07	0.73	0.00	1.63
Motor bike volume (LT)	0.41	0.42	0.58	0.62	−0.58	0.85	0.00	1.28
Medium truck volume (RT)	0.33	0.47	0.00	1.15	−0.17	0.71	0.00	1.23
Medium truck volume (Both)	0.59	0.54	0.77	0.42	−1.13	0.88	0.00	1.54
Extra-large truck volume (LT)	0.58	0.65	0.45	0.51	−1.44	0.79	0.00	1.65
Extra-large truck volume (RT)	0.25	0.39	0.00	1.11	−0.68	0.63	0.00	0.95
Extra-large truck Volume (Both)	0.63	0.70	0.45	0.40	−1.66	0.78	0.00	1.72
Trailer volume (Both)	0.71	0.66	0.93	0.29	−1.40	0.87	0.00	1.83
Hospitalised crash	0.57	0.39	0.45	0.01	−1.21	0.93	0.00	1.26
Not hospitalised	0.36	0.39	0.45	0.47	−1.52	0.80	0.00	1.00
PDO crash	0.30	0.28	0.45	0.35	−1.06	0.87	0.00	0.85

**P*-values of Shapiro-Wilk: $p < 0.01 < 0.05$.
Standard error of kurtosis = 0.918. Standard error of skewness = 0.472. MAD = median absolute deviation. Max. = maximum. Min. = minimum. SD = standard deviation

There were no significant issues with multicollinearity since all retained models had variance inflation factor (VIF) values less than 10 and tolerances greater than 0.10 based on the rule of thumb (O'Brien, 2007). Residual histograms also indicated that standardised residuals were almost normally distributed. The values of median absolute deviation which is a more robust statistic and more resilient to outliers in data than the classical standard deviation indicated acceptable stability or dispersion of our data set. Combined checks for the distribution of errors based on the Shapiro-Wilk test, skewness and kurtosis values, and boxplots showed no significant violation of error normality. Finally, the Durbin-Watson checks for correlations between residuals were satisfied (ie values were within 1 to 3) (Draper & Smith, 1998).

Since most of the residuals are approximately centred on zero, our models undoubtedly fit the assumption of heteroscedasticity. The 24 retained variables are therefore suitable for the construction of multiple regression models. Equation 1 was used to perform the multiple regression analysis with the backward elimination technique. Results of the tested assumptions including marginal effects plots for both turnings can be found in Appendix D.

$$FC = \beta_0 + \beta_i\,(VT_i + NS_j) + \ldots + \beta_{m+n}\,(VT_m + NS_n) + \xi \qquad \text{Equation 1}$$

Where *FC* denotes the response variable (fatal crash), *VT* signifies vehicle type *i* with given characteristics (speed and traffic volume taking into account left-turn and right-turn manoeuvres, $m = 21$), *CS* is non-fatal crash or severity (j = hospitalised, not hospitalised or property damage only, $n = 3$), β_0 represents the intercept, β = regression coefficients or slopes; for example, $\beta_1(VT_1 + NS_1)$ denotes regression coefficient (β_1) of the first independent variables and $\beta_{m+n}(VT_m + NS_n)$ denotes the last independent variables' regression coefficient (β_{m+n}) and ξ is residuals or prediction errors.

Results

Crash History of the Studied Road

Between 2015 and 2019, 290 crashes occurred along the studied road. Approximately 18% of the vehicles were damaged-only crashes, 26% were non-hospitalised, 43% were hospitalised crashes, and 13% were fatal crashes. Of the crashes, 31% occurred in the Asitey curve as shown in Figure 2. Notably, curves near settlement towns had more crashes than non-settlement areas. It is expected that drivers will decelerate as they get near settlement towns, therefore, higher crashes near settlement towns deviate from the norm. In addition, the highest number of crashes happened in or near steep slopes as shown in Appendix E.

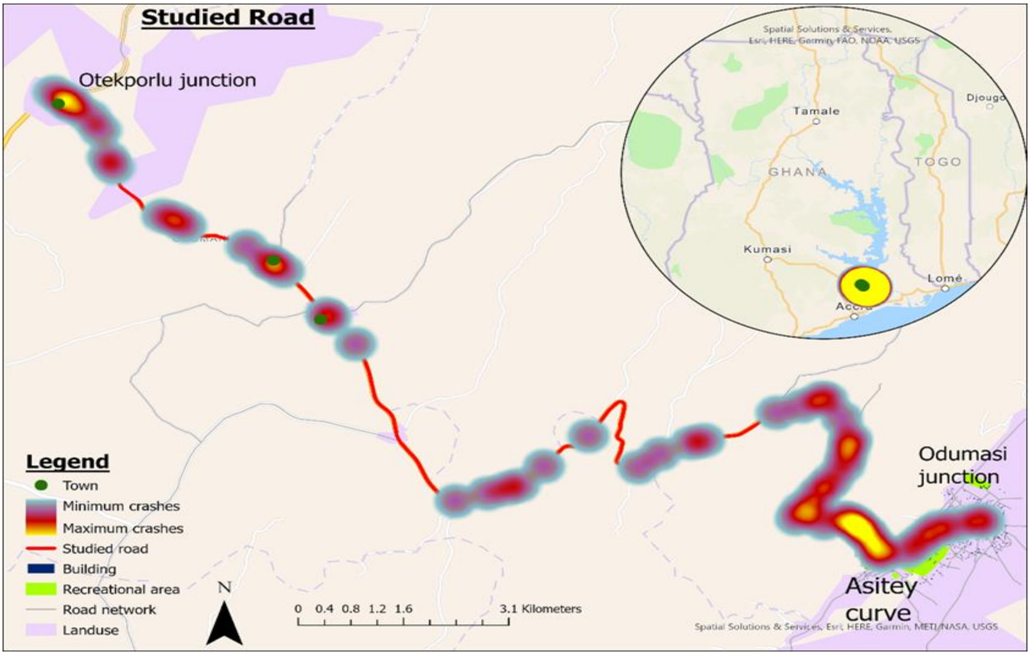

Figure 2: Crash locations along the studied road

Police crash reports indicate that 79% of crashes occurred in the daytime, and 13% of the night-time crashes happened in locations without street lights. The major vehicle collision type is vehicles running off the road. Also, crashes largely involved minibuses/tro-tros (32%), HGV (27%), and cars or taxis (26%). Drivers' inattention and vehicle brake failure accounted for 42% and 47% of crashes, respectively. Full details are provided in Figure 3.

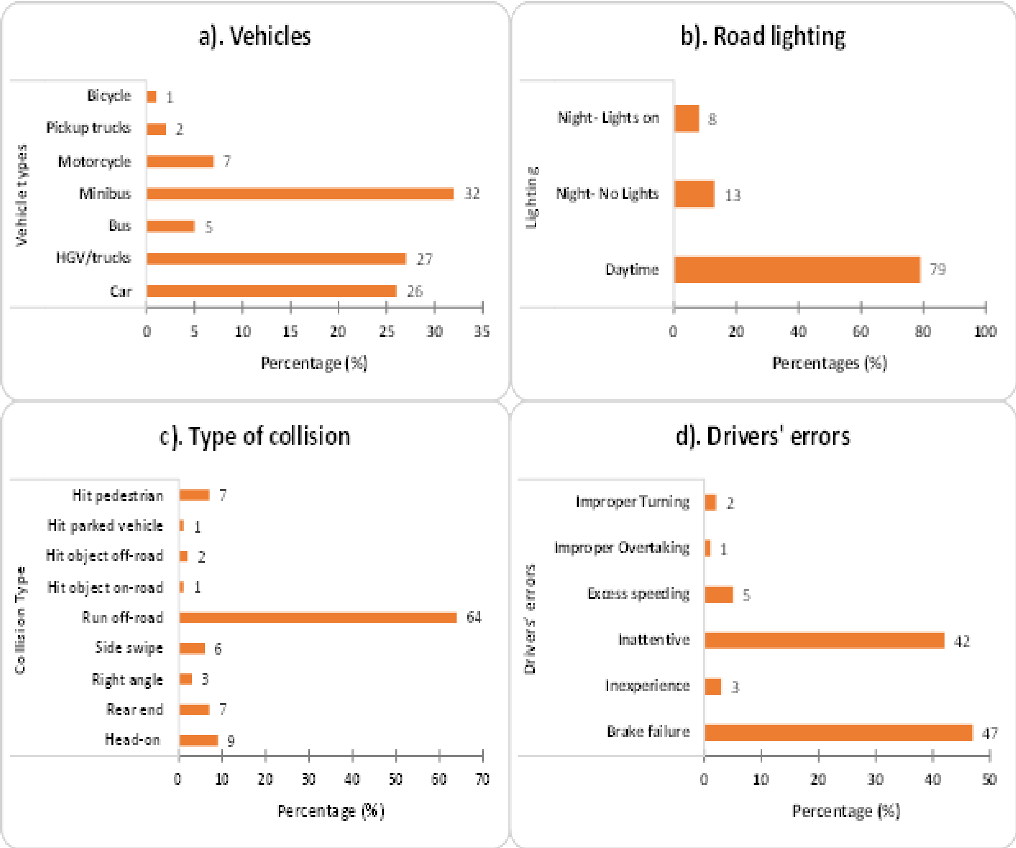

Figure 3: Causes of crashes based on police reports

Results of Traffic Survey, Road Inspection, and Victim Self-Reports

The traffic survey, road inspection, and interviews purported to get information on the traffic volume, speed, road conditions, and insight into the causes of fatal crashes from the perspectives of crash victims. Generally, mixed-traffic vehicles are involved comprising 12 vehicle types (Appendix F). Regarding the traffic volume, 2 295 vehicles traversed the road during the 24-hour count, and the daytime traffic (06:00 to 18:00) constituted 72%. Left-turning vehicles constituted 60% of the traffic volume. For vehicles, taxis constituted 32.5%, small buses (22.3%), and motorcycles (16.7%), among other things.

Regarding speed, whereas the 85th percentile of overall average speeds for all vehicles was 38 km/h, the 15th percentile was 18 km/h, and the average speed was 27 km/h. The speeds of private cars, taxis, pickup vehicles, and light trucks were relatively lower, but those of motorcycles and pickup vehicles were higher. Notably, several drivers violated speed regulations by driving above 50 km/h, particularly private cars (74 km/h), pickup vehicles (68 km/h), medium buses (64 km/h), taxis (59 km/h), and heavy trucks (58 km/h).

Regression Results

Although the spot speed and volume counts give insight into the traffic flow conditions on the road, they give no interpretation of the way in which these are associated with fatal outcomes. A multiple regression analysis was therefore evaluated to indicate the way in which the crash severity (ie property damage only, hospitalised crashes, and non-hospitalised crashes), vehicle speed, traffic volume, and turning movements (left and right turning) are associated with fatal crashes. The results indicated that these predictor variables are significantly associated with fatalities.

The association between left-turning vehicles and fatal crashes was analysed. The backward predictor entry outcomes of model 11 are highly significant, $F(8, 15) = 10.44$, $p < .001$, and each consecutive model rises the adjusted R^2, with the best model 11 explaining 76.7% of fatalities variance (Appendices G and H). Considering the individual standardised estimate (standardised slopes) and *p*-values in Table 2, average spot speeds, turning movements, directional traffic volume/flow, and crash severity were significant predictors of fatal crashes. Non-hospitalised crashes ($\beta = 1.04$), time-mean speeds of light trucks ($\beta = 0.49$), extra-large trucks ($\beta = 0.40$), and directional vehicle volume of pick-up/4WD ($\beta = 1.06$) vehicles were positively related to road traffic fatalities. On the other hand, the average spot speeds of shared taxis ($\beta = -0.38$), medium buses ($\beta = -0.55$) and small buses/vans ($\beta = -0.35$) and traffic volume contribution from motorbikes ($\beta = -1.10$) were negatively associated with fatal crashes.

Table 2: Association between predictor variables and fatal crashes in left-turning direction

Variable	$\boldsymbol{\beta}_{\text{unstd}}$	**SE**	$\boldsymbol{\beta}_{\text{std}}$	***t***	***p***	**Variable**	**Collinearity Statistics**	
							Tolerance	**VIF**
(Intercept)	0.057							(Intercept)
Non-hospitalised crashes	0.743	0.098	1.040	7.615	< .001	0.65	1.53	Non-hospitalised crashes
Shared tax speed	−0.141	0.057	−0.382	−2.461	0.026	0.55	1.83	Shared tax speed
Medium bus speed	−0.328	0.098	−0.547	−3.339	0.004	0.61	1.63	Medium bus speed

Variable	$\boldsymbol{\beta}_{\mathbf{unstd}}$	**SE**	$\boldsymbol{\beta}_{\mathbf{std}}$	***t***	***p***	**Variable**	**Collinearity Statistics**	
							Tolerance	**VIF**
Light truck speed	0.199	0.058	0.490	3.415	0.004	0.52	1.91	Light truck speed
Extra-large truck and others' speed	0.179	0.060	0.402	2.981	0.009	0.79	1.26	Extra-large truck and others' speed
Motor bike volume	−0.725	0.185	−1.097	−3.917	0.001	0.16	6.33	Motor bike volume
Pickup/4WD volume	0.479	0.126	1.057	3.796	0.002	0.17	5.86	Pickup/4WD volume
Small buses/Van speed	−0.151	0.070	−0.349	−2.155	0.048	0.49	2.05	Small buses/Van speed

Note: Only the best-performed model details are presented. β_{std} = standardised beta values. SE = standard error. β_{unstd} = unstandardised beta values.

In the right-turning lane, Model 7 $F(9, 14) = 20.11$, $p < .001$, was the best-performing model (Appendices I and J). As presented in Table 3, hospitalised crashes ($\beta = .59$, $t = 5.01$, $p < .001$), non-hospitalised crashes ($\beta = .36$, $t = 3.60$, $p = .003$), trailer vehicle speed ($\beta = .29$, $t = 2.56$, $p = .023$), and volume of medium trucks ($\beta = .52$, $t = 4.38$, $p < .001$) were positively associated to fatal crashes during right-turn manoeuvres in curves. Contrastingly, average spot speeds of private cars ($\beta = -.41$, $t = -4.15$, $p = 0.001$), small buses/vans ($\beta = -.36$, $t = -4.12$, $p = .001$), large buses ($\beta = -.25$, $t = -2.49$, $p = .026$), extra-large trucks and others ($\beta = -.34$, $t = -3.55$, $p = .003$) were inversely related to road traffic fatalities. The directional vehicle volume of pick-up/4WD is a statistically non-significant predictor of fatal crashes. Looking at the magnitude of standardised slopes, hospitalised crashes are the strongest predictor of the outcome variable followed by the vehicular volume of medium trucks.

Table 3: Association between predictor variables and fatal crashes in right-turning direction

Variable	$\boldsymbol{\beta}_{\mathbf{unstd}}$	**SE**	$\boldsymbol{\beta}_{\mathbf{std}}$	***t***	***p***	**Variable**	**Collinearity Statistics**	
							Tolerance	**VIF**
(Intercept)	0.433	0.100						(Intercept)
Private car speed	−0.209	0.050	−0.411	−4.146	< .001	0.72	1.38	Private car speed
Small bus/Van speed	−0.233	0.057	−0.356	−4.121	0.001	0.75	1.33	Small bus/Van speed
Light bus speed	−0.242	0.097	−0.253	−2.489	0.026	0.56	1.78	Light bus speed
Trailer speed	0.110	0.043	0.291	2.562	0.023	0.55	1.82	Trailer speed

Variable	β_{unstd}	SE	β_{std}	*t*	*p*	Variable	Collinearity Statistics	
							Tolerance	VIF
Extra-large truck and others speed	−0.126	0.036	−0.340	−3.553	0.003	0.75	1.33	Extra-large truck and others speed
Medium truck volume	0.309	0.071	0.520	4.376	< .001	0.43	2.34	Medium truck volume
Pickup/4WD volume	−0.134	0.066	−0.246	−2.023	0.063	0.44	2.27	Pickup/4WD volume
Hospitalised crashes	0.419	0.084	0.590	5.009	< .001	0.51	1.97	Hospitalised crashes
Non-hospitalised crashes	0.260	0.072	0.364	3.600	0.003	0.57	1.77	Non-hospitalised crashes

Note: Only the best-performed model details are presented. β_{std} = standardised beta values. SE = standard error. β_{unstd} = unstandardised beta values.

Furthermore, the combined effect of predictor variables on total fatal crashes in both directions was analysed. A total of 83.3% of the variance in fatal crashes was accounted for by the predictors. Model 8, $F(11, 12) = 11.43$, $p < .001$ outperformed the other models (Appendices K and L). At the aggregate data level, hospitalised crash victims ($\beta = .678$, $t = 5.80$, $p < .001$), property only damage crashes ($\beta = .59$, $t = 4.20$, $p = .001$) and average speeds of heavy trucks ($\beta = .35$, $t = 2.28$, $p = .042$) and light trucks ($\beta = .33$, $t = 2.74$, $p = .023$) and volume of medium trucks ($\beta = .64$, $t = 2.42$, $p = 0.032$) were positively associated with fatal crashes as presented in Table 4. However, the directional volume of trailers ($\beta = −.86$, $t = −3.64$, $p = 0.003$) and aggregate spot speeds of medium buses ($\beta = −.50$, $t = −2.95$, $p = .018$), shared taxis ($\beta = −0.41$, $t = −3.11$, $p = .009$) and extra-large trucks and others ($\beta = −.65$, $t = −4.47$, $p < .001$) had a negative association with fatalities. The time-mean speeds of pick-up/4WD and medium truck vehicles were not statistically significant predictors of fatalities.

Table 4: Association between predictor variables and fatal crashes in both directions

Variable	β_{unstd}	SE	β_{std}	*t*	*p*	Variable	Collinearity Statistics	
							Tolerance	VIF
(Intercept)	0.141	0.150						(Intercept)
Shared taxi avg speed	−0.340	0.109	−0.414	−3.112	0.009	0.55	1.83	Shared taxi avg speed
Pickup/4WD avg speed	0.106	0.055	0.230	1.932	0.077	0.62	1.61	Pickup/4WD avg speed
Medium bus avg speed	−0.290	0.098	−0.504	−2.948	0.012	0.34	2.95	Medium bus avg speed
Light truck avg speed	0.195	0.071	0.326	2.743	0.018	0.55	1.83	Light truck avg speed

Variable	β_{unstd}	SE	β_{std}	*t*	*p*	Variable	Collinearity Statistics	
							Tolerance	VIF
Medium truck avg speed	−0.186	0.097	−0.257	−1.921	0.079	0.79	1.27	Medium truck avg speed
Heavy truck avg speed	0.153	0.067	0.346	2.281	0.042	0.38	2.61	Heavy truck avg speed
Extra-large truck and others avg speed	−0.320	0.072	−0.648	−4.471	< .001	0.50	2.00	Extra-large truck and others avg speed
Medium truck volume total	0.324	0.134	0.639	2.420	0.032	0.14	7.38	Medium truck volume total
Trailer volume total	−0.363	0.100	−0.862	−3.635	0.003	0.18	5.62	Trailer volume total
Hospitalised crashes	0.480	0.083	0.677	5.800	< .001	0.76	1.32	Hospitalised crashes
Property damage only	0.584	0.139	0.592	4.204	0.001	0.43	2.36	Property damage only

Note: Only the best-performed model details are presented. avg = average. β_{std} = standardised beta values. SE = standard error. β_{unstd} = unstandardised beta values.

Facility Conditions and Perspectives of Crash Victims

The conditions of road infrastructure on the studied road showed that street lighting, drainage, pavement conditions, guard rails, road signage, road markings, vegetation cover, and pavement reflectors were either depleted or absent. Along the corridor, vegetation cover was protruding into the road. Regarding drainage, it was observed that the groundwater table had eroded the approach lanes to some curves showing several potholes and road pavement defects. Self-reports of crash victims re-echoed the state of the road pavement. According to Respondents 1 and 2,

> My right leg was amputated due to injuries sustained in a brake failure 20 years ago in the curve. Six passengers onboard the vehicle died on the spot and several others sustained devastating injuries. A large truck that had a brake failure ran into the light truck we boarded. In the process, all passengers and goods fell into a nearby ditch. Later, we realised our passenger had no form of insurance. I have since not used that stretch of the road because of the trauma. (Respondent 1)

> Our vehicle had a brake failure and the vehicle summersault several times before falling in the middle of the road. Some passengers died and others sustained varying degrees of injury, leaving traces of cuts, bruises, and fracture till date. (Respondent 2)

Discussion

This study has several notable findings that are envisaged to help road engineers and safety managers improve the state of road curves not only in Ghana but also globally. First, it is found that there were more crashes in curves near settlement towns than in non-settlement towns. This is consistent with previous road safety analysis studies (Damsere-Derry et al., 2007; Davis et al., 2006). Perhaps this is owing to pedestrians crossing the road abruptly or wrongful parking in settlement towns. Also, it is noteworthy that the incidence of daytime crashes and running off-road were recurring along the studied road. A previous study equally identified a higher incidence of fatal crashes and vehicle run-off in the daytime than at night-time in Ghana (Ackaah & Adonteng, 2011). These crash characteristics, therefore, make settlement areas more crash-prone than non-settlement areas. Drivers need more training regarding road curves. In addition, enhanced enforcement of traffic regulations through increased police visibility would be useful (Davis et al., 2006; Rezapour et al., 2018). Nonetheless, the association between road curves and crash frequency in settlement areas has been under-studied, and therefore would require further empirical investigation.

The next finding relates to driving behaviours and vehicle dynamics. Drivers' inattention and brake failure are the top two crash contributing factors based on police reports. These are consistent with past studies in Ghana (Gyimah, 2020; Oduro, 2012). In relation, a significant number of fatal crashes occurred on steep slopes. This could be due to skidding, drivers' loss of control, or limited sight distance (Fitzpatrick et al., 2000; Hunter & Owen, 1983). These are general national road traffic problems that are not only limited to road curves, and would therefore require macroscopic investigation and regulatory actions. To solve brake failure, Regulation 63 of the Road Traffic Regulations, 2012 (L.I. 2180) requires vehicle owners and drivers to ensure that the brake (1) is in good working condition, (2) when tested by the Licensing Authority, acts with approximately equal intensity on the wheels where the wheels are symmetrically placed about the longitudinal centre line of the vehicle. However, to date, no system exists to check the implementation of these regulations. This finding is similar to past studies on bus crashes in Ghana (Damsere-Derry et al., 2021; Sam et al., 2018). It is required that vehicle inspections be conducted periodically by the relevant traffic regulation agencies. To reduce driver inattention, driver training and empirical-based studies aimed at finding out the main distractions to driving on municipal roads and in road curves would be beneficial for road safety research.

The mixed-traffic flow on the road is a common phenomenon. The results indicated that traffic volume is significantly associated with fatal crashes. In developing countries, the mixed-traffic flow significantly contributes to collisions owing to the different vehicle sizes, occupancies, and speeds. Future studies can experiment with the impact of mixed traffic on collisions in curves. The high incidence of minibus crashes in the road curves is not surprising since past studies have identified it as a major road safety problem in Ghana (Damsere-Derry et al., 2021; Ojo et al., 2018). The volume of trailers was the strongest predictor of road fatalities. This is owing to limestone mining activities in the neighbourhood. These crash risks contributed to the mixed traffic and can be mitigated by increased driver education and vehicle maintenance.

Left-turn movements are more complex for drivers and result in more crashes than right-turn movements. Turning movements were found to be significantly associated with fatal crashes. The strong association between left-turn movements and fatal crashes is therefore consistent with the literature (Ren et al., 2015; Yan et al., 2006). It is also not surprising that the volume of motorcycles was the strongest predictor of fatal crashes among all of the vehicles in the left-turn lane since it has been found that motorcycle crashes have a high likelihood of fatal outcomes (Wahab & Jiang, 2019). Helmet enforcement together with other road safety mechanisms such as public education can therefore not be overemphasised.

Similar to the results by Aarts and Van Schagen (2006), the results in our study indicated that vehicle speed is significantly associated with fatal crashes. Because excess speeds can cause collisions in curves, drivers must decelerate when approaching curves (Nama et al., 2016; Vos et al., 2021). However, it was observed that the road had no posted speed limit. Damsere-Derry et al. (2007) observed that many roads in Ghana lack posted speed limits except the approach direction to settlement towns along highways and rural undivided sections where posted speed limits of 50 km/h and 80 km/h are found, respectively. Given that there are settlement towns along the studied road, a posted speed limit of 50 km/h is required. Increased police monitoring and enforcement can also contribute to reasonable speed in curves (Davis et al., 2006; Rezapour et al., 2018). Extant road safety research can investigate the reasonable speed limit for road curves and the ways in which it can be implemented.

Overall, crash-prone curves along the studied road require re-engineering and increased driver visibility. The deplorable state of the road infrastructure in curves can affect drivers’ decisions and car-following behaviour. Owing to the depleted pavement, vehicles manoeuvre into opposing lanes to avoid potholes. Since there is limited sight distance, collisions and vehicles running off the road can occur. Overall, the poor state of the road infrastructure reiterates the calls for improved road infrastructure in Ghana and other African countries (Alimo et al., 2022). The importance of posted speed limits and road signage has been long established in the road safety literature (Milošević & Milić, 1990). Immediate engineering interventions and treatments are expected. As developed from the literature, some treatments and countermeasures have been proposed in Figure 4 based on past research (Hummer et al., 2010).

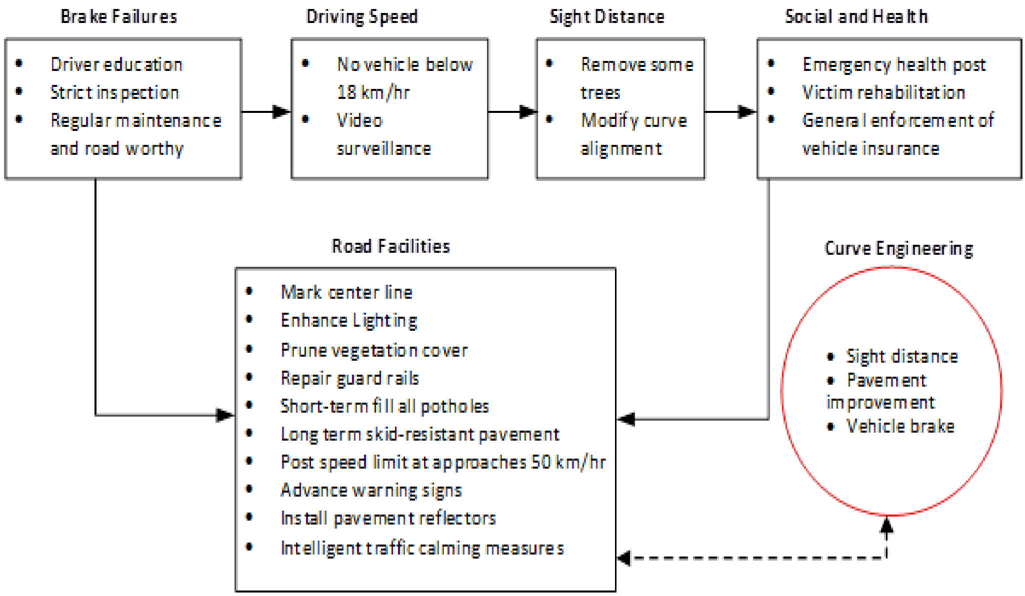

Figure 4: Suggested countermeasures for the identified crash contributing factors

Conclusion

To enhance road safety and engineering, this study diagnosed crash contributing factors along the Odumasi-Oterkpolu road in Ghana. Using crash data from 2015 to 2019, multiple regressions and spatial analysis were employed. It is found that victim self-reports indicated that vehicle brake failure and driver inattention are the main driving errors. Generally, the road has poor infrastructure such as lighting, guardrails, road signs, road markings, posted speed limits, and a pavement. Speed, traffic volume and the volume of motorcycles have the strongest association with fatal crashes. In addition, the majority of crashes involved left-turning vehicles. Accordingly, posted speed limits, enhanced lighting, pavement reconstruction in curves, and vehicle inspections are proposed.

In the future, researchers can experiment with a reasonable speed limit for mixed traffic in road curves for different road categories, alignments (vertical and horizontal curves), other geometric features, and driving environments. Also, sight-distance experiments can help explore other safety countermeasures for roads having similar curvature. In this study, we emphasise the need for enhanced road curve engineering in developing countries. We hope the findings can help promote safer communities where curvy roads are prevalent.

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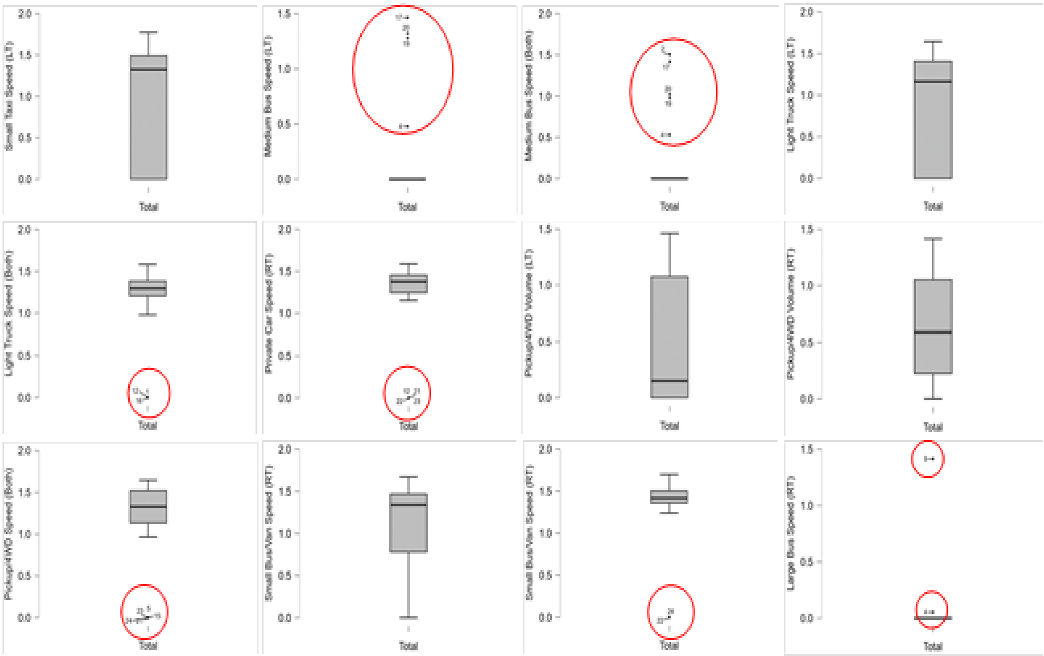
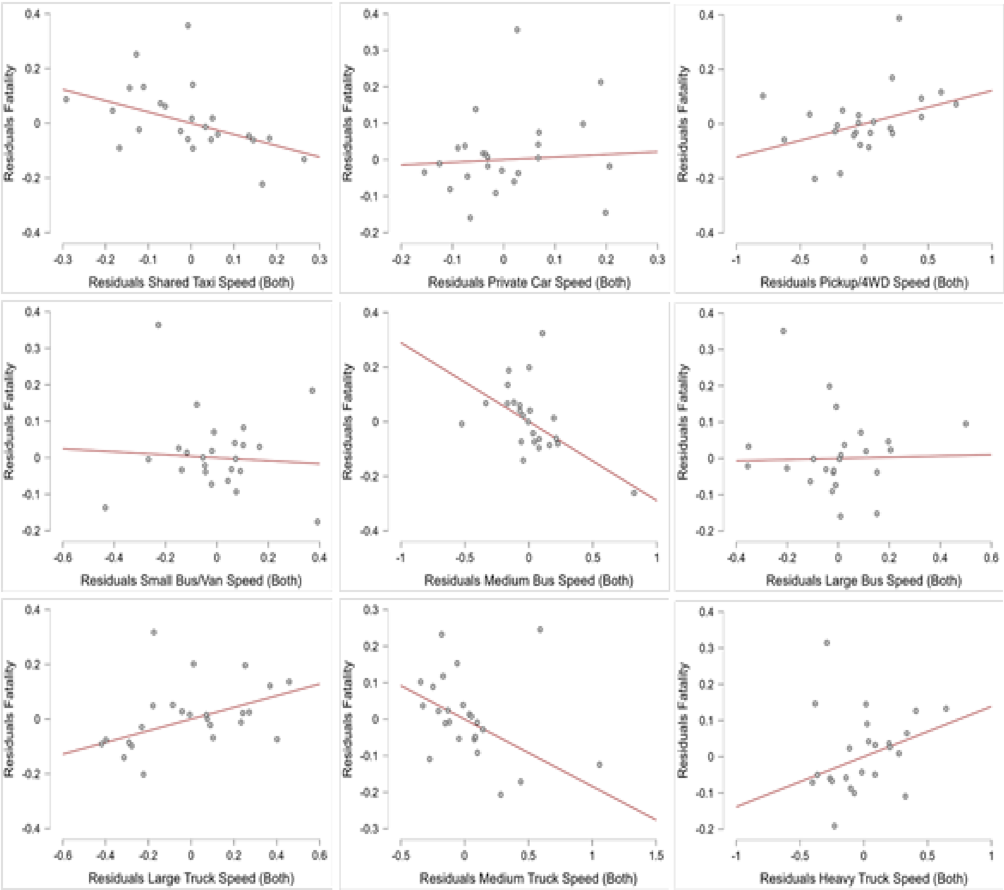
Appendices: Supplementary Results

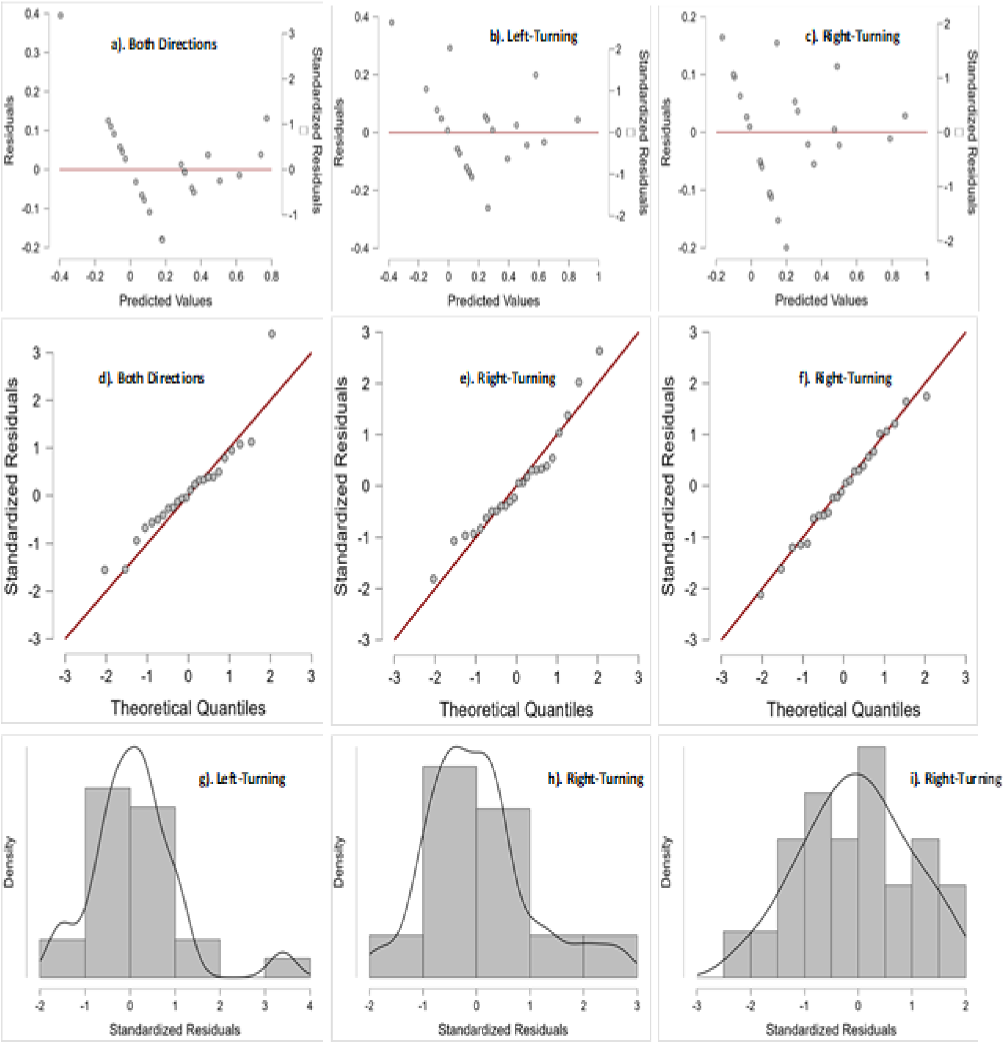
Appendix A: Box Plots of Variables Used in Models' Construction (Circled Red are Outliers)



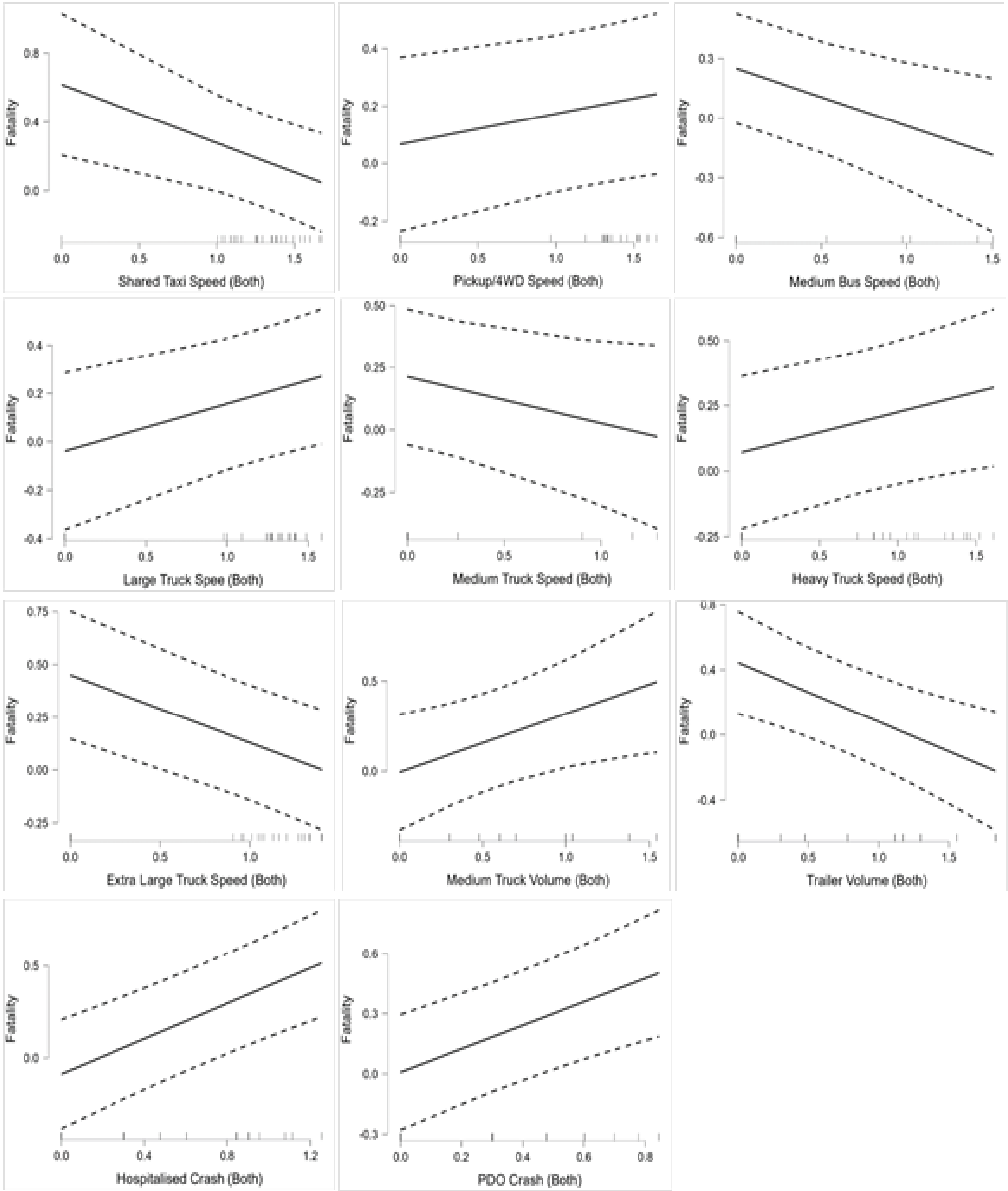
Appendix B: Partial Regression Plots for Both Turnings



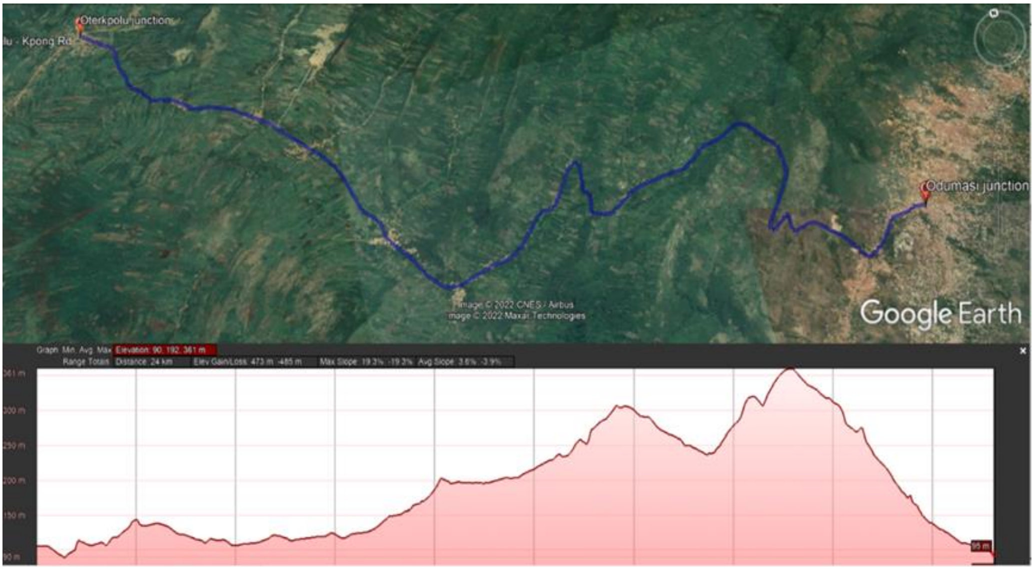
Appendix C: Residuals Versus Predicted, Q-Q Plot Standardised Residuals and Standardised Residuals Histogram for Both Directions, Left-Turning and Right-Turning



Appendix D: Marginal Effects Plots for Both Turnings



Appendix E: Elevation Profile of the Road



Appendix F: Summary of Traffic Survey

Vehicle Type	Speed (km/h)				Tine of day traffic volume			Percentage (%)
	Lowest	Highest	Modal	Mean	06:00–18:00	18:00–06:00	Total	
Motorcycle	9	41	35	26	227	157	384	16.7
Taxi	12	59	27	29	541	204	745	32.5
Private car	14	74	19	30	205	59	264	11.5
Pickup vehicle	18	68	44	29	164	30	194	8.5
Small bus	11	50	29	27	362	150	512	22.3
Medium bus	21	64	21	26	6	0	6	0.3
Large bus	11	26	24	21	3	1	4	0.2
Light truck	11	48	30	28	54	16	70	3.1
Medium truck	16	43	21	25	3	1	4	0.2
Heavy truck	11	58	16	27	49	4	53	2.3
Trailer	11	43	11	23	19	6	25	1.1
Extra-large truck	11	43	20	24	30	4	34	1.5
Average speed				27	Left-turning vehicles			60
Standard deviation				2.7	Right-turning vehicles			40
15th percentile				18	06:00 to 18:00			72
85th percentile				38	18:00 to 06:00			28

Appendix G: Model Summary for Left-Turning Direction

Model	R	R^2	Adjusted R^2	RMSE	Durbin-Watson	
					Autocorrelation	Statistic
1	0.953	0.908	0.576	0.193	−0.08	2.11
2	0.953	0.908	0.646	0.177	−0.07	2.07
3	0.952	0.906	0.690	0.165	0.01	1.94
4	0.951	0.904	0.724	0.156	0.07	1.82
5	0.950	0.902	0.749	0.149	0.04	1.86
6	0.947	0.897	0.763	0.145	−0.02	1.98
7	0.943	0.890	0.770	0.142	0.02	1.90
8	0.940	0.884	0.777	0.140	−0.02	2.02
9	0.933	0.871	0.771	0.142	−0.05	2.05
10	0.927	0.860	0.770	0.142	0.07	1.83
11	0.921	0.848	0.767	0.143	0.03	1.94

Note: *p*-value for the Durbin-Watson test is unavailable for weighted regression.

Appendix H: ANOVA for Left-Turning Direction

Model		Sum of Squares	*df*	Mean Square	*F*	*p*
1	Regression	1.841	18.0	0.102	2.733	0.135
	Residual	0.187	5.0	0.037		
	Total	2.028	23.0			
2	Regression	1.841	17.0	0.108	3.469	0.066
	Residual	0.187	6.0	0.031		
	Total	2.028	23.0			
3	Regression	1.837	16.0	0.115	4.201	0.031
	Residual	0.191	7.0	0.027		
	Total	2.028	23.0			
4	Regression	1.833	15.0	0.122	5.015	0.014
	Residual	0.195	8.0	0.024		
	Total	2.028	23.0			
5	Regression	1.829	14.0	0.131	5.909	0.006
	Residual	0.199	9.0	0.022		
	Total	2.028	23.0			
6	Regression	1.819	13.0	0.140	6.692	0.002
	Residual	0.209	10.0	0.021		
	Total	2.028	23.0			
7	Regression	1.805	12.0	0.150	7.423	0.001
	Residual	0.223	11.0	0.020		
	Total	2.028	23.0			
8	Regression	1.793	11.0	0.163	8.303	< .001
	Residual	0.236	12.0	0.020		
	Total	2.028	23.0			
9	Regression	1.766	10.0	0.177	8.739	< .001
	Residual	0.263	13.0	0.020		
	Total	2.028	23.0			
10	Regression	1.744	9.0	0.194	9.544	< .001
	Residual	0.284	14.0	0.020		
	Total	2.028	23.0			
11	Regression	1.720	8.0	0.215	10.444	< .001
	Residual	0.309	15.0	0.021		
	Total	2.028	23.0			

Appendix I: Model Summary for Right-Turning Direction

Model	R	R^2	Adjusted R^2	RMSE	Durbin-Watson	
					Autocorrelation	Statistic
1	0.979	0.959	0.881	0.103	−0.139	2.130
2	0.979	0.959	0.894	0.097	−0.136	2.126
3	0.978	0.957	0.902	0.093	−0.159	2.213
4	0.976	0.953	0.903	0.093	−0.114	2.137
5	0.973	0.946	0.897	0.095	−0.201	2.286
6	0.970	0.94	0.895	0.096	−0.200	2.229
7	0.963	0.928	0.882	0.102	−0.380	2.643

Note: *p*-value for the Durbin-Watson test is unavailable for weighted regression.

Appendix J: ANOVA for Right-Turning Direction

Model		**Sum of Squares**	***df***	**Mean Square**	***F***	***p***
1	Regression	1.944	15	0.130	12.330	< .001
	Residual	0.084	8	0.011		
	Total	2.028	23			
2	Regression	1.944	14	0.139	14.861	< .001
	Residual	0.084	9	0.009		
	Total	2.028	23			
3	Regression	1.941	13	0.149	17.202	< .001
	Residual	0.087	10	0.009		
	Total	2.028	23			
4	Regression	1.934	12	0.161	18.747	< .001
	Residual	0.095	11	0.009		
	Total	2.028	23			
5	Regression	1.919	11	0.174	19.153	< .001
	Residual	0.109	12	0.009		
	Total	2.028	23			
6	Regression	1.907	10	0.191	20.522	< .001
	Residual	0.121	13	0.009		
	Total	2.028	23			
7	Regression	1.883	9	0.209	20.110	< .001
	Residual	0.146	14	0.010		
	Total	2.028	23			

Appendix K: Model Summary for Both Directions

Model	R	R^2	Adjusted R^2	RMSE	Durbin-Watson	
					Autocorrelation	Statistic
1	0.960	0.922	0.642	0.178	0.121	1.666
2	0.960	0.922	0.701	0.162	0.124	1.662
3	0.960	0.922	0.742	0.151	0.111	1.707
4	0.960	0.921	0.774	0.141	0.097	1.728
5	0.959	0.920	0.796	0.134	0.038	1.850
6	0.959	0.919	0.814	0.128	0.045	1.848
7	0.957	0.916	0.824	0.125	0.041	1.830
8	0.955	0.913	0.833	0.121	0.007	1.882

Note: *p*-value for the Durbin-Watson test is unavailable for weighted regression.

Appendix L: ANOVA for Both Directions

Model		**Sum of Squares**	***df***	**Mean Square**	***F***	***p***
1	Regression	1.870	18	0.104	3.289	0.096
	Residual	0.158	5	0.032		
	Total	2.028	23			
2	Regression	1.870	17	0.110	4.174	0.043
	Residual	0.158	6	0.026		
	Total	2.028	23			
3	Regression	1.869	16	0.117	5.143	0.018
	Residual	0.159	7	0.023		
	Total	2.028	23			
4	Regression	1.869	15	0.125	6.244	0.007
	Residual	0.160	8	0.020		
	Total	2.028	23			
5	Regression	1.866	14	0.133	7.406	0.002
	Residual	0.162	9	0.018		
	Total	2.028	23			
6	Regression	1.864	13	0.143	8.758	< .001
	Residual	0.164	10	0.016		
	Total	2.028	23			
7	Regression	1.857	12	0.155	9.968	< .001
	Residual	0.171	11	0.016		
	Total	2.028	23			
8	Regression	1.851	11	0.168	11.426	< .001
	Residual	0.177	12	0.015		
	Total	2.028	23			