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An in-depth analysis of head-on crash severity and fatalities in Ghana

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ABSTRACT

Head-on collisions are often linked to more serious injuries compared to other types of crashes, due to the intense impact they cause. In low- and middle-income countries, these collisions frequently involve high occupancy public transportation vehicles, leading to higher fatality rates per crash. Given the high risk of injury and potential for multiple casualties, this study delves into the factors influencing the outcomes of head-on crashes and the number of fatalities in Ghana. The study analyzed six years of historical head-on collision data from Ghana and developed two models to address the issue. The injury-severity analysis was performed using a random parameter multinomial logit with heterogeneity in means and variances approach and aimed to identify the factors that have a significant impact on the severity of injuries sustained in head-on collisions, while the random parameters negative binomial fatality count model was designed to examine the factors that contribute to the number of fatalities in these crashes in the country. Results showed that head-on collisions with drivers over 65, buses, motorcycles, and those between 25 and 65 years of age were more likely to result in fatalities. Speeding and vehicle malfunctions were also found to be significant contributing factors to fatal head-on collisions. Head-on crashes involving minibuses and incidents where the driver was attempting to overtake another vehicle were found to be more likely to result in a higher number of fatalities. The results of this study uncover an intriguing interaction between human-related elements and socioeconomic factors, which pose obstacles to the Government's endeavor to upgrade the major highways in the country. Additionally, the increasing need for transportation has led to the presence of vehicles on the roads that may not meet safety standards. Consequently, it is no surprise that several of the study's findings align with expectations. Nevertheless, within the specific context of Ghana, these findings furnish compelling data-driven evidence supporting the adoption and implementation of the safe systems approach as a means to tackle fatal head-on collisions in the country.

1. Introduction

In comparison to other types of collisions, head-on crashes are generally linked to more severe injuries owing to the frequently high-

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force impact involved. In the United States, statistics indicate that approximately 2% of fatal crashes are categorized as head-on collisions, yet these incidents contribute to over 10% of total traffic-related fatalities. This stark disproportion underscores the catastrophic nature inherent to this specific type of crash [1]. In low and middle-income countries, and indeed rural areas in many high-income countries, head-on collisions are pronounced due to the high proportion of two-lane and undivided highways [2]. These head-on collisions often involve high occupancy public transport vehicles, thus contributing to higher numbers of fatalities per crash. For instance, in Ghana, nearly 2000 people are killed annually through road crashes and about 9% of the fatal crashes are head-on collisions. However, these head-on collisions account for 15% of road fatalities [2]. Evidently, on February 18, 2016, a Metro Mass Transit coach reportedly collided head-on with a goods cargo truck near Kintampo in the Bono East region of Ghana, killing 71 people [3]. Investigations revealed that the bus exceeded its intended capacity, carrying over 70 passengers instead of the designated maximum of 63. Adanu et al. [4] observed that the high proportion of fatalities per crash may perhaps be a leading contributing factor to the disproportional share of global road fatalities recorded in Sub-Saharan Africa. This phenomenon threatens the ability of countries in the developing world to achieve the United Nations Sustainable Development Goal Target 3.6 which called for halving "global deaths and injuries from traffic accidents" [5]. Due to the significant losses resulting from traffic crashes in general and particularly head-on collisions, reducing the severity of injury sustained in road crashes has long been a major concern for transportation agencies, vehicle manufacturers, and all other road safety stakeholders [6].

Head-on collisions have been attributed to human-centered factors such as distracted driving, drowsy driving, drunk and drugged driving, and wrong-way driving. Other factors such as hazardous roadway conditions and improper passing have also been identified as contributing to head-on crashes. Numerous studies have been conducted to mitigate the impact of these crashes by investigating the factors that contribute to their incidence [7–12]. For instance, Kardar and Davoodi (2020) investigated the factors that are associated with driver injury severity in head-on crashes [11]. They observed that head-on crashes that occur under dark and not-lighted conditions, on horizontally curved sections, and undulating terrain, and those that involve heavy vehicles record increased severity. Also, it was found that improper overtaking maneuvers, not wearing a seatbelt, and vehicle age contribute to more severe injuries, whereas rainy weather conditions were found to be associated with less severe outcomes. Liu and Fan (2019) utilized a mixed logit model approach to assess the crash factors that influence the severity of head-on collisions. Their study was able to show that driving under the influence of alcohol or drugs, grade or curve roadway configuration, old drivers, high speed limit, and the involvement of motorcycles increase the injury severity of head-on crashes. Sassi et al. (2018) explored head-on collisions of light motor vehicles (LMV) with heavy vehicles in relation to the socio-demographics, physical and mental health condition, and other driving-related factors of the at-fault driver. They found that at-fault LMV drivers were characterized as having mental health problems, personal relationship problems, long-term physical illness, being on some form of medication, or driving under the influence of alcohol [13]. Wali et al. (2018) investigated the degree of injury severity sustained by drivers involved in head-on collisions with respect to who was at fault in the crash [9]. According to their research, it was discovered that 8% of crashes resulted in serious or fatal injuries to drivers, regardless of fault. Additionally, in 4% of cases, the driver who was not at fault sustained serious or fatal injuries while the at-fault driver remained uninjured. Furthermore, the study revealed that if the at-fault driver was fatigued, asleep, or under the influence of alcohol, the likelihood of the not-at-fault driver sustaining a severe or fatal injury increased. Zeng et al. (2016) developed a Bayesian hierarchical ordered logit model to assess the injury severity of drivers in two-vehicle crashes [14]. The results show that older, female drivers, drivers not at fault, and those that did not use safety equipment were more likely to be injured. Liu and Fan (2019) used a partial proportional odds model to analyze the factors that influence the injury severity of head-on crashes in North Carolina [15]. The results of this research showed that fatal injury outcome is highly probable on roadways with a speed limit greater than 50 mph. Gårder (2006) analyzed the severity of head-on crashes on two-lane rural highways in Maine and found that head-on crashes are primarily due to over-speeding and inattention, whereas Deng et al. (2006) identified factors such as narrow road segments, nighttime, pavement width, and braking performance on wet surfaces as major contributing factors in severe head-on crashes [16,17]. Miltner and Salwender (1995) investigated the influencing the factors that influence the severity of injuries sustained by restrained front seat occupants involved in head-on collisions between cars [18]. The results of their multivariate analysis revealed that speeds, deformation depth, and occupant age influenced crash injury severity. Olabarria et al. (2015) investigated the factors associated with the likelihood of head-on crashes on two-way inter-urban roads using the Poisson regression model where they found the presence of median and paved shoulder less than 2.45 m to be associated with lower crash probability [19]. Strandroth et al. (2012) observed that the injury risk associated with frontal crashes between passenger cars and heavy goods vehicles (HGV) was borne more by the car occupants in frontal collisions [20].

An examination of prior research has uncovered significant factors that contribute to the occurrence of head-on collisions and their outcomes. Given the high risk of injury and potential for multiple casualties, this study delves into the influences on head-on crash outcomes and the factors that lead to the number of fatalities in Ghana. Data from six years of head-on collisions was collected and analyzed. The results of this study aim to not only add to the existing understanding of head-on crashes in low- and middle-income nations but also provide guidance for policymakers in Ghana to develop and implement effective road safety measures.

The remainder of the paper will present a discussion of the methods adopted for the study, a description of the data used, the model estimation results, a discussion of the results and recommendations, and end with a general conclusion.

2. Methodology

Many different statistical and econometric modeling methods have been used to assess the relationships that exist between various crash factors and injury outcomes. In this present study, random parameters multinomial logit with heterogeneity in means and variances model was adopted to investigate the crash factors that are significantly associated with the injury outcomes in head-on collisions, while a random parameters negative binomial model was developed to assess the factors that contribute to the number of people killed in these crashes. These models were adopted to account for unobserved heterogeneity (unobserved factors that may vary across observations) in the crash data [21]. Accounting for unobserved heterogeneity is important to ensure that inferences that would be made from the model results are accurate. For the injury severity analysis, four discrete crash outcome categories are considered in this study: fatal injury, hospitalized (or incapacitating) injury, minor injury, and no injury. In order to obtain a reliable and accurate model, an injury severity function S_{in} that determines the probability that crash n will result in injury severity i [22] is defined as:

$$S_{in} = \beta_i X_{in} + \varepsilon_{in} \tag{1}$$

In Equation (1), β_i is a vector of estimable parameters for injury outcome i (fatal injury, hospitalized injury, minor injury, and no injury), X_{in} is a vector of independent variables that influence the probability of recording injury outcome i in crash n and ε_{in} is the stochastic error term. If ε_{in} follows an independent and identically distributed extreme value Type I distribution [22], and allowing for parameter variations across observations through the introduction of a mixing distribution [23], the resulting random parameters logit model is expressed as:

$$P_n(i) = \int \frac{exp\ (\beta_i X_{in})}{\Sigma\ exp(\beta_i X_{in})} f(\beta|\varphi) d\beta \tag{2}$$

Where $f(\beta|\varphi)$ is the density of β and φ corresponds to a vector of parameters of the density function (mean and variance), $P_n(i)$ is the probability of injury category i in crash n conditional on $f(\beta|\varphi)$. β now can account for observation-specific variations in the impact of X on injury severity probabilities, with $f(\beta|\varphi)$ used to determine β. In Equation (2), the probabilities in the random parameter logit are calculated as a weighted average of different values of β across observations where β can remain fixed or differ among observations. Heterogeneity in means and variances of random parameters is accounted for by allowing β_i to vary across crashes as [24–26]):

$$\beta_i = \beta + \Theta_i Z_i + \sigma_i\ exp(\omega_i W_i) \upsilon_i \tag{3}$$

where β is the mean parameter estimate across all crashes, Z_i represent the explanatory variables' vector that captures heterogeneity in the mean with parameter vector Θ_i, and W_i is a vector of attributes that capture heterogeneity in standard deviation σ_i with corresponding parameter vector ω_i and a disturbance term υi. The estimation of this model is performed using simulated maximum likelihood estimation, where the logit probabilities shown in Equation (3) are approximated by drawing values of β from $f(\beta|\varphi)$ for given values of φ, using 1000 Halton draws [27,28]. In this study, the functional form of the parameter density function of the random parameters was the normal distribution [29]. Furthermore, marginal effects were calculated to assess how the explanatory variables influence the probabilities of different injury severity outcomes [30].

Given that the number of fatalities per crash is a non-negative integer, it is suitable to employ a count-data modeling technique to analyze the factors that impact the count of people killed. Count data is most effectively modeled using Poisson regression or its derivatives, depending on the characteristics of the outcome variable. These approaches are specifically designed to handle count data and provide insights into the factors that influence the count of fatalities in a crash. For the basic Poisson model, the probability $P(n_i)$ of crash i having n_i fatalities is shown in Equation (4) as:

$$P(n_i) = \frac{EXP(-\lambda_i)\lambda_i^{n_i}}{n_i!} \tag{4}$$

Where λ_i is the Poisson parameter for crash i, which is crash i's expected number of fatalities, $E[n_i]$. Poisson regression specifies the Poisson parameter λ_i (the expected number of people killed) as a function of explanatory variables by typically using a log-linear function:

$$\lambda_i = EXP(\beta X_i) \tag{5}$$

Where X_i is a vector of explanatory variables and β is a vector of estimable parameters [30].

As mentioned previously, Poisson regression might not be suitable when the assumption of equal mean and variance is violated. The Poisson distribution assumes that the mean and variance of the outcome variable are the same. However, if the data exhibits underdispersion (where the mean is greater than the variance) or overdispersion (where the mean is less than the variance), using Poisson regression can result in inaccurate standard errors for the estimated parameter vector, leading to incorrect inferences. To address this issue, an alternative model known as the negative binomial model can be employed. The negative binomial model is a derivative of the Poisson model that accommodates the possibility of unequal mean and variance. It provides a more flexible approach for modeling count data that exhibits overdispersion. By allowing for different mean and variance values, the negative binomial model can yield more accurate parameter estimates and reliable inferences in such situations as:

$$\lambda_i = EXP(\beta X_i + \varepsilon_i) \tag{6}$$

Where $EXP(\varepsilon_i)$ is a gamma-distributed error term with a mean of 1 and variance α. This additional term allows the variance to differ from the mean. To account for unobserved heterogeneity, estimable parameters can be expressed as:

$$\beta_i = \beta + \varphi_i \tag{7}$$

Table 1
Descriptive statistics of relevant variables available for analysis.

Variable	Frequency	Percentage	Variable	Frequency	Percentage
Year			*Lighting conditions*		
2013	838	14.9%	Day	3378	60.0%
2014	933	16.6%	Night-No lights	930	16.5%
2015	860	15.3%	Night-Lights off	126	2.2%
2016	895	15.9%	Night-Lights on	1196	21.2%
2017	909	16.1%	*Road description*		
2018	1197	21.3%	Straight and flat	4573	81.2%
Month of the year			Curve	532	9.4%
January	404	7.2%	Incline	144	2.6%
February	420	7.5%	Curve and incline	363	6.4%
March	453	8.0%	Bridge	17	0.3%
April	436	7.7%	Others	2	0.0%
May	483	8.6%	*Road surface type*		
June	459	8.1%	Tar good	4054	72.0%
July	416	7.4%	Tar few potholes	1027	18.2%
August	462	8.2%	Gravel	284	5.0%
September	465	8.3%	Earth few potholes	43	0.8%
October	519	9.2%	Earth many potholes	174	3.1%
November	544	9.7%	Others	48	0.9%
December	571	10.1%	*Shoulder type*		
Day of the week			Tarred	3556	63.2%
Monday	782	13.9%	Untarred	550	9.8%
Tuesday	742	13.2%	No shoulder	1520	27.0%
Wednesday	667	11.8%	*Shoulder condition*		
Thursday	752	13.4%	Good	2989	53.2%
Friday	894	15.9%	Poor	1007	17.9%
Saturday	955	17.0%	Overgrown	106	1.9%
Sunday	840	14.9%	No shoulder	1520	27.0%
Time of crash			*Location type*		
Midnight to 6am	548	9.7%	Not at junction	4592	81.5%
6am to Midday	1210	21.5%	Crossroads	198	3.5%
Midday to 6pm	1822	32.4%	T-junction	653	11.6%
6pm to Midnight	2052	36.4%	Staggered intersection	61	1.1%
Weather			Y-intersection	32	0.6%
Clear	4531	80.5%	Roundabout	54	1.0%
Fog/mist	117	2.1%	Railway crossing	5	0.1%
Rain	45	0.8%	Other	37	0.7%
Dust	21	0.4%	*Road surface condition*		
Others	918	16.3%	Dry	5558	98.8%
Contributing factor			Wet	50	0.9%
None	4456	37.4%	Muddy	16	0.3%
Inexperience	231	1.9%	*Location*		
Inattentive	4257	35.8%	Urban	2649	47.0%
Too fast	1431	12.0%	Village	308	5.5%
Too close	142	1.2%	Rural	2675	47.5%
No signal	29	0.2%	*Driver sex*		
Improper overtaking	642	5.4%	Male	5505	98.0%
Improper turning	105	0.9%	Female	115	2.0%
Fatigued/Asleep	27	0.2%	*Driver age*		
Other	585	4.9%	Less than 25	486	8.7%
Casualty age			25–45	3973	70.8%
Less than 10	321	2.2%	45–60	984	17.5%
Between 10 and 20	920	6.3%	More than 60	171	3.0%
Between 20 and 40	8937	61.5%	*License status*		
Between 40 and 60	3736	25.7%	Full	2682	86.6%
More than 60	615	4.2%	Provisional	311	10.0%
Casualty type			Learner	12	0.4%
Driver	7045	48.5%	Unlicensed	85	2.7%
Passenger	7473	51.5%	Unknown	8	0.3%
Vehicle type			*Drinking and driving*		
Car	4641	40.2%	Not suspected	5571	99.0%
Heavy Goods Vehicle	1247	10.8%	Suspected	28	0.5%
Tractor	58	0.5%	Tested and positive	11	0.2%
Bus	460	4.0%	Tested and negative	8	0.1%
Minibus	1532	13.3%	Unknown	9	0.2%
Motorcycle	2616	22.7%	*Vehicle ownership*		
Pickup	634	5.5%	Government	108	0.9%
Bicycle	187	1.6%	Company	1167	10.1%

(*continued on next page*)

Table 1 (*continued*)

Variable	Frequency	Percentage	Variable	Frequency	Percentage
Other	78	0.7%	Private	6020	52.2%
Unknown	8	0.1%	Taxi	1889	16.4%
Tricycle	69	0.6%	Bus	1885	16.4%
Rickshaw	5	0.0%	Others	459	4.0%

Where φ_i is a randomly distributed term with a specified probability density function (for example a normally distributed term with a mean of 0 and variance σ^2). The Poisson parameter then becomes $\lambda_i|\varphi_i = EXP(\beta X_i)$ in the Poisson model and $\lambda_i|\varphi_i = EXP(\beta X_i + \varepsilon_i)$ in the negative binomial with the corresponding probabilities for Poisson or negative binomial being $P(n_i|\varphi_i)$. A variable is considered random if the standard deviation of the parameter density is statistically significant. Conversely, if the estimated standard deviation is

Table 2
Random parameters with heterogeneity in mean and variance model estimation results for head-on collision casualty injury severity.

Variable	Defined in function of	Parameter estimate	t-Statistic	Marginal effects			
				Fatal injury	Hospitalized injury	Minor injury	No injury
Constant	Fatal injury	−1.42	−21.46				
Constant	Hospitalized injury	0.29	7.29				
Constant	Minor injury	−0.13	−3.02				
Random parameter							
Speed	Fatal injury	0.03	0.13	0.0105	−0.0041	−0.0035	−0.0029
Standard deviation of "Speed" (normally distributed)		1.49	4.39				
Heterogeneity in means of random parameter							
Speed: Minibus	Fatal injury	−1.25	−4.84				
Speed: Light Goods Vehicle	Fatal injury	−0.52	−1.79				
Heterogeneity in variance of random parameter							
Speed: Casualty older than 65 years	Fatal injury	1.24	2.42				
Vehicle defect							
Steering	Fatal injury	−0.30	−1.97	−0.0007	0.0003	0.0003	0.0002
Suspension	Hospitalized injury	−1.81	−1.74	0.0002	−0.0005	0.0001	0.0002
Tyres	No injury	−0.49	−2.59	0.0001	0.0004	0.0003	−0.0008
Vehicle type							
Motorcycle	Fatal injury	1.84	33.15	0.0673	−0.0266	−0.0275	−0.0132
Bus	Hospitalized injury	−0.15	−2.48	0.0006	−0.0025	0.0012	0.0007
Heavy Goods Vehicle	Minor injury	−0.95	−2.78	0.0001	0.0002	−0.0004	0.0002
Private car	No injury	0.68	17.42	−0.0061	−0.0237	−0.0234	0.0533
Vehicle ownership							
Company	Minor injury	−0.55	−8.00	0.0009	0.0034	−0.0073	0.003
Commercial	No injury	−0.56	−14.08	0.0052	0.0176	0.0155	−0.0384
Contributing factor							
Distracted driving	Minor injury	−0.15	−4.05	0.0018	0.0043	−0.0093	0.0032
Drowsy driving	Minor injury	0.55	2.10	−0.0001	−0.0002	0.0004	−0.0001
Overtaking	No injury	−0.53	−5.94	0.0006	0.0019	0.0017	−0.0042
Casualty characteristics							
Pillion rider	Hospitalized injury	1.11	16.23	−0.0061	0.0133	−0.0034	−0.0039
Driver	Minor injury	0.99	25.55	−0.0215	−0.0338	0.0847	−0.0294
Bus passenger	Fatal injury	0.43	6.87	0.0106	−0.005	−0.0033	−0.0023
Unknown seating position	Hospitalized injury	0.61	2.30	−0.0001	0.0004	−0.0002	−0.0002
Casualty age less than 25	Hospitalized injury	0.50	11.19	−0.0037	0.0174	−0.008	−0.0057
Casualty age between 25 and 45	Fatal injury	0.61	10.36	0.0321	−0.0116	−0.0127	−0.0078
Casualty age between 45 and 65	Fatal injury	0.84	11.16	0.0129	−0.0048	−0.0048	−0.0034
Female	Hospitalized injury	0.40	8.94	−0.0034	0.0147	−0.0059	−0.0054
Driver characteristics							
Driver not at fault	Hospitalized injury	−0.21	−6.17	0.0027	−0.0147	0.0063	0.0057
Full license	Hospitalized injury	−0.33	−9.99	0.0047	−0.0283	0.0122	0.0114
Probationer	Minor injury	0.36	5.00	−0.0005	−0.002	0.0038	−0.0013
Driver age less than 25	No injury	−0.40	−5.09	0.0008	0.0021	0.0016	−0.0045
Driver age between 25 and 45	Fatal injury	−0.24	−4.26	−0.0166	0.0062	0.0061	0.0043
Driver age between 45 and 65	Minor injury	−0.10	−2.31	0.0007	0.0015	−0.0034	0.0013
Model fit statistics							
Number of observations		19,129					
Log likelihood at zero		−26518.42					
Log likelihood at convergence		−23685.82					
McFadden Pseudo R-sq		0.11					

statistically indistinguishable from zero, the parameter is deemed to be fixed across the entire crash population.

3. Data description

The head-on collision data used in this study were sourced from the Ghana National Road Traffic Accident Database, which is maintained at the Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR). The data were obtained from the Motor Traffic and Transport Department (MTTD) of the Ghana Police Service. Since 1991, this crash database has been the main data source for research and policy decision-making regarding road crashes in Ghana. Six years (2013–2018) of crash records were obtained and used in this study. Querying the database allowed for the selection of crash factors such as driver characteristics, passenger characteristics, vehicle characteristics, crash characteristics, environmental factors, and roadway attributes. For the injury severity analysis, the study used four injury severity levels (fatal injury, hospitalized injury, minor injury, and no injury) as classification criteria for crash injury outcomes and the casualty fatalities count model was based on the number of casualties that either died on the spot or died within 30 days of the crash. After the data cleaning process, a total of 5632 observations were available for analysis. Based on the crash outcome, 1637 (representing 29.1%) crashes were fatal, 1863 (representing 33.1%) had the highest severity sustained to be hospitalized injury, 1209 (representing 21.5%) were minor injuries, and 923 (representing 16.4%) recorded no injury. In terms of casualty injury, 2620 were killed, 6249 sustained hospitalized injuries, 5590 sustained minor injuries, and 4670 people suffered no injury. This indicates that on overage more than one person is killed in a fatal head-on collision. Considering that more than one person is killed in a fatal head-on collision in Ghana, it is imperative to assess what factors influence the number of head-

Table 3
Random parameters negative binomial model estimation results for number of head-on collision fatalities.

Variable	Parameter estimate	t-statistic	Average marginal effect
Constant	0.384	3.62	
Standard deviation of parameter distribution	0.081	3.58	
Collision partners			
Car-Motorcycle	−0.307	−2.46	−0.430
Bus-Minibus	0.620	5.06	0.870
Light Goods Vehicle-Minibus	0.523	6.39	0.734
Minibus-Motorcycle	−0.368	−4.02	−0.517
Car-Minibus	0.166	2.00	0.233
Temporal characteristics			
Weekend	−0.063	−2.18	−0.088
December	−0.082	−2.81	−0.115
January	0.272	4.01	0.382
Between midday and 7pm	0.027	1.74	0.038
Vehicle characteristics			
Pickup	−0.076	−1.60	−0.106
Commercial vehicle	0.302	4.80	0.424
Multiple defects	−0.170	−3.55	−0.238
Tyre defect	0.330	1.82	0.464
Contributing factors			
Minibus overtaking	0.132	1.71	0.185
Motorcycle overtaking	−0.049	−2.23	−0.068
Light Goods Vehicle overtaking	0.041	3.27	0.057
Car overtaking	−0.183	−2.13	−0.257
Speed	0.111	2.07	0.156
Roadway and lighting condition			
Paved road	0.078	2.31	0.109
Wet pavement	0.078	0.27	0.109
Standard deviation of parameter distribution	0.874	4.41	
Clear weather	−0.170	−2.53	−0.238
Standard deviation of parameter distribution	0.112	4.06	
Curve	0.012	0.13	0.016
Standard deviation of parameter distribution	0.664	13.25	
Poor shoulder condition	−0.094	−3.14	−0.132
Dark	−0.145	−1.86	−0.204
Location characteristic			
Urban area	−0.128	−1.91	−0.179
Driver characteristic			
Driver age between 25 and 45	0.043	0.66	0.060
Standard deviation of parameter distribution	0.356	14.02	
Dispersion parameter for negative binomial distribution			
Dispersion parameter	16.688	3.91	
Number of observations	1637		
Log-likelihood with constant only	−4190.04		
Log-likelihood at convergence	−2360.14		
McFadden Pseudo R-sq	0.44		

on collision fatalities in the country. The descriptive statistics of the variables available for model estimation are presented in Table 1. Preliminary analysis of the data revealed that the highest number of head-on collisions happened on Saturdays and between 6pm-midnight. Driver inattention, speeding, and wrongful overtaking have also been identified as the leading contributing factors of head-on collisions in the country. About 87% of head-on collision casualties were between 20 and 60 years old. Cars, minibuses, heavy goods vehicles, and motorcycles are the leading vehicle types to be involved in head-on collisions. It has also been revealed that only 2% of drivers involved in head-on collisions are female. More passengers (51.5%) than drivers (48.5%) were injured or killed in the crashes.

4. Model estimation results

Table 2 displays the results of the random parameters logit model, which considers heterogeneity in mean and variance for head-on injury severity, along with the corresponding marginal effects. On the other hand, Table 3 showcases the random parameters negative binomial model, which explores the factors linked to the number of fatal casualties in head-on crashes in Ghana. The findings reveal a wide range of crash factors that are associated with both injury severity outcomes and fatalities in head-on collisions. Importantly, these variables were found to be statistically significant at a significance level of 0.05. The results are presented in two parts: the first section presents the analysis of injury severity, while the second section focuses on the analysis of fatality counts.

5. Injury-severity analysis

Twenty-six variables were found to be statistically significant in the head-on crash injury severity model. A discussion of the injury-severity influence of specific factors follows after a description of the heterogeneity in means and variances check for the model.

5.1. Heterogeneity in mean and variances

The injury severity model was checked for heterogeneity in the means and variances for all the variables with statistically significant random parameters (Table 2). Of these variables, the speed indicator variable was found to be statistically significant as a random variable in the model indicating its varying influence on the injury severities. The normal distribution provided the best statistical fit for the random parameter. This variable has a mean of 0.03 and a standard deviation of 1.49 suggesting that this variable is positive for 25.5% of the observations (increasing the likelihood of fatal injury) and negative for 75.5% of the observations (decreasing the likelihood of fatal injury). Two variables were also found to be statistically significant in heterogeneity in means (minibus and light goods vehicle) in the model. The minibus indicator variable decreased the mean of the speed random parameter indicating a decrease in the likelihood of fatal injury and suggesting an increase in the likelihood of non-fatal injury for head-on crashes involving over speeding minibuses. Similarly, the mean of the speed of the light goods vehicle indicator decreased the probability of fatal injury. One parameter (indicator variable for casualty older than 65 years) was found to produce a significant heterogeneity in the variance of the speed random parameter in the model. This variable increased the variance of the speed random variable. The other injury-severity contributing factors are grouped and discussed below.

5.2. Vehicle defects

As shown in Table 2, three vehicle-related variables were found to be significant in the model. The results show that head-on collisions that occurred as a result of steering defects have decreased the likelihood of fatal injury by 0.0007 but the probability of the other injury outcomes is high whereas that of the indicator variables for suspension defect and tyre defects increased the likelihood of fatal injury by 0.0002 and 0.0001, respectively. This shows that suspension rod and tyre defects are more likely to result in fatal head-on collisions in Ghana.

5.3. Vehicle/crash type characteristics

Motorcycle-involved head-on collisions were observed to have a higher chance of resulting in fatal injury. Similarly, Table 2 shows that the probability of recording fatal injury outcome increases by 0.0006 and 0.0001 respectively for bus and heavy good vehicle head-on crashes, while the probability of sustaining some form of injury is lower for private cars.

5.4. Vehicle ownership

It was further observed that head-on collisions involving company vehicles and commercial vehicles were more likely to record some form of injury. The marginal effects indicate that in the case of company vehicles, the chance of minor injury is lower and the chances of injury outcomes is higher, whereas in the case of commercial vehicles, the chance of injury is higher while the probability of no injury is lower.

5.5. Driver actions/contributing factors

Regarding the effect of driver actions or contribution on the injury severity outcomes, distracted driving, drowsy driving, and overtaking were found to be statistically significant in the model. The indicator variables for distracted driving and overtaking were found to increase the likelihood of fatal injury by 0.0018 and 0.0006 respectively, while the drowsy driving variable decreases the likelihood of fatal injury by 0.0001 but increase the likelihood of minor injury. Head-on collisions that involved a speeding vehicle were also more likely to record fatal injury.

5.6. Casualty characteristics

The casualty age variable was grouped into four categories: casualty age less than 25 years, between 25 and 45, age between 45 and 65 years, and greater than 65 years. Three age group variables were found to be statistically significant in the model. The results show that the casualty age less than 25 years indicator variable increased the probability hospitalized injury by 0.0174 but the likelihood of the other injury outcomes is low. It has also been observed that the indicator variables for adult casualty aged between 45 and 65 years and casualty aged between 25 and 45 increased the probability of fatal injury by 0.0129 and 0.0321, respectively. The bus passenger variable was found to be significant in model and increased the probability of fatal injury by 0.0106. Female casualties were less likely to be killed but more likely to sustain injuries that warrant hospitalization, like motorcycle passengers. Drivers on the other hand were more likely to sustain minor injury.

5.7. Driver characteristics

Three driver age group variables were found to be significant in the models. The model estimation results show that drivers aged less than 25 years and those aged between 45 and 65 years were more likely to be involved in fatal head-on crashes while those aged between 25 and 45 years were less likely to get into fatal injury crashes. The probationer drive variable was found to increase the probability of minor injury by 0.0038 and crashes involving drivers with full license were observed to have high chances to be fatal. The results further reveal that in head-on collisions, the driver not at fault was more likely to be killed.

6. Fatality count analysis

Table 3 presents the random-parameters negative binomial model result for understanding the association between various crash factors and the number of fatalities recorded in a head-on collision in Ghana. A total of 1637 fatal crashes were analyzed and 26 crash-related variables were found to significantly influence the number of fatalities. Five variables, including a constant, were found to be random and the remaining 22 variables had fixed effects. The model provides a good fit for the crash data, with McFadden Pseudo R-sq of 0.44. The model was estimated by using simulation-based maximum likelihood with 500 Halton draws and the normal distribution as the functional form of the random parameters.

Regarding the parameters found to be random, the wet pavement variable results in a random parameter that is normally distributed, with a mean of 0.078 and standard deviation of 0.874. This indicates that 46.4% of the distribution is less than 0 and 53.6% is greater than 0, implying that the majority of head-on collisions that happen on wet pavements result in an increased number of fatalities. The average marginal effect of this variable is 0.109. The indicator variable for clear weather head-on collisions also results in a random parameter that is normally distributed, with a mean of −0.170 and standard deviation of 0.112. These values plotted on the normal distribution curve reveal that only 6.5% of the distribution is greater than 0 and 93.5% of the distribution is less than 0. This means that the majority of the crashes that occurred under clear weather condition resulted in decreased number of fatalities. The average marginal effect of the clear weather variable is −0.238. The collision in a curve variable produced a random parameter with a mean of 0.012 and standard deviation of 0.664. Given these distributional parameters, 48.3% of the distribution is less than 0 and 50.7% of the distribution is greater than 0. This indicates over half of the crashes that occurred in a curve resulted in increased fatalities. The average marginal effect for the curve indicator variable is 0.016. The variable for driver aged between 25 and 45 also resulted in a random parameter that is normally distributed, with mean of 0.043 and standard deviation of 0.356 (giving 45.2% of the distribution being less than 0 and 54.8% greater than 0), indicating that majority of head-on collisions involving drivers aged between 25 and 45 had increased number of fatalities.

For the fixed effect variables, marginal effects of the variables indicate that head-on collisions involving motorcycles (i.e., collisions between car and motorcycle, and collisions between minibus and motorcycle) have decreased fatalities, whereas, collision between bus and minibus increases the number of persons killed by an average of 0.87. Similarly, collisions between LGVs and minibuses and collisions between cars and minibuses increase the number of fatalities by average of 0.734 and 0.233, respectively. The results further show that head-on collisions that occur on weekends and those that occur in the month of December have decreased number of fatalities while collisions that occur in January and collisions that occur between midday and 7pm have increased average number of fatalities. Head-on collision involving at least one pickup have lower number of persons killed. However, collisions involving commercial vehicles and those involving vehicles with tyre defects (mostly tyre blow outs) on an average record increased fatalities. It has also been found that head-on collisions that occur as a result of wrong overtaking by a minibus and LGV have higher fatalities, whereas decreased fatalities are recorded on average when the wrongful overtaking involves a car or motorcycle. Further, it was observed that head-on collisions that resulted from over-speeding have an increased number of persons killed and collisions in urban areas on average have decreased fatalities. Interestingly, the average marginal effect for the dark roadway variable indicates a 0.204 decrease in the number of fatalities, and the poor roadway shoulder condition variable is also associated with a decrease in the number of persons killed in a head-on collision.

7. Discussion of results and recommendations

This study revealed some interesting findings regarding head-on-collision crashes in Ghana. The contributing factors found from the two model results reinforce some previous findings in several other studies [31–33]. For example, speeding was found to be a significant contributing factor in fatal crashes as well as determining factor in the number of fatalities as observed in other studies [34,35]. Boateng (2021) attributes such risky driving behavior to the overall driving culture in the country [36]. In the particular instance of risky driving among high-occupancy vehicles such as intercity public transport buses, Damsere-Derry et al. (2021) posited that increasing demand, especially during peak seasons may be a driving factor in such behaviors among these drivers [25]. Further, Afukaar (2003) suggested that increased enforcement of speed limits could also be useful in reducing reckless driving in the country [37]. Due to resource constraints in constantly deploying police personnel and the perceived corruption among law enforcers, the use of speed cameras may perhaps be appropriate in the Ghanaian context. Indeed, speed limit enforcement cameras have been shown to significantly reduce speeding violations, crashes, and injuries resulting thereof [35,38,39].

Another basic driving phenomenon that contributes to a high number of head-on crashes and fatalities is wrongful overtaking by drivers. Interestingly, previous studies [33,36,40] have also identified overtaking as a significant factor in fatal crashes in the country. This may be due to the large proportion of undivided roads in Ghana. As a countermeasure to overtaking-related head-on crashes, road medians offer an effective control for overtaking behaviors [32]. Also, the safer roads concept may be adopted in reengineering roadways to be more forgiving of driving errors and violations. For instance, overtaking lanes may be provided to allow faster vehicles to safely pass by slower ones to avoid dangerous overtaking maneuvers that could lead to head-on collisions. Afukaar (2003) and Sam (2018) advocated for constructing speed humps at high-risk locations on roadways as an affordable speed calming measure and centerline rumble strips at dangerous roadway sections that are prone to improper overtaking [32,37]. Evidentially, Sayed et al. (2010) found about a 30% reduction in head-on collisions at roadway sections that have centerline rumble strips [41].

However, risky driving behavior such as speeding and overtaking could also be attitudinal [31,40]. These findings point to an increased driver-centric countermeasure. Hence, interventional measures should focus on driver training, frequent educational programs, safety campaigns, and law enforcement for behavioral change to improve road safety. To be targeted in the implementation of these countermeasures, this study provides further insight into who these high-risk drivers are, based on the type of vehicles that get into severe injury head-on crashes in the country. This study reveals that large commercial vehicles in the form of buses, minibuses, and motorcycles were significant contributors to fatal crashes. These public transport vehicles carry many passengers at a time. As such, crashes involving these vehicle categories tend to record some form of injury. For the most part, these vehicles are privately owned, and the public transport industry is largely informal and unregulated [36]. The drivers employed in these commercial bus services face challenging working conditions characterized by various issues, including low wages, intense competition, job insecurity, mandatory daily fees imposed by car owners without negotiation, and harassment from corrupt police officers who demand bribes [42]. These factors influence their risky driving behaviors that contribute to road crashes in the country [43–45].

Literature also suggests that the high number of young adults in causalities could be due to the general youthful structure of the population in the country [46]. Studies found that the aberrant driving behaviors of drivers in this age bracket, limited training, lack of confidence to handle emergency situations, and higher risk-taking nature [43,47] contribute to road crashes. Periodic refresher courses for younger drivers/riders on traffic law adherence and good driving/riding principles and attitudes should be considered [46]. Further, previous findings which show that middle-aged drivers in Ghana are more likely to drive under the influence of alcohol [48] provide the basis for increased roadside breathalyzer checkpoints to curb the practice.

Various vehicle defects were also found to contribute to the fatal crashes similar to a study on road traffic crashes in Ghana [46] which reveals that more than 35% of all crashes can be attributed to some vehicle defects. Literature suggests that vehicular defects in Ghana is a result of inadequate vehicle maintenance [31,43], unsafe vehicle design [49], and the importation of salvaged, overaged, and used vehicles from many high-income countries [36]. A high proportion of these vehicles are often converted into commercial public transport vehicles. Programs focusing on regular vehicle safety inspections can help to curb some of the crashes resulting from vehicle defects. Also, governmental policies on the importation of used vehicles should be enforced to ensure that vehicles that are imported into the country meet specified international safety standards.

8. Conclusion

Head-on collisions are widely recognized as among the most severe and perilous types of crashes due to the amplified forces involved, which can cause extensive damage to both vehicles and their occupants. Several factors can contribute to head-on collisions, including driver errors such as speeding, distracted driving, or driving under the influence of substances. Additionally, road design, infrastructure, vehicle design and technology, as well as environmental conditions like weather and visibility, can also play a role in such collisions. Given the alarming frequency and high fatality rate of head-on collisions in Ghana, this study aimed to investigate the contributing factors as part of a broader endeavor to identify cost-effective solutions for reducing the number of fatalities and injuries resulting from these devastating crashes.

The study utilized six years of historical head-on collision data from Ghana and employed two models to investigate the issue. The first model, an injury-severity model, aimed to identify the factors that have a significant impact on the severity of injuries sustained in head-on collisions. The second model, the fatality count model, focused on examining the factors that influence the number of fatalities in head-on crashes across the country. The findings of the study indicated that head-on collisions involving drivers aged over 65 years, buses, motorcycles, and individuals aged between 25 and 65 were more likely to result in fatalities. Moreover, speeding and certain vehicle malfunctions were identified as significant contributors to fatal head-on collisions. The fatality count model demonstrated that head-on collisions involving minibuses and instances where drivers attempted to overtake other vehicles were more likely to result in a higher number of fatalities. The study's results provide support for implementing the safe systems approach to effectively address road traffic crashes in Ghana.

Considering the high proportion of two-lane roads in the country's road network, it is crucial to pinpoint the road segments that are most prone to head-on collisions, in order to implement appropriate countermeasures. As a short-term solution, low-cost strategies such as centerline pavement markings and centerline rumble strips can be installed on roads to help delineate the road and separate opposing directions of travel. Providing additional lateral separation between the two solid center line markings on these two-lane highways can also reduce head-on crashes. In the long term, the construction of physical lane separators to separate opposing traffic and reduce the risk of lane-changing crashes is also recommended. Furthermore, enhancing driver education on hazardous driving practices and providing basic vehicle maintenance knowledge, as well as empowering passengers to speak out against reckless drivers, could aid in preventing some of these crashes and enhance overall road safety in the country.

Author contribution statement

Emmanuel Adanu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

William Agyemang: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Abhay Lidbe: Analyzed and interpreted the data; Wrote the paper.

Offei Adarkwa; Steven Jones: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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