Analysis of Injury Severity of Drivers Involved Different Types of Two-Vehicle Crashes Using Random-Parameters Logit Models with Heterogeneity in Means and Variances

Wu, Qiang; Song, Dongdong; Wang, Chenzhu; Chen, Fei; Cheng, Jianchuan; Easa, Said M.; Yang, Yitao; Yang, Wenchen

DOI
10.1155/2023/3399631

Publication date
2023

Document Version
Final published version

Published in
Journal of Advanced Transportation

Hindawi
Journal of Advanced Transportation
Volume 2023, Article ID 3399631, 15 pages
https://doi.org/10.1155/2023/3399631

Research Article

Analysis of Injury Severity of Drivers Involved Different Types of Two-Vehicle Crashes Using Random-Parameters Logit Models with Heterogeneity in Means and Variances

Qiang Wu ,[1] Dongdong Song ,[2] Chenzhu Wang ,[3] Fei Chen ,[3] Jianchuan Cheng,[3] Said M. Easa,[4] Yitao Yang,[5] and Wenchen Yang [6,7]

[1]*School of Transportation, Nantong University, Nantong, China*
[2]*School of System·Science, Beijing Jiaotong University, Beijing 100044, China*
[3]*School of Transportation, Southeast University, 2 Sipailou, Nanjing, Jiangsu 210096, China*
[4]*Department of Civil Engineering, Toronto Metropolitan University, Toronto, Ontario M5B 2K3, Canada*
[5]*Department of Transport & Planning, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1, Delft 2628 CN, Netherlands*
[6]*National Engineering Laboratory for Surface Transportation Weather Impacts Prevention, Broadvision Engineering Consultants Co., Ltd., Kunming 650200, China*
[7]*Yunnan Key Laboratory of Digital Communications, Kunming 650103, China*

Correspondence should be addressed to Dongdong Song; 19114009@bjtu.edu.cn and Chenzhu Wang; 448617592@qq.com

Received 27 January 2023; Revised 14 June 2023; Accepted 11 July 2023; Published 11 October 2023

Academic Editor: Long Truong

This study proposes random-parameters multinomial logit models, with heterogeneity in means and variances, to explore the differences in the factors influencing injury severities of drivers involved in different types of two-vehicle crashes. The models are verified using crash data from the United Kingdom (UK) over three years (2016–2018). Three types of crashes are separately identified (car-car, car-truck, and truck-truck crashes). In this study, a wide variety of potential variables, including the driver, vehicle, road, and environmental characteristics, are considered, with two possible injury-severity outcomes: severe and slight injury. The results show that unobserved heterogeneity existed for young drivers in both car-car and truck-truck crash models and the 30 mph speed limit in the three separate models. Remarkably variations are observed in crashes involving different types of vehicles. The driver's age and gender, speeding, sideswipes, presence of junctions, weekdays, unlit, and weather conditions significantly impact driver-injury severities in various types of vehicle crashes. These findings are expected to help policymakers seek to improve highway safety and implement proper safety countermeasures.

1. Introduction

Traffic crashes, particularly those involving severe and fatal injuries, have resulted in an enormous loss in terms of human, economic, and social aspects. Worldwide, almost 1.3 million deaths were caused yearly by road traffic crashes [1]. Furthermore, 62% of the crashes across six years (2012–2018) reported by the police were two-vehicle crashes [2, 3]. The Crash Report Sampling System (CRSS) analysis also illustrated that the drivers are the most affected group injured or killed in traffic crashes. Specifically, over 75% of all drivers in the US were injured or killed in 2018.

In addition, the injury-severity levels of both parties are expected to differentiate involving different vehicle-type crashes (such as car-car, car-truck, and truck-truck crashes). In 2017, among the 4,761 people killed in crashes with the involvement of large trucks, 72% were occupants of other vehicles [3]. Moreover, the drivers of passenger cars tend to sustain serious injuries when colliding with trucks. Furthermore, almost half of the motor vehicle crashes that occurred on I-80 from Wyoming were crashes involving trucks, with a remarkable proportion of fatalities caused by car-truck crashes [4]. Concerning the considerable variations in injury outcomes among vehicles of light and heavy weights, the type of vehicles is suggested to be a critical element in injury modeling analysis.

Overwhelming evidence illustrated the unobserved heterogeneity in current traffic safety literature. Numerous economic modeling approaches were recently used to analyze the injury severities of crashes on highways to address this critical challenge. Examples include the latent class models [5], random-parameter ordered models [6], and random-parameters logit models [7–9]. By accommodating variations of the explanatory variables across the observations and factors affecting the means and variances of the parameter density functions of the random parameters, the random-parameters logit models with heterogeneity in means and variances approaches are supposed to be more flexible in accounting for the unobserved heterogeneity, specified by the statistical superiority in terms of accuracy and reduced heterogeneity [10–12].

Given this, this study comprehensively estimates the injury severities of two-vehicle crashes using advanced statistical models given the types of vehicles involved in the crash. The study methodology is shown in Figure 1. The methodology involves a literature review of the injury severities involving two-vehicle crashes. Then, the data used for this study are described, followed by an introduction to the methodological approach. Then, a detailed discussion of the model estimation results is presented. Finally, the last section summarizes the findings of this study and discusses potential future directions. As shown in Figure 1, by collecting the characteristics of driver, vehicle, roadway, and environment among the car-car, truck-truck, and car-truck crashes, a series of models will be estimated based on the random-parameters multinomial logit models. Then, based on the random parameters, significant factors, and marginal effects, some valuable findings can be revealed, and practical applications can be implemented.

2. Literature Review

Table 1 briefly summarizes the significant factors determining driver's injury-severity outcomes in previous two-vehicle crash studies. Varieties of explanatory factors regarding driver, vehicle, roadway, and environmental characteristics have been found to affect the injury severity in two-vehicle crashes. As for vehicle characteristics, most relevant studies have investigated the influence of vehicle types on injury severity. Few studies have focused on comparing injury severity between different vehicle crashes to identify differential effects of the same explanatory variables. However, the authors in [28] used binary logistic modeling with a Bayesian inference approach to investigate occupant injury severity of truck-involved crashes based on vehicle types on a mountainous freeway. However, their study was constrained to truck-involved crashes. Furthermore, the authors in [29] developed the heteroscedastic ordered logit models to analyze driver's injury severity in single- and two-vehicle crashes and compare how the effects of explanatory variables vary across various types of crashes. However, traditional logit and probit models assume that the estimated parameters are fixed for all observations, causing biased parameter estimates and erroneous inferences [30]. Previous reviews summarized by several researchers have presented comprehensive studies of unobserved heterogeneity [30–32].

Recently, a more advanced statistical method has been used to fully address possible unobserved heterogeneity in the means and variances of the random parameters [33]. The application of this advanced modeling framework enables capturing the multilayered unobserved heterogeneity of the crash data in terms of (a) estimated parameters varying across the observations; (b) factors affecting the mean of the parameter density function of the random parameters (and thus shifts in the peak of the distribution of the betas); and (c) factors affecting the variance of the parameter density function of the random parameters (and thus changes in the tails of the distribution of the betas). However, research utilizing random-parameters logit models with heterogeneity in means and variances models in the context of different types of vehicle crashes is limited.

To fill this research gap, a random-parameters logit model with heterogeneity in means and variances model is estimated to examine the difference in contributing factors of injury severity of drivers involved in different types of vehicle crashes.

3. Data Description

Three-year crash data from the United Kingdom (UK) were drawn from the STATS19 dataset, the most comprehensive and publicly available crash database in the UK containing information obtained from police crash reports [34]. The dataset comprises three files: accident, vehicle, and casualty. We used this study's accident and vehicle reference numbers to merge the three subsets. After merging, the analysis unit in the current paper is the *accident*. Each case contains the time/date of accident occurrence, weather, road, light conditions, posted speed limit, road type, driver's age and gender, vehicle type, first impact point of the vehicle, vehicles' maneuvers, and injury-severity level. A total of 8,373 two-vehicle crashes were extracted (missing and unreliable data were removed): 4,992 crashes involving car-car crashes, 2,770 crashes involving car-truck crashes, and 681 crashes involving truck-truck crashes.

The dependent variable of the models is the "*injury-severity level*." Following the STATS19 injury classification, three injury-severity outcomes are considered in this study: slight injury, severe injury, and fatality. Crashes resulting in no injuries are not recorded in the dataset [35]. Because of the relatively low number of fatality crashes (1.33% of total two-vehicle crashes), fatal injuries and serious injuries were combined into one category of injury severity. Therefore, this study reclassifies cases using two severity levels: slight injury and severe injury (including serious injury and fatality) (86.02% and 13.98% for slight injury and severe injury in car-car crashes, note that 89.56% and 10.44% for slight

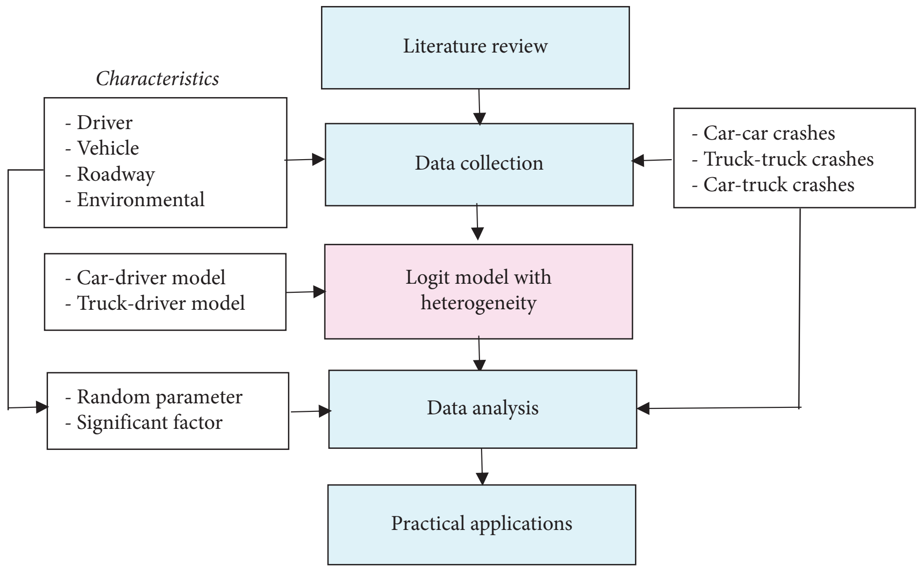

Figure 1: Flowchart of the study methodology.

Table 1: A summary of studies on the severity of two-vehicle crashes.

Variable names	Key findings
(a) Driver characteristics	
Gender	Female drivers are more likely to be injured [13–15]. In contrast, the authors in [16] found that male drivers are more likely to sustain the probability of severe injury.
Age	Older drivers are usually more severely injured [13–15, 17–19]. However, the authors in [16] found that middle-aged drivers are more likely to sustain the probability of severe injury.
Seatbelt used	Drivers without use of safety equipment are more likely to be injured [13, 20, 21].
Alcohol involved	The alcohol involvement variable is more likely to sustain the probability of severe injury outcomes [16, 19, 20, 22, 23].
Fault status	The authors in [13] found that not-at-fault drivers are more likely to be injured. Furthermore, the authors in [18] examined and compared the effect of selected variables on driver-injury severities of both at-fault and not-at-fault drivers.
(b) Vehicle characteristics	
Vehicle type	The involvement of trucks tends to increase the probability of more severe injuries [13, 22, 24]. In contrast, the authors in [14, 23] found that passenger cars are usually associated with increased injury severity.
Age of vehicle	The increased age of a vehicle is found to increase the injury severity of drivers [13–15].
Vehicle action	Some vehicle actions before the crash (i.e., left turn) significantly influence driver-injury severities [20].
(c) Roadway characteristics	
Speed limit	Posted speed limit variable considerably affects the injury-severity outcomes [15–17, 21, 23, 25].
Road grade	The author in [20] found that road grade variable imposes significantly influences driver-injury severities.
(d) Environmental characteristics	
Weather condition	Weather conditions (such as windy, rainy, or snowy) could significantly increase driver-injury severities [22, 24, 26, 27]. The authors in [14] found that adverse weather conditions have no similar effect.
Lighting condition	Lighting conditions are found to be significant factors influencing multiple-vehicle crashes [14, 20–22, 24].

injury and severe injury of car drivers in car-truck crashes, 80.19% and 19.81% for slight injury and severe injury of truck drivers in car-truck crashes, whereas 80.91% and 19.09% for slight injury and severe injury in truck-truck crashes, respectively). Table 2 presents the descriptive statistics of these variables in injury-severity models.

Table 2: Descriptive statistics of significant variables in the injury-severity model.

Variables	Car-car CD		Truck-truck TD		Car-truck CD		Car-truck TD	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Day of week (1 if weekdays, 0 otherwise)	0.687	0.464	0.797	0.402	0.717	0.451	0.717	0.451
Day of week (1 if weekends, 0 otherwise)	0.313	0.464	0.203	0.402	0.283	0.451	0.283	0.451
Road type (1 if roundabout, 0 otherwise)	0.033	0.178	0.015	0.120	0.031	0.174	0.031	0.174
Road type (1 if one-way street, 0 otherwise)	0.006	0.077	0.003	0.054	0.003	0.058	0.003	0.058
Road type (1 if dual carriageway, 0 otherwise)	0.173	0.378	0.410	0.492	0.191	0.393	0.191	0.393
Road type (1 if single carriageway, 0 otherwise)	0.777	0.416	0.555	0.497	0.762	0.426	0.762	0.426
Road type (1 if slip road, 0 otherwise)	0.010	0.100	0.015	0.120	0.010	0.098	0.010	0.098
Road type (1 if unknown, 0 otherwise)	0.001	0.028	0.003	0.054	0.003	0.058	0.003	0.058
Speed limit (1 if 20 mph, 0 otherwise)	0.027	0.163	0.021	0.142	0.013	0.113	0.013	0.113
Speed limit (1 if 30 mph, 0 otherwise)	0.473	0.499	0.188	0.391	0.340	0.474	0.340	0.474
Speed limit (1 if 40 mph, 0 otherwise)	0.137	0.344	0.117	0.322	0.141	0.349	0.141	0.349
Speed limit (1 if 50 mph, 0 otherwise)	0.069	0.253	0.059	0.235	0.089	0.285	0.089	0.285
Speed limit (1 if 60 mph, 0 otherwise)	0.232	0.422	0.289	0.454	0.305	0.460	0.305	0.460
Speed limit (1 if 70 mph, 0 otherwise)	0.063	0.242	0.326	0.469	0.112	0.315	0.112	0.315
Light conditions (1 if daylight, 0 otherwise)	0.703	0.457	0.803	0.398	0.772	0.419	0.772	0.419
Light conditions (1 if darkness-lights lit, 0 otherwise)	0.207	0.405	0.082	0.275	0.117	0.322	0.117	0.322
Light conditions (1 if darkness-lights unlit, 0 otherwise)	0.006	0.075	0.003	0.054	0.004	0.061	0.004	0.061
Light conditions (1 if darkness-no lighting, 0 otherwise)	0.074	0.262	0.097	0.296	0.091	0.288	0.091	0.288
Light conditions (1 if darkness-unknown, 0 otherwise)	0.011	0.103	0.015	0.120	0.016	0.124	0.016	0.124
Weather conditions (1 if fine, 0 otherwise)	0.797	0.402	0.838	0.368	0.828	0.378	0.828	0.378
Weather conditions (1 if raining, 0 otherwise)	0.174	0.380	0.138	0.345	0.138	0.345	0.138	0.345
Weather conditions (1 if snowing, 0 otherwise)	0.003	0.057	0.009	0.094	0.004	0.067	0.004	0.067
Weather conditions (1 if fog or mist, 0 otherwise)	0.005	0.069	0.012	0.108	0.009	0.094	0.009	0.094
Weather conditions (1 if other, 0 otherwise)	0.020	0.140	0.003	0.054	0.021	0.144	0.021	0.144
Road surface (1 if dry, 0 otherwise)	0.627	0.484	0.698	0.460	0.660	0.474	0.660	0.474
Road surface (1 if wet or damp, 0 otherwise)	0.353	0.478	0.285	0.452	0.319	0.466	0.319	0.466
Road surface (1 if snow, 0 otherwise)	0.002	0.045	0.006	0.076	0.003	0.058	0.003	0.058
Road surface (1 if frost or ice, 0 otherwise)	0.013	0.114	0.009	0.094	0.016	0.127	0.016	0.127
Road surface (1 if flood over 3 cm deep, 0 otherwise)	0.004	0.065	0.003	0.054	0.001	0.038	0.001	0.038
Urban area (1 if urban, 0 otherwise)	0.504	0.500	0.223	0.417	0.343	0.475	0.343	0.475
Rural area (1 if rural, 0 otherwise)	0.494	0.500	0.777	0.417	0.657	0.475	0.657	0.475
Vehicle maneuver (1 if reversing, 0 otherwise)	0.003	0.057	0.003	0.054	0.002	0.043	0.004	0.067
Vehicle maneuver (1 if parked, 0 otherwise)	0.007	0.083	0.040	0.195	0.011	0.105	0.024	0.153
Vehicle maneuver (1 if waiting to go, 0 otherwise)	0.022	0.147	0.047	0.212	0.027	0.161	0.029	0.169
Vehicle maneuver (1 if slowing or stopping, 0 otherwise)	0.039	0.193	0.103	0.304	0.049	0.216	0.048	0.214
Vehicle maneuver (1 if moving off, 0 otherwise)	0.038	0.192	0.023	0.152	0.041	0.198	0.026	0.158
Vehicle maneuver (1 if turning, 0 otherwise)	0.194	0.395	0.078	0.268	0.152	0.359	0.153	0.360
Vehicle maneuver (1 if changing lane, 0 otherwise)	0.013	0.115	0.019	0.137	0.015	0.121	0.012	0.110
Vehicle maneuver (1 if overtaking, 0 otherwise)	0.024	0.154	0.019	0.137	0.037	0.190	0.018	0.132
Vehicle maneuver (1 if going ahead other, 0 otherwise)	0.659	0.474	0.668	0.471	0.666	0.472	0.685	0.465
First point of impact (1 if did not impact, 0 otherwise)	0.010	0.102	0.015	0.120	0.013	0.115	0.007	0.081
First point of impact (1 if front, 0 otherwise)	0.651	0.477	0.580	0.494	0.625	0.484	0.639	0.481
First point of impact (1 if back, 0 otherwise)	0.096	0.294	0.236	0.425	0.131	0.338	0.128	0.334
First point of impact (1 if offside, 0 otherwise)	0.158	0.365	0.115	0.319	0.146	0.353	0.152	0.359
First point of impact (1 if nearside, 0 otherwise)	0.085	0.278	0.054	0.227	0.084	0.277	0.075	0.264
Age of vehicle (1 if data missing, 0 otherwise)	0.096	0.294	0.160	0.367	0.085	0.279	0.143	0.350
Age of vehicle (1 if below three years, 0 otherwise)	0.151	0.359	0.241	0.428	0.165	0.371	0.280	0.449
Age of vehicle (1 if 3–10 years, 0 otherwise)	0.451	0.498	0.465	0.499	0.427	0.495	0.410	0.492
Age of vehicle (1 if above ten years, 0 otherwise)	0.301	0.459	0.134	0.341	0.323	0.468	0.167	0.373
Sex of driver (1 if male, 0 otherwise)	0.575	0.494	0.975	0.156	0.601	0.490	0.931	0.253
Sex of driver (1 if female, 0 otherwise)	0.425	0.494	0.025	0.156	0.399	0.490	0.069	0.253
Age band of driver (1 if below 25 years, 0 otherwise)	0.204	0.403	0.084	0.277	0.187	0.390	0.111	0.314
Age band of driver (1 if 26–45 years, 0 otherwise)	0.403	0.491	0.461	0.499	0.412	0.492	0.485	0.500
Age band of driver (1 if 46–65 years, 0 otherwise)	0.271	0.445	0.411	0.492	0.273	0.446	0.363	0.481
Age band of driver (1 if above 65 years, 0 otherwise)	0.123	0.328	0.044	0.205	0.128	0.334	0.041	0.199
Driver home area type (1 if data missing, 0 otherwise)	0.079	0.269	0.132	0.339	0.089	0.284	0.097	0.297
Driver home area type (1 if urban area, 0 otherwise)	0.683	0.465	0.646	0.479	0.610	0.488	0.667	0.471
Driver home area type (1 if small town, 0 otherwise)	0.100	0.299	0.109	0.311	0.125	0.331	0.100	0.300

Table 2: Continued.

Variables	Car-car CD		Truck-truck TD		Car-truck CD		Car-truck TD	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Driver home area type (1 if rural, 0 otherwise)	0.138	0.345	0.113	0.317	0.176	0.381	0.136	0.343
Month (1 if spring, 0 otherwise)	0.236	0.425	0.213	0.410	0.214	0.410	0.214	0.410
Month (1 if summer, 0 otherwise)	0.249	0.433	0.267	0.443	0.257	0.437	0.257	0.437
Month (1 if autumn, 0 otherwise)	0.270	0.444	0.279	0.449	0.269	0.443	0.269	0.443
Month (1 if winter, 0 otherwise)	0.245	0.430	0.241	0.428	0.261	0.439	0.261	0.439
Crash time (1 if off-peak time, 0 otherwise)	0.632	0.482	0.681	0.466	0.611	0.488	0.611	0.488
Crash time (1 if morning peak, 0 otherwise)	0.165	0.371	0.213	0.410	0.230	0.421	0.230	0.421
Crash time (1 if evening peak, 0 otherwise)	0.203	0.402	0.106	0.308	0.159	0.366	0.159	0.366

4. Logit Model

Separate random-parameter logit models with heterogeneity in means and variances (RPLHMV) were estimated to identify the factors influencing the driver's injury and severity involved in different vehicle crashes. To begin with, an injury-severity function, Y_{in}, that determines the driver-injury-severity level i in crash n, is specified as follows [36–38]:

$$Y_{\text{in}} = \beta_{\mathbf{i}}\mathbf{X}_{\mathbf{in}} + \varepsilon_{\text{in}}, \quad (1)$$

where $\mathbf{X}_{\mathbf{in}}$ are vectors of explanatory variables that affect driver-injury-severity level i (slight injury or severe injury) in crash n, $\beta_{\mathbf{i}}$ is a vector of corresponding estimable parameters, and ε_{in} is an error term assumed to follow an independent and identical distribution with zero mean and variance σ^2. To account for unobserved heterogeneity, random parameters with heterogeneity in means and variances are introduced as follows [30, 38, 39]:

$$\beta_{\text{in}} = \beta_i + \Theta_{\mathbf{in}}\mathbf{Z}_{\mathbf{in}} + \sigma_{\text{in}}\text{EXP}\left(\psi_{\mathbf{in}}\mathbf{W}_{\mathbf{in}}\right) + \upsilon_{\text{in}}, \quad (2)$$

where β_i is the mean parameter estimate across all crashes, $\mathbf{Z}_{\mathbf{in}}$ are vectors of explanatory variables that influence the mean, $\Theta_{\mathbf{in}}$ are vectors of corresponding estimable parameters, $\mathbf{W}_{\mathbf{in}}$ are vectors of explanatory variables that capture heterogeneity in variances, σ_{in}, $\psi_{\mathbf{in}}$ is a vector of corresponding estimable parameters, and υ_{in} is a disturbance term. Then, the outcome probability of the RPLHMV model formulation can be expressed as follows [26]:

$$P_n(i|\varphi) = \int \frac{\exp(\beta_{\mathbf{i}}\mathbf{X}_{\mathbf{in}})}{\sum_{i\in I}\exp(\beta_{\mathbf{i}}\mathbf{X}_{\mathbf{in}})} f(\beta_{\mathbf{i}}|\boldsymbol{\varphi})\text{d}\beta_{\mathbf{i}}, \quad (3)$$

where $p_n(i|\varphi)$ is the probability of injury-severity level i conditional on $f(\beta_{\mathbf{i}}|\varphi)$ and $f(\beta_{\mathbf{i}}|\varphi)$ is the density function of β_{i}, with φ referring to a vector of parameters (means and variances).

The RPLHMV model is estimated with a simulated maximum likelihood method, and 1,000 Halton draws are used to achieve stable parameter estimates [40]. Regarding the distribution of the random parameters, the normal distribution is used to achieve the best goodness of fit [7, 41–44].

The pseudo-elasticities are computed to quantitatively describe the impact of explanatory variables on the driver-injury severities. In this paper, all variables used in the estimated models are binary indicator variables. Therefore, the pseudo-elasticities quantify the change in outcome probability when an explanatory variable changes from "0" to "1" [37, 43].

We conducted chi-square distributed likelihood ratio tests to determine whether there is any difference between injury-severity outcomes for vehicle types. To begin, likelihood ratio tests were conducted to compare injury-severity outcomes for vehicle types. The test statistic is [45–48]

$$\chi_t^2 = -2\left[LL\left(\beta_{\text{combined},t}\right) - LL\left(\beta_{\text{car-car},t}\right) - LL\left(\beta_{car-truck,t}\right) - LL\left(\beta_{\text{truck-truck},t}\right)\right], \quad (4)$$

where $LL(\beta_{\text{combined},t})$ is the log-likelihood at the convergence of the model using all of the available two-vehicle crash data in the year t, $LL(\beta_{\text{car-car},t})$ is the log-likelihood at the convergence of the model using car-car crash data only in year t, $LL(\beta_{\text{car-truck},t})$ is the log-likelihood at the convergence of the model using car-truck crash data only in year t, and $LL(\beta_{\text{truck-truck},t})$ is the log-likelihood at the convergence of the model using truck-truck crash data only in year t. The model estimate gained from the test gave an χ^2 values of 61.64 with 12 degrees of freedom. The modeling approach specified the null hypothesis that statistically significant parameters in truck-car crash models are stable and can be rejected at 99.99% confidence level.

5. Results

Table 3 presents the model estimation results based on the random-parameter logit models with heterogeneity in means and variances, indicating a very good overall model fit with McFadden R-Squared between 0.374 and 0.478. Based on the estimated results, a detailed discussion is shown as follows.

5.1. Random-Parameters Insights. For the car-car model, there are two statistically significant variables as random parameters (see Table 3), including young car driver (between 26–45 years) and the 30 mph speed limit. Among them, the young car-driver (between 26–45 years) indicator is significant as a normally distributed random parameter, wherein 92.44% of the observations increase the probability

Table 3: Model results of injury severity of drivers involved in different types of vehicle crashes.

Variables	Car-car crashes		Truck-truck crashes		Car-truck crashes			
	CD model[a]		TD model[a]		CD model		TD model	
	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat
Constant	1.048	3.97	2.398	2.14	1.868	7.30	1.234	3.49
Random parameters								
Age band of car driver (1 if 26–45 years, 0 otherwise)	0.471	2.46	—	—	—	—	—	—
Standard deviation values for 26–45 years car drivers (normally distributed)	0.328	3.54	—	—	—	—	—	—
Age band of truck driver (1 if 26–45 years, 0 otherwise)	—	—	0.569	2.51	—	—	0.152	1.14
Standard deviation values for 26–45 years truck drivers (normally distributed)	—	—	0.865	3.46	—	—	—	—
Heterogeneity in the mean of random parameter: male	0.598	4.12	—	—	—	—	—	—
Heterogeneity in the mean of random parameter: darkness—lights lit	—	—	−0.364	−1.67	—	—	—	—
Speed limit (1 if 30 mph, 0 otherwise)	−0.447	−3.56	−0.234	−1.75	−0.618	−3.95	−0.418	−4.15
Standard deviation values for the 30 mph speed limit (normally distributed)	0.185	6.07	0.271	8.80	—	—	0.789	14.36
Heterogeneity in the mean of random parameter: weekdays	—	—	—	—	—	—	0.476	2.54
Heterogeneity in the variance of random parameter: rural areas	—	—	—	—	—	—	1.094	7.03
Fixed parameters								
Driver characteristics								
Gender of car driver (1 if female, 0 otherwise)	0.444	3.52	—	—	0.410	2.43	—	—
Gender of truck driver (1 if male, 0 otherwise)	—	—	1.012	0.96	0.067	0.64	0.258	0.93
Age band of car driver (1 if 65 years above, 0 otherwise)	0.327	2.16	—	—	0.766	5.72	—	—
Age band of truck driver (1 if 65 years above, 0 otherwise)	—	—	0.601	1.31	—	—	0.093	0.31
Vehicle characteristics								
Age of car vehicle (1 if 3–10 years, 0 otherwise)	—	—	—	—	−0.032	−0.24	—	—
Age of truck vehicle (1 if above ten years, 0 otherwise)	—	—	—	—	—	—	0.399	2.46
Car vehicle maneuver (1 if speeding, 0 otherwise)	0.959	2.69	—	—	0.228	1.90	0.407	1.01
Truck vehicle maneuver (1 if speeding, 0 otherwise)	—	—	0.013	0.02	—	—	—	—
Car vehicle maneuver (1 if turning, 0 otherwise)	0.345	2.83	—	—	—	—	—	—
Truck vehicle maneuver (1 if changing lane, 0 otherwise)	—	—	—	—	0.586	3.70	1.070	2.33
First point of impact (1 if front, 0 otherwise)	0.701	3.58	—	—	0.184	1.49	0.812	2.95
First point of impact (1 if offside, 0 otherwise)	0.571	2.34	−1.389	−4.28	0.789	3.51	—	—
Roadway characteristics								
Road area type (1 if rural, 0 otherwise)	—	—	0.958	2.35	0.182	1.73	0.073	0.42
Road area type (1 if urban, 0 otherwise)	−0.314	−2.74	—	—	—	—	—	—
Road type (1 if dual carriageway, 0 otherwise)	0.273	2.16	—	—	0.237	1.65	—	—
Road type (1 if roundabout, 0 otherwise)	−0.645	−2.01						
Road type (1 if junctions, 0 otherwise)	—	—	0.813	2.11	—	—	—	—
Environmental characteristics								
Light conditions (1 if darkness-no lighting, 0 otherwise)	2.127	2.07	0.585	1.83	0.250	0.31	0.320	2.08
Light conditions (1 if darkness-lights lit, 0 otherwise)	0.503	3.22	—	—	—	—	—	—
Weather conditions (1 if fine, 0 otherwise)	−0.213	−1.97	—	—	—	—	—	—
Weather conditions (1 if raining, 0 otherwise)	—	—	0.742	2.33	0.981	2.40	—	—
Season (1 if summer, 0 otherwise)	0.253	2.66	—	—	—	—	—	—
Day of week (1 if weekdays, 0 otherwise)	—	—	0.071	0.28	—	—	0.521	2.62

Table 3: Continued.

Variables	Car-car crashes		Truck-truck crashes		Car-truck crashes			
	CD model[a]		TD model[a]		CD model		TD model	
	Coeff	*t*-stat	Coeff	*t*-stat	Coeff	*t*-stat	Coeff	*t*-stat
Crash time (1 if off-peak time, 0 otherwise)	0.192	2.14	—	—	0.323	3.02	—	—
Goodness-of-fit measures								
Number of observations	4992		681		2770		2770	
Log-likelihood at convergence	−1885.2		−301.2		−1236.4		−844.5	
McFadden R-squared	0.374		0.435		0.465		0.478	
Akaike information criterion (AIC)	3814.4		628.4		2508.8		1730.9	

[a]TD: truck driver and CD: car driver.

of severe injury (and in a reduction in the rest 7.56%). Furthermore, the male indicators increase the mean of this young car-driver indicator, thus increasing the likelihood of severe injuries. Most young male car drivers tend to be overconfident in their driving skills and are more likely to exhibit improper actions. However, they lack enough emergency response capabilities, resulting in severe and fatal injuries. Therefore, more enforcement and education programs about young male car drivers should be enhanced. The 30 mph speed limit indicator is significant, with a lower probability of severe injury for 99.22% of the observations.

There are two statistically significant variables as random parameters for the truck-truck model (see Table 3). The 30 mph speed limit is also significant, with a low probability of severe injury for 80.62% of the observations. The young truck driver (between 26 and 45 years) indicator is significant as a normally distributed random parameter, wherein 74.49% of the observations increase the probability of severe injury (and a reduction in the rest of 25.51%). Furthermore, the dark-lighted indicator decreases the mean of this young truck driver indicator, thus decreasing the likelihood of severe injuries. Driving at night, truck drivers are more likely to be tired, leading to misjudgment of the driving speed, thereby inducing severe crashes. Therefore, when making the nighttime scheduling plan, the truck drivers should be arranged reasonably to prevent fatigued driving. To that end, highly efficient street lighting over road segments with a high proportion of large trucks should be considered to improve visibility during nighttime conditions. Also, drivers should be careful with relatively lower speeds when driving on artificially lit road sections.

For the car-truck model, there is only one statistically significant variable (see Table 3). However, the 30 mph speed limit indicator is also significant, where 70.19% of the observations decrease the probability of severe injury. Note that the weekday indicator increases the mean of the 30 mph speed limit indicator, making severe injuries more likely. Our finding seems to be consistent with the literature in which the author clarified that lower proportions of trucks characterize weekends compared to weekdays [28, 49]. Again, note that the variance of the speed limit indicator is affected by the rural area indicator, which increases its variance (it makes the distribution tail of the parameter density function flatter and thus offers a more uniformly shaped distribution of the betas), reflecting higher variability.

5.2. Significant Factor Analysis

5.2.1. Car-Car Crashes (Car Driver Model). As shown in Table 4, there are three statistically significant driver-related variables in the car-car crash model. Female drivers are associated with a 15.56% risk of severe injury compared to male drivers. A possible explanation for these results may be the lack of enough emergency response capabilities, resulting in serious and even fatal injuries. Young drivers are linked to a 10.71% increased risk of severe injury. Most young drivers (between 26 and 45 years) tend to be overconfident in their driving skills and are more likely to exhibit improper actions. However, they lack enough emergency response capabilities, resulting in severe injury. More enforcement and education programs about young drivers should be enhanced. In addition, old drivers (65 years above) are associated with a 2.76% increased risk of severe injury. The physical function of old drivers is programmed to diminish with age. And the reaction lag is also more likely to lead to severe injury crashes. Consequently, old drivers should attend regular physical check-ups and driving safety education; if failing a driving test, they could be considered to take the initiative to return their driver's license or take compulsory license suspension.

Four vehicle-related variables, speeding, turning, head-on collision, and sideswipes collision, all have statistically significant effects on the injury severity of drivers in the car-car crash model. Among them, speeding is associated with a 3.54% increased risk of severe injury. When speeding while driving, the view of drivers becomes narrower. Furthermore, more kinetic energy after the collision is more likely to result in severe and fatal injuries. Turning is associated with a 6.01% increased risk of severe injury. When a vehicle turns, the view of drivers also becomes narrower, and they are more inattentive. Notably, the study found that both side and frontal crashes increased the risk of severe injury in car-car crashes and that side crashes are more likely to result in severe injury than frontal crashes (38.46% vs. 4.27%). The main reason may be that the impact of the hit vehicle was on the side, meaning that at least one driver did not pay attention to oncoming traffic in the other direction. Hence, a high-speed collision is more likely to result in severe injury. More importantly, the vehicle's protection does not even work for the driver in the side direction.

Four roadway-related variables, including roundabouts, dual carriageway, 30 mph speed limit, and urban areas, are statistically significant in affecting the driver-injury severities in the car-car crash model. Among them, crashes that occurred at roundabouts are associated with a 1.96% increased risk of severe injury. The speed of vehicles is generally slower at roundabouts, reducing the likelihood of serious crashes. However, due to improper actions (such as speeding or running a red light), they often collide with the other vehicles at the roundabout, thereby increasing the probability of slight crashes. Compared with single lanes, automotive vehicles driving in dual lanes are prone to frequent lane change behavior, increasing the risk of severe injury by 4.20%. The 30 mph speed limit indicator decreases the probability of severe injury by 23.18%. Finally, compared to rural roads, the overall lower vehicle speeds on urban roads reduce the risk of severe injury by 14.33%.

Five environment-related variables, including dark lighted, dark no light, sunny, off-peak crash time, and summer, have a statistically significant effect on the injury severity of drivers in the car-car crash model. It is highlighted that under the dark lights, the perception of the external environment weakened the perception abilities of hazardous situations. When driving at night after working for long hours during the daytime, car drivers are more likely to be tired, leading to misjudgment of the driving speed,

Table 4: Marginal effects result of injury severity of drivers involved in different types of vehicle crashes.

Variables	Car-car crashes CD model[a]		Truck-truck crashes TD model[a]		Car-truck crashes CD model		Car-truck crashes TD model	
	MI	SI	MI	SI	MI	SI	MI	SI
Random parameters								
Age band of car driver (1 if 26–45 years, 0 otherwise)	−0.0146	0.1071						
Age band of truck driver (1 if 26–45 years, 0 otherwise)			−0.0311	0.1605			−0.0070	0.0666
Speed limit (1 if 30 mph, 0 otherwise)	0.0232	−0.2318	0.0210	−0.2030	0.0245	−0.1855	0.0121	−0.1832
Fixed parameters								
Driver characteristics								
Gender of car driver (1 if female, 0 otherwise)	−0.0233	0.1556			−0.0702	0.2695		
Gender of truck driver (1 if male, 0 otherwise)			−0.1917	0.7950	−0.0082	0.0318	−0.0254	0.2146
Age band of car driver (1 if 65 years above, 0 otherwise)	−0.0050	0.0276			−0.0326	0.0655		
Age band of truck driver (1 if 65 years above, 0 otherwise)			−0.0079	0.0185			−0.0005	0.0034
Vehicle characteristics								
Age of car vehicle (1 if 3–10 years, 0 otherwise)					0.0010	−0.0043		
Age of truck vehicle (1 if above ten years, 0 otherwise)							−0.0099	0.0566
Car vehicle maneuver (1 if speeding, 0 otherwise)	−0.0017	0.0354			−0.0338	0.1180	−0.0012	0.0060
Truck vehicle maneuver (1 if speeding, 0 otherwise)			−0.0001	0.0002				
Car vehicle maneuver (1 if turning, 0 otherwise)	−0.0067	0.0601						
Truck vehicle maneuver (1 if changing lane, 0 otherwise)					−0.0208	0.1799	−0.0028	0.0103
First point of impact (1 if front, 0 otherwise)	−0.0056	0.0427			−0.0264	0.0890	−0.0057	0.0980
First point of impact (1 if offside, 0 otherwise)	−0.0717	0.3846	−0.0245	0.3038	−0.0091	0.0946		
Roadway characteristics								
Road area type (1 if rural, 0 otherwise)			−0.0113	0.0928	0.0184	−0.0929	−0.0014	0.0085
Road area type (1 if urban, 0 otherwise)	0.0149	−0.1433						
Road type (1 if dual carriageway, 0 otherwise)	−0.0053	0.0420			−0.0071	0.0381		
Road type (1 if roundabout, 0 otherwise)	−0.0014	0.0196						
Road type (1 if junctions, 0 otherwise)			−0.0107	0.0752				
Environmental characteristics								
Light conditions (1 if darkness—no lighting, 0 otherwise)	−0.0004	0.0115	−0.0163	0.0404	−0.0002	0.0007	−0.0239	0.2231
Light conditions (1 if darkness—lights lit, 0 otherwise)	−0.0128	0.0910						
Weather conditions (1 if fine, 0 otherwise)	0.0242	−0.1459						
Weather conditions (1 if raining, 0 otherwise)			−0.1264	0.4958	−0.0025	0.0280		
Season (1 if summer, 0 otherwise)	−0.0101	0.0530						
Day of week (1 if weekdays, 0 otherwise)			−0.0107	0.0461			−0.0073	0.0920
Crash time (1 if off-peak time, 0 otherwise)	−0.0180	0.1032			−0.0432	0.1543		

[a]TD: truck driver, CD: car driver, SI: severe injury, and MI: minor injury.

thereby inducing severe crashes. A sunny environment decreases the likelihood of severe injury by 14.59%. The off-peak time and summer indicators increase the estimated odds of a severe injury by 5.30% and 10.32%, respectively.

5.2.2. Truck-Truck Crashes (Truck Driver Model). As shown in Table 4, there are three statistically significant driver-related variables in the truck-truck crash model. Male drivers are associated with a 79.50% increased risk of severe injury compared with female drivers. On the one hand, due to the particularity of the truck occupation, the proportion of male drivers is more than females. On the other hand, compared to car drivers, truck drivers often need to drive longer to reach their destination. Drivers' fatigue driving is a significant cause of traffic accidents. Therefore, truck drivers should ensure sufficient sleep before driving, and if tired when driving, they should immediately go to the nearest service area and rest to ensure safe driving. Young drivers (26–45 years) and older drivers (65 years above) increase the odds of a severe injury by 16.05% and 1.85%, respectively.

Two vehicle-related variables, including speeding and sideswipes collision, have a statistically significant effect on the injury severity of drivers in the truck-truck crash model. Among them, speeding contributes to more severe injuries. The reason could be a significant speed difference between trucks based on their loads and weight-to-power ratio. It is also a common occurrence that trucks pass each other using the left lane. Lower severe injuries are found during sideswipes compared to different collision types. It seems possible that sideswipes contribute to more slight injury crashes compared to severe injuries. A recent study by the authors in [50] reported that sideswipes have different levels of impact on injury severity under other weather conditions.

Three roadway-related variables, including junctions, 30 mph speed limit, and rural areas, have a statistically significant effect on the injury severity of drivers in the truck-truck crashes model. Among them, the presence of junctions increases severe injuries by an estimated odds of 7.52% on average, compared to no junction conditions, respectively. The results are consistent with the previous studies where higher injury severity was reported for the presence of freeway merging and diverging segments [28, 51]. The speed limit indicator decreases the probability of severe injury. Finally, drivers drive faster on rural roads, which are mostly single lanes (such as no clear division of traffic direction, no intermediate guardrail, shoulder width is limited, etc.), resulting in severe injury or fatality crashes. Therefore, truck drivers should look at the rural road before starting the heterogeneous section and slow down. In addition, advance warning signs should be implemented ahead of the heterogeneous section to warn drivers.

Three environment-related variables, including dark, no light, weekdays, and rainy, have a statistically significant effect on the injury severity of drivers in the truck-truck crash model. The inclement weather conditions increase the severe injuries by an estimated odd of 49.58% on average compared to clear weather, which is opposite to the previous truck occupant model. Unlit conditions increase severe injuries by an estimated odd of 4.04% on average compared to light. The results are consistent with the previous studies where higher injury severity was reported for the presence of unlit conditions [28, 50]. Finally, among the crash characteristics, severe injury is increased during weekdays. This result complies with other studies where the author clarified the presence of a lower percentage of trucks on weekends compared to weekdays as the possible reason behind this [48, 50, 52, 53].

5.2.3. Car-Truck Crashes

(1) Car Driver Model. As shown in Table 4, there are three statistically significant driver-related variables in the car-truck crash model. Among them, the estimated odds of a severe injury increased by 6.55% and 26.95% on average, with the car drivers being old and female, respectively. The previous study on driver-injury severities at various locations also reported that older and female drivers have a higher probability of more severe injuries [28]. Note that young male truck drivers increase their risk of serious injury or fatality crashes and increase the probability of severe injury crashes for car drivers. Young male truck drivers are often overconfident in their driving skills. As a result, they are more likely to engage in dangerous driving behaviors, leading to serious and fatal injuries while hindering other vehicles from driving normally on the road. Therefore, it is necessary to strengthen safety education for young male truck drivers and, at the same time, increase the punishment for the corresponding improper driving behavior. However, some studies have also shown that young drivers are less likely to be involved in serious injuries and fatal injuries in car-truck crashes due to their physical strengths and emergency response capabilities [10].

Five vehicle-related variables, including speeding car, changing truck, age of the car (3–10 years), head-on collision, and sideswipes collision, have a statistically significant effect on injury severity of car drivers in the car-truck crashes model. While investigating driving errors, car drivers' improper actions significantly increase the estimated odds of car and truck driver severe injuries by 11.80% and 0.60% on average, respectively. The results also show that car drivers are more responsible than truck drivers for contributing more severe injuries to truck drivers in car-truck crashes [28]. More enforcement and education programs about car drivers should be enhanced. Truck changing lane behavior significantly increases the probability of severe injury and fatality crashes for both car and truck drivers. Due to the large size of trucks, there is a blind-vision zone when changing or turning, leading to serious injury crashes. Therefore, some interventions should be implemented, such as reminding the rear car to pay attention to avoid, but also through the vehicle's advanced equipment to increase the back view of the truck driver. Older cars between 3 and 10 years reduce the probability of severe injury for drivers of cars. It is recommended that vehicles need regular servicing (3–10 years) and reach a longer service life (such as more

Table 5: Model comparisons.

Variables	Car-car crashes	Truck-truck crashes	Car-truck crashes	
	CD model	TD model	CD model	TD model
Driver characteristics				
Sex of car driver (1 if female, 0 otherwise)	↑		↑	
Sex of truck driver (1 if male, 0 otherwise)		↑	↑	↑
Age band of car driver (1 if 26–45 years, 0 otherwise)	↑			
Age band of truck driver (1 if 26–45 years, 0 otherwise)		↑		↑
Age band of car driver (1 if 65 years above, 0 otherwise)	↑		↑	
Age band of truck driver (1 if 65 years above, 0 otherwise)		↑		↑
Vehicle characteristics				
Age of car vehicle (1 if 3–10 years, 0 otherwise)			↓	
Age of truck vehicle (1 if above ten years, 0 otherwise)				↑
Car vehicle maneuver (1 if speeding, 0 otherwise)	↑		↑	↑
Car vehicle maneuver (1 if turning, 0 otherwise)	↑			
Truck vehicle maneuver (1 if speeding, 0 otherwise)		↑		
Truck vehicle maneuver (1 if changing lane, 0 otherwise)			↑	↑
First point of impact (1 if front, 0 otherwise)	↑		↑	↑
First point of impact (1 if offside, 0 otherwise)	↑	↓	↑	
Roadways characteristics				
Speed limit (1 if 30 mph, 0 otherwise)	↓	↓	↓	↓
Road type (1 if roundabout, 0 otherwise)	↓			
Road type (1 if junctions, 0 otherwise)		↑		
Road type (1 if dual carriageway, 0 otherwise)	↑		↑	
Road area type (1 if urban, 0 otherwise)	↓			
Road area type (1 if rural, 0 otherwise)		↑	↑	↑
Environment characteristics				
Light conditions (1 if darkness–no lighting, 0 otherwise)	↑	↑	↑	↑
Light conditions (1 if darkness–lights lit, 0 otherwise)	↑			
Weather conditions (1 if fine, 0 otherwise)	↓			
Weather conditions (1 if raining, 0 otherwise)		↑	↑	
Season (1 if summer, 0 otherwise)	↑			
Day of week (1 if weekdays, 0 otherwise)		↑		↑
Crash time (1 if off-peak time, 0 otherwise)	↑		↑	

↑indicates an increase in the likelihood of severe injuries; ↓indicates a decrease in the likelihood of severe injuries. TD: truck driver and CD: car driver.

than ten years) to consider scrap processing and replacing the new car to get safer driving. Notably, the study found that both side and frontal crashes increased the risk of severe injury of car drivers in car-truck crashes and that side crashes are more likely to result in severe injury than frontal crashes.

Three roadway-related variables, including dual carriageway, 30 mph speed limit, and rural areas, have a statistically significant effect on the injury severity of car drivers in the car-truck crashes model. Among them, the 30 mph speed limit indicator decreases car drivers' probability of severe injury. The result is easy to understand intuitively, and a higher speed limit has been found in the literature to be related to severe injury crashes [50, 54]. The rural roadway indicator decreases the car drivers' probability of severe injuries [52]. Compared with single lanes, automotive vehicles driving in dual lanes are associated with a risk of severe injury by 3.81%. The authors in [55] found that a car driver has a greater response to stimulus than a truck driver and maintains as small a front gap as possible. In addition, trucks generally have fewer braking capabilities than cars. The authors in [28] show that car drivers are more responsible than truck drivers for contributing to more severe injuries to truck drivers in car-truck crashes. Therefore, when the road conditions allow, it is appropriate to set up separate lanes for passengers and trucks or large trucks' special lanes. Still, on the other hand, we must also prevent other vehicles from occupying the truck lane.

Three environment-related variables, including dark no light, off-peak time, and rainy, have a statistically significant effect on the injury severity of car drivers in the car-truck crashes model. The unlit conditions, rain conditions, and off-peak times increase the estimated odds of a severe injury of car drivers by 0.07%, 2.80%, and 15.43% on average, respectively.

(2) Truck Driver Model. As shown in Table 4, there are three statistically significant driver-related variables in the car-truck crash model. Among them, the estimated odds of a severe injury increased by 6.66%, 0.34%, and 21.46% on average, with the truck drivers being young, old, and male, respectively.

Four vehicle-related variables, including speeding car, changing truck, age of truck (10 years above), and head-on collision, have a statistically significant effect on injury severity of truck drivers in the car-truck crash model. While investigating driving errors, truck drivers' improper actions have no statistically significant impact on the injury severity of car drivers. Therefore, it can be concluded that car drivers are more responsible for severe injuries in car-truck crashes. Similar results were found in previous studies [28]. Likewise, truck changing, head-on collisions, and older trucks (10 years above) increase the estimated odds of a severe injury of truck drivers by 1.03%, 9.80%, and 5.66% on average, respectively.

Two roadway-related variables, including the 30 mph speed limit and rural areas, have a statistically significant effect on the injury severity of truck drivers in the car-truck crashes model. Among them, the speed limit indicator decreases truck drivers' probability of severe injury. In contrast, the rural roadways indicator increases truck drivers' likelihood of severe injuries.

Two environment-related variables, including dark, no light, and weekdays, have a statistically significant effect on the injury severity of truck drivers in the car-truck crash model. Unlit conditions and weekdays increase the truck drivers' estimated odds of a severe injury by 22.31% and 9.20% on average, respectively. Drivers are driving at night with inadequate road lighting and a limited range of vehicle lights, making it more difficult for drivers to judge the road conditions and speed. Therefore, it is appropriate to increase the lighting at night and the length of lighting, especially for some roadways sections with a high proportion of large trucks. Among the crash characteristics, the severe injury of truck drivers also increased during weekdays. This result complies with other studies [50, 55].

To that end, Table 5 summarizes the effects of statistically significant variables on injury severity by vehicle and driver type.

6. Conclusions

Using three-year crash data from the UK, this study develops a random parameters logit model with heterogeneity in means and variances to explore the injury severity of drivers. The estimated models reveal that varieties of drivers, vehicles, roads, and environment attributes affect drivers' injury severities. The main conclusions are summarized as follows:

(1) The random parameters logit with heterogeneity in the means and variances (RPLHMV) model provides a superior statistical fit. It offers additional insights compared to the traditional lower-order logit model counterparts by accommodating variations of the explanatory variables across the observations and factors affecting the means and variances of the parameter density functions of the random parameters. This allows us to identify additional factors that may play a role in determining a parameter's true effect on injury severity.

(2) More importantly, concerning the contributing factors affecting the driver's severe injuries, separate injury-severity models based on vehicle and driver types offer valuable insights. However, inconsistency exists in the determinants of each model. For example, only the speed limit is statistically significant in all the models, while others show significance, not in all models. In addition, young car drivers, car turning, roundabouts, urban areas, dark lights lit, fine conditions, and summer indicators have a significant effect only in car-car crash models. Similarly, some variables, including the age of drivers, gender, speeding, sideswipes, and weekdays, are significant in one driver model (truck driver or car driver) but not in other driver models.

(3) The findings offer numerous practical implications:

   (a) More enforcement and education programs about young and male drivers should be enhanced. Old truck drivers should attend regular physical check-ups and driving safety education; if failing a driving test, they could be considered to take the initiative to return their driver's license. And car drivers are more responsible for respective severe injuries in car-truck crashes.

   (b) It is recommended that vehicles need regular servicing (3–10 years) and reach a longer service life (such as more than ten years) to consider doing vehicle scrap processing and replace the new truck to get safer driving. Due to the large size of trucks, there is a blind-vision zone when changing or turning, leading to serious injury crashes. Therefore, some interventions should be implemented, such as reminding the rear car to pay attention to avoid, but also through the vehicle's advanced equipment to increase the back view of the truck driver.

   (c) Our findings indicate that young drivers either lack adequate knowledge or experience complying with the highway code at junctions or violate traffic laws, as this results in severe crashes. Thus, more educational programs should be implemented to prevent young drivers from illegally driving, such as disobeying right-of-way, stop signs, and road markings.

   (d) Serious injury crashes are more likely to occur when driving at night. Therefore, truck service time must be carefully considered while creating the evening schedule plan to prevent drowsiness. Additionally, drivers should take precautions while traveling at a comparatively slower speed on the areas of the road that are artificially lit.

   (e) Among the crash characteristics, severe injury is increased during weekdays for truck-involved crashes. Therefore, warning signs should be implemented to warn car drivers, especially for some roadways sections with a high proportion of large trucks during weekdays.

(4)This study also has some limitations. Firstly, it is noted that certain data-specific biases, particularly resulting from the shortcomings of the crash reporting system, may affect the empirical

conclusions of the analysis (for example, the omission of no-injury crashes). In addition, the injury severity of both drivers might be correlated with being involved in the same crash. Another natural extension would be to examine the potential correlation considering the crash injury-severity levels of both parties. Lastly, more two-vehicle crash datasets should be included in the future to investigate the temporal stability and then to help policy-makers to take necessary measures in reducing motorcycle-involved crashes by forming appropriate and time-efficient strategies.

Data Availability

The dataset has been presented in this paper.

Disclosure

The views expressed in this paper are those of the authors and do not represent those of sponsors, who are accountable for the accuracy of the data and information presented. The opinions expressed herein do not necessarily represent the official views or policies of any organization or agency, and the contents should not be regarded as a definitive standard, specification, or regulation.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

All authors reviewed the results and approved the final version of the manuscript.

Acknowledgments

This study was supported by the Science and Technology Program of the Department of Transportation, Yunnan Province, China (grant numbers 2019303 & 2021-90-2) and Shanxi Provincial Innovation Center Project for Digital Road Design Technology (grant number 202104010911019).

References

[1] World Health Organization, *Global Status Report on Road Safety 2018*, WHO, Geneva, Switzerland, 2018, https://www.who.int/publications/i/item/9789241565684.

[2] National Highway Traffic Safety Administration. Large Trucks, 2019.

[3] National Highway Traffic Safety Administration, "State Traffic Data: Traffic Safety Fact Sheet," 2017, https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813368.pdf.

[4] M. T. Haq, M. Zlatkovic, and K. Ksaibati, "Occupant injury severity in passenger car-truck collisions on interstate 80 in Wyoming: a Hamiltonian Monte Carlo Markov chain Bayesian inference approach," *Journal of Transportation Safety & Security*, vol. 14, no. 3, pp. 498–522, 2022.

[5] A. Behnood and F. L. Mannering, "An empirical assessment of the effects of economic recessions on pedestrian-injury crashes using mixed and latent-class models," *Analytic Methods in Accident Research*, vol. 12, pp. 1–17, 2016.

[6] E. Dabbour, S. Easa, and M. Haider, "Using fixed-parameter and random-parameter ordered regression models to identify significant factors that affect the severity of drivers' injuries in vehicle-train collisions," *Accident Analysis & Prevention*, vol. 107, pp. 20–30, 2017.

[7] P. C. Anastasopoulos and F. Mannering, "An empirical assessment of fixed and random parameter logit models using crash- and non-crash-specific injury data," *Accident Analysis & Prevention*, vol. 43, no. 3, pp. 1140–1147, 2011.

[8] G. Azimi, A. Rahimi, H. Asgari, and X. Jin, "Severity analysis for large truck rollover crashes using a random parameter ordered logit model," *Accident Analysis & Prevention*, vol. 135, Article ID 105355, 2020.

[9] A. Hosseinzadeh, A. Moeinaddini, and A. Ghasemzadeh, "Investigating factors affecting severity of large truck-involved crashes: comparison of the SVM and random parameter logit model," *Journal of Safety Research*, vol. 77, pp. 151–160, 2021.

[10] A. Behnood and F. Mannering, "Time-of-day variations and temporal instability of factors affecting injury severities in large-truck crashes," *Analytic Methods in Accident Research*, vol. 23, Article ID 100102, 2019.

[11] M. Waseem, A. Ahmed, and T. U. Saeed, "Factors affecting motorcyclists' injury severities: an empirical assessment using random parameters logit model with heterogeneity in means and variances," *Accident Analysis & Prevention*, vol. 123, pp. 12–19, 2019.

[12] C. Wang, F. Chen, Y. Zhang, and J. Cheng, "Spatiotemporal instability analysis of injury severities in truck-involved and non-truck-involved crashes," *Analytic Methods in Accident Research*, vol. 34, Article ID 100214, 2022.

[13] Q. Zeng, H. Wen, and H. Huang, "The interactive effect on injury severity of driver-vehicle units in two-vehicle crashes," *Journal of Safety Research*, vol. 59, pp. 105–111, 2016.

[14] E. Dabbour, O. Dabbour, and A. A. Martinez, "Temporal stability of the factors related to the severity of drivers' injuries in rear-end collisions," *Accident Analysis & Prevention*, vol. 142, Article ID 105562, 2020.

[15] H. Gong, T. Fu, Y. Sun et al., "Two-vehicle driver-injury severity: a multivariate random parameters logit approach," *Analytic Methods in Accident Research*, vol. 33, Article ID 100190, 2022.

[16] I. Obaid, A. Alnedawi, G. M. Aboud, R. Tamakloe, H. Zuabidi, and S. Das, "Factors associated with driver-injury severity of motor vehicle crashes on sealed and unsealed pavements: random parameter model with heterogeneity in means and variances," *International Journal of Transportation Science and Technology*, vol. 12, no. 2, pp. 460–475, 2022.

[17] S. Yasmin, "Examining driver-injury severity in two-vehicle crashes- a copula based approach," *Accident Analysis & Prevention*, vol. 66, pp. 120–135, 2014.

[18] V. R. Duddu, P. Penmetsa, and S. S. Pulugurtha, "Modeling and comparing injury severity of at-fault and not at-fault drivers in crashes," *Accident Analysis & Prevention*, vol. 120, pp. 55–63, 2018.

[19] L. Song, W. Fan, and Y. Li, "Time-of-day variations and the temporal instability of multi-vehicle crash injury severities under the influence of alcohol or drugs after the Great Recession," *Analytic Methods in Accident Research*, vol. 32, 2021.

[20] Z. Li, "Examining driver-injury severity in intersection-related crashes using cluster analysis and hierarchical Bayesian models," *Accident Analysis & Prevention*, vol. 120, pp. 139–151, 2018.

[21] M. Rezapour, M. Moomen, and K. Ksaibati, "Ordered logistic models of influencing factors on crash injury severity of single and multiple-vehicle downgrade crashes: a case study in Wyoming," *Journal of Safety Research*, vol. 68, pp. 107–118, 2019.

[22] Q. Wu, "Mixed logit model-based driver-injury severity investigations in single-and multi-vehicle crashes on rural two-lane highways," *Accident Analysis & Prevention*, vol. 72, pp. 105–115, 2014.

[23] M. Yu, C. Zheng, and C. Ma, "Analysis of injury severity of rear-end crashes in work zones: a random parameters approach with heterogeneity in means and variances," *Analytic Methods in Accident Research*, vol. 27, Article ID 100126, 2020.

[24] C. Chen, "A multinomial logit model-Bayesian network hybrid approach for driver-injury severity analyses in rear-end crashes," *Accident Analysis & Prevention*, vol. 80, pp. 76–88, 2015.

[25] N. Alnawmasi and F. Mannering, "The impact of higher speed limits on the frequency and severity of freeway crashes: accounting for temporal shifts and unobserved heterogeneity," *Analytic Methods in Accident Research*, vol. 34, 2022.

[26] N. Eluru, M. Bagheri, L. F. Miranda-Moreno, and L. Fu, "A latent class modeling approach for identifying vehicle driver-injury severity factors at highway-railway crossings," *Accident Analysis & Prevention*, vol. 47, pp. 119–127, 2012.

[27] C. Wang, "Temporal stability of factors affecting injury severity in rear-end and non-rear-end crashes: a random parameter approach with heterogeneity in means and variances," *Analytic Methods in Accident Research*, vol. 35, 2022.

[28] M. T. Haq, M. Zlatkovic, and K. Ksaibati, "Investigating occupant injury severity of truck-involved crashes based on vehicle types on a mountainous freeway: a hierarchical Bayesian random intercept approach," *Accident Analysis & Prevention*, vol. 144, Article ID 105654, 2020.

[29] C. Lee and X. Li, "Analysis of injury severity of drivers involved in single-and two-vehicle crashes on highways in Ontario," *Accident Analysis & Prevention*, vol. 71, pp. 286–295, 2014.

[30] F. L. Mannering, V. Shankar, and C. R. Bhat, "Unobserved heterogeneity and the statistical analysis of highway accident data," *Analytic Methods in Accident Research*, vol. 11, pp. 1–16, 2016.

[31] P. T. Savolainen, "The statistical analysis of highway crash-injury severities: a review and assessment of methodological alternatives," *Accident Analysis & Prevention*, vol. 43, no. 5, pp. 1666–1676, 2011.

[32] F. L. Mannering and C. R. Bhat, "Analytic methods in accident research: methodological Frontier and future directions," *Analytic Methods in Accident Research*, vol. 1, pp. 1–22, 2014.

[33] M. Islam and F. Mannering, "A temporal analysis of driver-injury severities in crashes involving aggressive and non-aggressive driving," *Analytic Methods in Accident Research*, vol. 27, Article ID 100128, 2020.

[34] Department for Transport, "Reported Road Casualties in Great Britain: Notes, Definitions, Symbols and Conventions," Department for Transport, editor, 2019, https://www.gov.uk/government/publications/road-accidents-and-safety-statistics-notes-and-definitions/reported-road-casualties-in-great-britain-notes-definitions-symbols-and-conventions.

[35] G. Fountas and T. Rye, "A note on accounting for underlying injury-severity states in statistical modeling of injury accident data," *Procedia Computer Science*, vol. 151, pp. 202–209, 2019.

[36] F. Ye, C. Wang, W. Cheng, and H. Liu, "Exploring factors associated with cyclist injury severity in vehicle-electric bicycle crashes based on a random parameter logit model," *Journal of Advanced Transportation*, vol. 2021, Article ID 5563704, 12 pages, 2021.

[37] S. Washington, M. G. Karlaftis, F. Mannering, and P. Anastasopoulos, *Statistical and Econometric Methods for Transportation Data Analysis*, CRC Press, Boca Raton, FL, USA, 2020.

[38] S. S. Ahmed, J. Cohen, and P. C. Anastasopoulos, "A correlated random parameters with heterogeneity in means approach of deer-vehicle collisions and resulting injury-severities," *Analytic Methods in Accident Research*, vol. 30, Article ID 100160, 2021.

[39] C. Wang, P. Zhang, F. Chen, and J. Cheng, "Modeling injury severity for nighttime and daytime crashes by using random parameter logit models accounting for heterogeneity in means and variances," *Journal of Advanced Transportation*, vol. 2022, Article ID 7871338, 12 pages, 2022.

[40] D. McFadden and K. Train, "Mixed MNL models for discrete response," *Journal of Applied Econometrics*, vol. 15, no. 5, pp. 447–470, 2000.

[41] A. Behnood and F. Mannering, "The effect of passengers on driver-injury severities in single-vehicle crashes: a random parameters heterogeneity-in-means approach," *Analytic Methods in Accident Research*, vol. 14, pp. 41–53, 2017.

[42] G. Fountas and P. C. Anastasopoulos, "A random thresholds random parameters hierarchical ordered probit analysis of highway accident injury-severities," *Analytic Methods in Accident Research*, vol. 15, pp. 1–16, 2017.

[43] G. Fountas, P. C. Anastasopoulos, and M. Abdel-Aty, "Analysis of accident injury-severities using a correlated random parameters ordered probit approach with time variant covariates," *Analytic Methods in Accident Research*, vol. 18, pp. 57–68, 2018.

[44] M. A. Seyfi, K. Aghabayk, A. M. Karimi Mamaghan, and N. Shiwakoti, "Modeling the motorcycle crash severity on nonintersection urban roadways in the Australian state of victoria using a random parameters logit model," *Journal of Advanced Transportation*, vol. 2023, Article ID 2250590, 12 pages, 2023.

[45] F. Mannering, "Temporal instability and the analysis of highway accident data," *Analytic Methods in Accident Research*, vol. 17, pp. 1–13, 2018.

[46] Q. Hou, X. Hou, J. Leng, and F. Mannering, "A note on out-of-sample prediction, marginal effects computations, and temporal testing with random parameters crash-injury severity models," *Analytic Methods in Accident Research*, vol. 33, Article ID 100191, 2022.

[47] C. Wang, M. Ijaz, F. Chen, Y. Zhang, J. Cheng, and M. Zahid, "Evaluating gender differences in injury severities of non-helmet wearing motorcyclists: accommodating temporal shifts and unobserved heterogeneity," *Analytic methods in Accident Research*, vol. 36, Article ID 100249, 2022.

[48] D. Song, X. Yang, P. C. Anastasopoulos, X. Zu, X. Yue, and Y. Yang, "Temporal stability of the impact of factors determining drivers' injury severities across traffic barrier crashes in mountainous regions," *Analytic Methods in Accident Research*, vol. 39, Article ID 100282, 2023.

[49] M. Moomen, M. Rezapour, and K. Ksaibati, "An investigation of influential factors of downgrade truck crashes: a logistic regression approach," *Journal of Traffic and Transportation Engineering*, vol. 6, no. 2, pp. 185–195, 2019.

[50] M. Uddin and N. Huynh, "Truck-involved crashes injury severity analysis for different lighting conditions on rural and urban roadways," *Accident Analysis & Prevention*, vol. 108, pp. 44–55, 2017.
[51] W. Y. Mergia, D. Eustace, D. Chimba, and M. Qumsiyeh, "Exploring factors contributing to injury severity at freeway merging and diverging locations in Ohio," *Accident Analysis & Prevention*, vol. 55, no. 1, pp. 202–210, 2013.
[52] X. Zhu and S. Srinivasan, "Modeling occupant-level injury severity: an application to large-truck crashes," *Accident Analysis & Prevention*, vol. 43, no. 4, pp. 1427–1437, 2011.
[53] D. Song, X. Yang, Y. Yang, P. Cui, and G. Zhu, "Bivariate joint analysis of injury severity of drivers in truck-car crashes accommodating multilayer unobserved heterogeneity," *Accident Analysis & Prevention*, vol. 190, Article ID 107175, 2023.
[54] M. Osman, R. Paleti, S. Mishra, and M. M. Golias, "Analysis of injury severity of large truck crashes in work zones," *Accident Analysis & Prevention*, vol. 97, pp. 261–273, 2016.
[55] J. Weng, Q. Meng, and X. Yan, "Analysis of work zone rear-end crash risk for different vehicle-following patterns," *Accident Analysis and Prevention*, vol. 72, pp. 449–457, 2014.