applied sciences

MDPI

Article

Analysis of the Severity of Heavy Truck Traffic Accidents Under Different Road Conditions

Ziqun Tian [1], Facheng Chen [1,*], Sheqiang Ma [1] and Mengzhu Guo [2]

[1] Department of Traffic Management School, People's Public Security University of China, Beijing 100038, China; tt33581@163.com (Z.T.); masheqiang@163.com (S.M.)
[2] School of Transportation, Jilin University, Changchun 130022, China; guomz@jlu.edu.cn
* Correspondence: chenfchengzc@126.com

Abstract: The rising frequency of heavy truck accidents in China poses a significant public safety risk, endangering lives and property. However, current research based on data from heavy truck accidents in China remains limited, making it challenging to support the formulation of traffic management measures. To mitigate the severity of these accidents, this study analyzed five years of heavy truck accident data from a specific region in China and developed logistic regression models for different road conditions. The aim was to identify the key factors influencing accident severity and understand the underlying mechanisms. The findings revealed that, under urban road conditions, the severity of heavy truck accidents is significantly impacted by factors such as lighting conditions, road safety attributes, driver age, and vehicle driving status. On highways, accident severity is largely influenced by visibility, roadside protection measures, intersection and section types, vehicle driving status, inter-vehicle accident types, and road safety features. On expressways, critical factors include inter-vehicle accident types, driver violations, visibility, and road alignment. In conclusion, the factors contributing to the severity of heavy truck accidents vary according to road conditions, which necessitates tailored traffic management strategies. The study's findings offer theoretical support for more targeted approaches to preventing and controlling heavy truck traffic accident severity under different road conditions in China.

Keywords: traffic safety; heavy truck; road conditions; traffic accident severity; cause analysis; logistic regression model

Citation: Tian, Z.; Chen, F.; Ma, S.; Guo, M. Analysis of the Severity of Heavy Truck Traffic Accidents Under Different Road Conditions. *Appl. Sci.* **2024**, *14*, 10751. https://doi.org/10.3390/app142210751

Academic Editors: Giuseppe Lacidogna and Andrea Carpinteri

Received: 6 August 2024
Revised: 8 November 2024
Accepted: 19 November 2024
Published: 20 November 2024

1. Introduction

In China, road freight transport accounts for 72.4% of the total freight transport, with heavy truck transport playing a pivotal role and having a significant impact on the national economy and social development [1,2]. Although heavy trucks play an irreplaceable role in road transport, their large size, heavy load, easy rollover, and braking difficulties make them more likely to cause traffic accidents, especially those resulting in mass casualties [3]. In recent years, the number of serious traffic accidents involving heavy trucks has been steadily increasing, causing significant loss of life and property [4]. In addition to China, heavy truck accidents have caused significant losses and fatalities worldwide. In South Korea, truck-related accidents made up 13% of all traffic accidents, and the proportion of fatalities caused by truck traffic accidents was 24% in 2019 [5]. In Europe, heavy trucks are involved in 4.5% of police-reported traffic incidents and 14.2% of fatal traffic accidents [6]. In Australia, despite comprising only about 3% of registered vehicles, heavy trucks account for 18% of all road fatalities [7]. In the United States, the number of fatal truck accidents increased from 3211 in 2009 to 5788 in 2021, with each fatal injury averaging an economic cost of $1,778,000, according to the National Safety Council injury information of 2021 [8]. Thus, comprehensive research on heavy truck operational safety is essential to inform targeted preventive measures, helping traffic management departments to minimize both the frequency and severity of such accidents.

Heavy truck safety research primarily addresses two aspects: driver behavior and accident analysis. Most current studies focus on the driving behavior of heavy truck drivers, including analyses of driving behavior, identification of dangerous behaviors, and assessments of driving safety risks [9]. This aspect of research primarily targets the operational processes of heavy trucks and can aid in reducing the occurrence of heavy truck traffic accidents. However, the randomness associated with accident occurrences means that it is impossible to completely avoid traffic accidents [10]. The "Vision Zero" initiative also suggests that the main goal of road traffic safety management should be to minimize the serious consequences of accidents, such as casualties, rather than solely preventing the occurrence of traffic accidents [11].

Research on heavy truck traffic accidents can provide a basis for reducing the severity of traffic accidents. Such studies typically rely on traffic accident data recorded by traffic management departments, which usually include the severity of accidents (such as property damage, personal injury, and fatalities), personnel information, vehicle performance, road conditions, traffic environment, and illegal behaviors [12,13]. Currently, research on heavy truck traffic accidents primarily includes statistical analyses of accident characteristics and modeling analyses of accident severity. In terms of statistical analysis of heavy truck accident characteristics, Sun [14] analyzed and summarized the characteristics of heavy truck traffic incidents based on factors such as accident form, time, load, speed, weather, and driver age. Li et al. [15] compared heavy truck traffic accident data from Zhejiang and Jilin provinces in China and found significant differences in the number, severity, causes, and complexity of accidents between the two regions. However, statistical analyses of accident characteristics can only provide a rough indication of simple patterns, which cannot directly support the formulation of traffic management measures aimed at reducing accident severity.

Severity modeling typically employs accident severity as the dependent variable and factors such as personnel data, vehicle performance, road conditions, traffic environment, and violations as independent variables. By establishing models, researchers aim to identify the key factors influencing the severity of heavy truck traffic incidents, thereby guiding traffic management departments in targeted prevention and control. Given the discrete nature of severity data and the need for model interpretability, logistic regression models are frequently employed to analyze accident severity [16–25]. In previous studies, scholars have commonly examined multiple dimensions in selecting independent variables, including driver, vehicle, road, environment, and violations, as shown in Table 1.

Table 1. Analysis of the independent variables.

Dimensions	Variables	References
Driver	Age	[17–20,22]
	Gender	[17–20,22]
	Driving experience	[17,19,24,25]
Vehicle	Accident forms	[16,18,25]
	Accident types	[20]
Road	Road alignment	[18,20,21,24]
	Road surface conditions	[18,22,23]
Environment	Weather	[17,18,20,22–25]
	Lighting conditions	[17,19,21,22,24]
	Visibility	[17,23]
Violations	Speeding	[18,21,24,25]
	Drunk Driving	[21,24,25]
	Distracted Driving	[18,24,25]
	Unqualified Driver	[25]

By modeling the above independent variables, researchers have drawn the following conclusions: Regarding driver factors, driver age and experience significantly impact accident severity. Younger, less experienced drivers are more likely to be involved in severe accidents [18,19,23,24]. Regarding road factors, road alignment significantly affects accident severity, with curved and sloped sections increasing accident severity [18,20,21]. Regarding environmental factors, weather and lighting conditions significantly influence accident severity, with adverse weather (rain and snow), low-light areas, and nighttime conditions more likely to result in severe injuries [18–23]. Regarding violation factors, driver misconduct significantly increases accident severity, with distracted driving, speeding, and drunk driving notably escalating accident severity [18,21,24,25]. Additionally, researchers conducted comparisons targeting specific variables, resulting in the following findings: Chen et al. [20] compared the severity of single-vehicle (SV) and multi-vehicle (MV) accidents involving heavy trucks and discovered significant differences in how various factors—such as driver, vehicle, road, and environmental variables—affect accident severity. Choi et al. [21] compared the causes of heavy truck accidents under normal and adverse weather conditions, finding that the factors contributing to accident severity vary considerably between the two weather scenarios. Uddin et al. [22] compared the causes of heavy truck accidents in rural and urban areas, revealing that the causes differ significantly depending on the regional context and recommended separate modeling studies for different types of areas.

In summary, while current research has examined the causes of heavy truck accident severity from multiple dimensions—including driver, road, and environmental factors—most of this research is based on datasets from the United States, with some studies using data from Canada, South Korea, and other countries. There is a notable lack of modeling analyses of heavy truck accident severity based on Chinese datasets. Due to substantial differences in laws, regulations, traffic management measures, and road standards between China and other countries, research conducted on foreign datasets may not be entirely applicable to China. Furthermore, previous studies have shown that factors impacting heavy truck accident severity differ considerably across contexts, underscoring the need for targeted, context-specific research.

To reduce the severity of heavy truck traffic accidents in China, this study uses traffic accident data involving heavy trucks recorded by traffic management departments over the past five years in a specific region. Accident severity (categorized as general and fatal) serves as the dependent variable, with 15 factors across 5 dimensions (driver, vehicle, road, environment, and illegal behavior) as independent variables. A logistic regression model is established to analyze the key factors affecting the severity of heavy truck traffic accidents and underlying mechanisms. Drawing on the suggestion to conduct separate studies on the causes of heavy truck accidents under different conditions, this study recognizes the significant differences in traffic management measures, design standards, and types of traffic conflicts across different road types in China (urban roads, highways, and expressways). Therefore, separate models for analyzing the severity of heavy truck traffic accidents on urban roads, highways, and expressways are developed, aiming to provide a theoretical basis for Chinese traffic management departments to reduce the severity of heavy truck traffic accidents.

This paper investigates heavy truck traffic accidents through several key parts, beginning with data processing and conducting statistical analysis on independent and dependent variables; establishing separate logistic regression models for urban roads, highways, and expressways; completing tolerance testing; analyzing model results; and identifying critical factors influencing accident severity across different road conditions. Then, we propose targeted countermeasures based on the results. Finally, our findings are compared with previous studies, revealing similarities and unique characteristics specific to Chinese accidents. In the final section, we point out study limitations and future research directions.

2. Data Preparation

The data used in this study were obtained from the traffic police department's database in a certain region (due to confidentiality, we cannot disclose the name) of China over the past five years (2019–2023). According to Chinese standards, heavy trucks are defined as trucks with a total weight exceeding 12 tons and a length over 6 m. After excluding blank, abnormal, and ambiguous data from 1734 records, 1592 records were retained for the construction of the model. In our dataset, accident type classification included three categories: property damage, injury, and fatal accidents. Consequently, accident severity was classified into two categories: general accidents (including property damage and injury accidents) and fatal accidents. The data processing steps are shown in Figure 1.

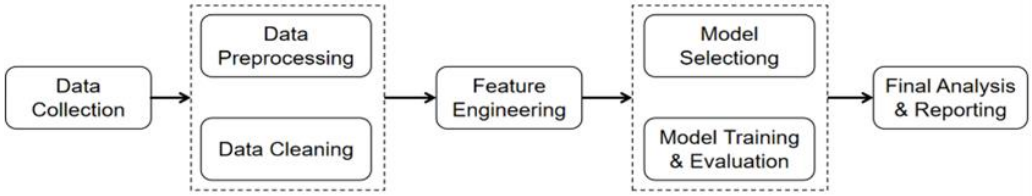

Figure 1. Data Flow Chart.

Accident severity factors were categorized into five dimensions: driver, vehicle, road, environment, and violations. Driver-related factors included age and driving experience. As most heavy truck drivers are male, gender was not considered. Vehicle factors included vehicle driving status, inter-vehicle accident types, and accident forms. Road factors consisted of road surface conditions, intersection section types, physical isolation conditions (Presence or absence of central isolation or vehicle-pedestrian isolation), roadside protection measures, road safety attributes (Inspection by traffic management departments to identify potential road hazards), and road alignment. Environmental factors included weather, visibility, and lighting conditions. These 15 variables were selected based on the dataset provided by the traffic management department. Relevant traffic accident records were extracted, and variables with a high percentage of missing values that could not be supplemented were removed. Referring to independent variables used in previous studies, we ultimately retained these 15 variables potentially associated with accident severity.

Different road types have unique design standards and control measures, as well as different types of conflict points. Therefore, roads were categorized into three types: urban roads, highways, and expressways. In the region studied, the total road network length is approximately 28,000 km, with urban roads, highways, and expressways accounting for 22%, 67%, and 11%, respectively. The severity of heavy truck accidents served as the dependent variable, and the influencing factors of five different dimensions were taken as independent variables, with the descriptive statistics and assignments of the variables shown in Tables 2 and 3.

Table 2. Descriptive statistics and assignment of dependent variables.

Dependent Variable	Road Type	Variable Name	Variable Frequency
Accident Severity	Urban roads	General accidents: Y = 0	206
		Fatal accidents: Y = 1	304
	Highways	General accidents: Y = 0	236
		Fatal accidents: Y = 1	317
	Expressways	General accidents: Y = 0	386
		Fatal accidents: Y = 1	143

Table 3. Descriptive statistics and assignment of independent variables.

Independent Variables	Variable Frequency		
	Urban Roads	Highways	Expressways
Age			
Under 30	55	71	58
>30–40	206	238	220
>40–50	184	199	202
Above 50	65	45	49
Driving experience			
Under 5 years	43	32	32
>5–10 years	128	123	110
>10–15 years	132	164	151
>15–20 years	109	112	108
Above 20 years	98	122	128
Driving status			
Straight	249	393	426
Non-straight	261	160	103
Accident types			
Side Collision	275	205	44
Rear-end Collision	15	103	384
Other direction Collision	69	77	62
Non-vehicle Accident	151	168	39
Accident forms			
Collision moving Vehicle	377	415	356
Collision stationary Vehicle	53	63	131
Single Vehicle Accident	4	14	17
Scrape or Run Over Pedestrian	50	44	22
Other Inter-vehicle Accident	26	17	3
Road surface conditions			
Wet	45	32	40
Dry	465	521	489
Intersection section types			
Intersection *	286	259	39
Section	224	294	490
Physical isolation conditions			
Center Isolation	276	105	100%
Vehicle-pedestrian Isolation	21	24	
Center + Vehicle-pedestrian Isolation	27	17	
No Isolation	186	407	
Roadside protection measures			
Protection	330	146	474
No Protection	180	407	55
Road safety attributes			
Hazard	105	205	160
No Hazard	405	348	369
Road alignment			
Curved or Sloped	15	29	33
Straight and Level	495	524	496
Weather			
Overcast	45	31	43
Rain/Snow/Fog	24	25	31
Sunny	441	497	455
Visibility			
Under 50 m	21	90	62
>50–100 m	109	140	173
>100–200 m	108	101	117
Above 200 m	272	222	177
Lighting conditions			
Daytime	260	258	117
Night with Streetlights	222	163	174
Night without Streetlights	28	132	238

Table 3. *Cont.*

Independent Variables	Variable Frequency		
	Urban Roads	Highways	Expressways
Violations			
Not Following Lane Regulations	14	59	18
Not Maintaining Safe Distance in Same Lane	4	17	122
Illegal Parking	7	25	57
Not Yielding as Required	65	64	8
Vehicle Faults or Not Meeting Technical Standards	5	38	60
Violating Traffic Signals (Signs, Markings, etc.)	38	45	18
Illegal Overtaking, Reversing, Meeting, U-turning	3	13	15
Speeding	9	13	8
Overloading (Excessive Load, Height, Width, Length)	12	38	41
Drunk Driving	45	47	40
Unqualified Driver for Heavy Truck	14	31	5
Pedestrian or Non-motor Vehicle Violation	41	19	15
Distracted Driving	206	122	108
Other (natural disasters, accidental event)	47	22	14

* Under expressway conditions, intersections represent the converging and diverging areas.

Statistical analysis of heavy truck accidents across the three road types in Table 2 reveals similarities in driver characteristics. Driver age primarily falls between 30 and 50 years, with the 30–40 age group comprising the largest share at 40.4%, 43.4%, and 41.6% across the road types. In terms of driving experience, most drivers have between 5 to 20 years of experience, with those having 10–15 years of experience making up the highest proportion at 25.9%, 29.7%, and 28.5%.

Regarding vehicle status, there are distinct features of heavy truck accidents across the different road types. On highways and expressways, accidents mainly occur when vehicles are driving straight, whereas in urban areas, straight and non-straight driving accidents are roughly equal. Side collisions are more frequent on urban roads and highways, while rear-end collisions dominate on expressways. Additionally, accidents involving stationary vehicles are significantly higher on expressways compared to urban roads and highways.

Regarding road conditions, there are significant differences in the intersection section types, physical isolation conditions, and roadside protection measures at the locations where heavy truck traffic accidents occur across the three types of roads. On urban roads and highways, accidents occur almost equally at intersections and on road sections. However, on expressways, accidents predominantly occur on road sections, with only a few occurring in merging and diverging areas. Furthermore, on highways, most accidents occur in areas without physical isolation, whereas, on urban roads, accidents tend to happen in areas with isolation. For roadside protection, most accidents on highways occur in areas without protection, while on urban roads and expressways, accidents are more frequent in areas with protection.

Regarding environmental conditions, visibility and lighting conditions also differ across road types. Most highway and expressway accidents occur in low visibility (under 200 m), while urban road accidents typically occur with normal visibility (over 200 m). In terms of lighting, the number of accidents during the daytime and nighttime is relatively similar for urban roads and highways, whereas, on expressways, most accidents occur at night.

Regarding violations, the main violations contributing to accidents on urban roads include distracted driving, not yielding as required, drunk driving, pedestrian or non-motor vehicle violations, and traffic signal violations. On highways, the main violations are distracted driving, not yielding as required, not following lane regulations, drunk driving, and traffic signal violations. On expressways, not maintaining a safe distance in the same lane, distracted driving, vehicle faults or failure to meet technical standards, illegal parking, and overloading are the major violations leading to accidents. It is evident that distracted driving is a major contributing factor across all three road types, accounting for 40.4%, 22.1%, and 20.4% of accidents, respectively.

This analysis indicates that heavy truck accident characteristics vary by road condition, warranting separate modeling and targeted discussions for each road type.

3. Model Building

Both the dependent and independent variables in this paper are categorical variables. The dependent variable is binary, and a probabilistic nonlinear binary logistic regression is selected in SPSS v26.0 [26] to analyze the influencing factors of traffic accident severity. To ensure there was no multicollinearity among the independent variables, a collinearity test was conducted.

3.1. Construction of Binary Logistic Regression Model

In the analysis of influencing factors of traffic accidents, y = 0 represents general accidents, and y = 1 represents fatal accidents. In binary logistic regression, it is assumed that y has only two possible values, which can be predicted by the linear combination of feature X. The hypothesis function of the model is as follows:

$$h_\theta(X) = \frac{1}{1 + e^{\theta^T X}} \tag{1}$$

In the formulas, $h_\theta(X)$ is the prediction of the probability; θ is the parameter vector of the model; X is the input eigenvector.

3.2. Odds Ratio

In logistic regression, the odds ratio is used to measure the effect of an independent variable on the dependent variable. Specifically, the odds ratio indicates the multiple by which the odds (i.e., the ratio of the probability of occurrence of an event to the probability of non-occurrence) of the dependent variable change for each unit increase in the independent variable. If θ_j is the regression coefficient of the independent variable x_j, then the odds ratio is as follows:

$$OR_j = e^{\theta_j} \tag{2}$$

3.3. Collinearity Test

When multiple variables are included in multiple linear regression analysis, multicollinearity may occur. These variables are not only significantly correlated with the dependent variable but also with each other. Tolerance and the Variance Inflation Factor (VIF) are widely used measures to detect multicollinearity between variables, assessing the degree of multicollinearity between the i-th independent variable and the other independent variables in the regression model. Tolerance is a statistical measure used to detect multicollinearity in regression models. It is defined as the proportion of variance in a predictor that is not explained by the other predictors in the model [27].

The Variance Inflation Factor (VIF) is another commonly used measure to detect multicollinearity [28]. First, for each independent variable, it is treated as the dependent variable, and all other independent variables are used as independent variables for linear regression to obtain R_i^2. Then, the tolerance and VIF of the independent variable can be calculated as follows:

$$Tol_i = 1 - R_i^2 \tag{3}$$

$$VIF_i = \frac{1}{1 - R_i^2} \tag{4}$$

In the formulas, when R_i^2 approaches 0, VIF approaches 1, indicating weaker correlation among independent variables; when R_i^2 approaches 1, VIF becomes larger, indicating stronger correlation among independent variables. Usually, a VIF value of less than 5 is considered to indicate no correlation among independent variables. The collinearity test results are shown in Table 4.

Table 4. Collinearity test result.

Independent Variables	Tolerance	*VIF*
Accident Form	0.633	1.579
Accident Type	0.632	1.582
Weather	0.781	1.28
Lighting Conditions	0.919	1.088
Violations	0.926	1.08
Visibility	0.906	1.104
Road Surface Condition	0.76	1.316
Road Alignment	0.972	1.029
Intersection Section Type	0.883	1.132
Road Physical Isolation	0.769	1.301
Roadside Protection Measures	0.766	1.306
Road Safety Attributes	0.956	1.046
Age	0.874	1.144
Driving Experience	0.83	1.205
Driving Status	0.941	1.063

After multicollinearity test analysis, it can be found that the *VIF* values of the 15 independent variables are all around 1, indicating that there is no significant collinearity among the independent variables. They can be analyzed as independent variables in the model.

4. Model Parameter Calibration

The core of logistic regression is the calculation of the parameter θ, which is estimated using the maximum likelihood function. A common loss function employed is the cross-entropy loss, which is given by:

$$J(\theta) = -\frac{1}{m}\sum_{i=1}^{m}\left[y^{(i)}\log(h_\theta(x^{(i)})) + (1-y^{(i)})\log(1-h_\theta(x^{(i)}))\right] \quad (5)$$

In the formulas, m is the number of samples; $y^{(i)}$ is the true label of the i-th sample; $h_\theta(x)$ is the prediction of the probability; $x^{(i)}$ is the feature vector of the i-th sample. The results of the parameter calibration are shown in Table 5.

Table 5. Model calibration results.

Urban Roads		**Highways**		**Expressways**			
Influencing Factors	β	Influencing Factors	β	Influencing Factors	β	Influencing Factors	β
Lighting Conditions		**Accident Types**		**Accident Types**		9 = Overload	0.031
1 = Daytime	−0.160	1 = Side Collision	0.258	1 = Side Collision	−1.522	10 = Drunk Driving	−0.618
2 = Night with Streetlights	0.608	2 = Rear-end Collision	−0.216	2 = Rear-end Collision	−0.454	11 = Unqualified Driver	−1.043
Road Safety Attributes (1 = Hazard)	0.687	3 = Other Collision	−0.943	3 = Other Collision	−1.387	12 = Pedestrian or Non-motor Vehicle Violation	−1.038
Age		**Visibility**		**Violations**		13 = Distracted Driving	−0.051
1 = 30–40	0.623	1 = 50–100 m	−1.005	1 = Not Following Lane Regulations	−1.120	**Visibility**	
2 = 40–50	0.762	2 = 100–200 m	−1.263	2 = Not Maintaining Safe Distance in Same Lane	−0.660	1 = 50–100 m	1.014
3 = 50+	1.343	3 = 200+ meters	−1.646	3 = Illegal Parking	0.265	2 = 100–200 m	1.192
Driving Status (1 = Straight)	0.421	**Intersection Section Type** (1 = Intersection)	−0.44	4 = Not Yielding as Required	0.279	3 = 200+ meters	0.728
Constant	−1.645	**Roadside Protection Measures** (1 = Protection)	−0.583	5 = Vehicle Not Meeting Technical Standards	0.709	**Road Alignment** (1 = Curved)	1.654
		Road Safety Attributes (1 = Hazard)	0.547	6 = Violating Traffic Signals	0.749	**Constant**	0.971
		Driving Status (1 = Straight)	0.451	7 = Illegal Overtaking, Reversing, Meeting, U-turning, etc.	−0.262		
		Constant	0.728	8 = Speeding	0.949		

In the model goodness-of-fit test, this paper employs the Hosmer-Lemeshow test, which can more intuitively assess the goodness-of-fit of the binary logistic regression model.

By grouping the data and comparing the predicted probabilities and actual results of each group, the overall fit of the model is evaluated. This better reflects the model fit. Unlike the Wald test, the Hosmer-Lemeshow test does not rely on the normality assumption of the estimated coefficients. The test results show that the chi-square values of the logistic models for the three different road types are 0.920 (df = 7), 5.355 (df = 8), and 6.274 (df = 8), all less than the chi-square critical value of 15.507 at df = 8. The significance levels are 0.996, 0.719, and 0.617, respectively, all not reaching the significant level, i.e., $p > 0.05$. This indicates that the overall fit of the model is good, and the independent variables can effectively explain the dependent variables. The logistic regression models for the severity of heavy truck traffic accidents on urban roads, highways, and expressways are as follows:

$$P^{(1)} = \{Y^{(1)} = 1/X\} = \frac{e^{-0.16x_{11}^{(1)}+0.608x_{12}^{(1)}+0.687x_{2}^{(1)}+0.623x_{31}^{(1)}+0.762x_{32}^{(1)}+1.343x_{33}^{(1)}+0.421x_{4}^{(1)}-1.645}}{1+e^{-0.16x_{11}^{(1)}+0.608x_{12}^{(1)}+0.687x_{2}^{(1)}+0.623x_{31}^{(1)}+0.762x_{32}^{(1)}+1.343x_{33}^{(1)}+0.421x_{4}^{(1)}-1.645}} \tag{6}$$

$$P^{(2)} = \{Y^{(2)} = 1/X\} = \frac{e^{0.258x_{11}^{(2)}-0.216x_{12}^{(2)}-0.943x_{13}^{(2)}-1.005x_{21}^{(2)}-1.263x_{22}^{(2)}-1.646x_{23}^{(2)}-0.44x_{3}^{(2)}-0.583x_{4}^{(2)}+0.547x_{5}^{(2)}+0.451x_{6}^{(2)}+0.728}}{1+e^{0.258x_{11}^{(2)}-0.216x_{12}^{(2)}-0.943x_{13}^{(2)}-1.005x_{21}^{(2)}-1.263x_{22}^{(2)}-1.646x_{23}^{(2)}-0.44x_{3}^{(2)}-0.583x_{4}^{(2)}+0.547x_{5}^{(2)}+0.451x_{6}^{(2)}+0.728}} \tag{7}$$

$$P^{(3)} = \{Y^{(3)} = 1/X\} = \frac{e^{-1.522x_{11}^{(3)}-0.454x_{12}^{(3)}-1.387x_{13}^{(2)}-1.12x_{21}^{(3)}-\ldots-0.051x_{213}^{(3)}+1.014x_{31}^{(3)}+1.192x_{32}^{(3)}+0.728x_{33}^{(3)}+1.654x_{4}^{(3)}+0.971}}{1+e^{-1.522x_{11}^{(3)}-0.454x_{12}^{(3)}-1.387x_{13}^{(2)}-1.12x_{21}^{(3)}-\ldots-0.051x_{213}^{(3)}+1.014x_{31}^{(3)}+1.192x_{32}^{(3)}+0.728x_{33}^{(3)}+1.654x_{4}^{(3)}+0.971}} \tag{8}$$

Formulas (6)–(8) represent the logistic regression models for the severity of heavy truck traffic accidents on urban roads, ordinary highways, and expressways, respectively. In these formulas, x_1 to x_i correspond to the independent variable codes shown in Table 4 for each road condition affecting the severity of heavy truck traffic accidents. For example, in the case of urban roads, x_1 is Lighting Conditions, x_2 is Road Safety Attributes, x_3 is Age, and x_4 is Driving Status. The same coding method is applied for independent variables on highways and expressways.

5. Mechanism Analysis of Heavy Truck Traffic Accident Severity

After completing the parameter calibration for all eligible influencing factors, we used a forward stepwise binary logistic regression model to analyze the mechanism by which different factors affect the severity of heavy truck accidents.

5.1. Mechanism Analysis of Urban Road Accidents

Heavy truck accidents on urban roads are significantly correlated with four variables: lighting conditions, road safety attributes, driver age, and vehicle driving status. And driving experience, inter-vehicle accident types, accident forms, road surface conditions, intersection section types, physical isolation conditions, roadside protection measures, alignment, weather, visibility, and violations are not significant factors. The results are shown in Table 6.

Table 6. Regression Analysis Results of Heavy Truck Accidents on Urban Roads.

Influencing Factors	β	Standard Error	Wald	df	Significance	Exp (β)
Lighting Conditions			15.603	2	0.000	
1 = Daytime	−0.160	0.423	0.143	1	0.705	0.852
2 = Night with Streetlights	0.608	0.427	2.026	1	0.155	1.837
Road Safety Attributes (1 = Hazard)	0.687	0.229	9.027	1	0.003	1.987
Age			11.654	3	0.009	
1 = 30–40	0.623	0.342	3.317	1	0.069	1.864
2 = 40–50	0.762	0.347	4.827	1	0.028	2.142
3 = 50+	1.343	0.404	11.066	1	0.001	3.832
Driving Status (1 = Straight)	0.421	0.190	4.882	1	0.027	1.523
Constant	−1.645	0.532	9.580	1	0.002	0.193

(1) Driver aspects: Age is a significant factor affecting urban heavy truck traffic accident severity, with a significance of $0.009 < 0.05$. The probability of fatal accidents occurring among drivers of different age groups indicates that as age increases, the probability of fatal accidents increases, with drivers aged over 50 having the highest probability, 3.832 times that of drivers under 30. This could be due to the decline in physical function and extended reaction time with age, making it difficult for older drivers to respond quickly in emergencies.
(2) Vehicle aspects: The driving status of the vehicle is a significant factor affecting urban heavy truck traffic accident severity. When the vehicle is driving straight, the probability of fatal accidents is 1.523 times that of non-straight driving. Compared to non-straight driving status, heavy trucks tend to drive at relatively higher speeds when going straight. Additionally, heavy trucks have the prominent characteristic of carrying large loads. The combination of these features makes it difficult for straight-moving heavy trucks to brake and stop promptly in the event of sudden incidents, often leading to severe traffic accidents.
(3) Road conditions: Road safety attributes are significant factors affecting urban heavy truck traffic accident severity. When there are hazards on the road, the probability of fatal accidents is 1.987 times that of roads without hazards. Road hazards, including poor visibility, unclear traffic markings, improper placement of traffic signs, and pavement damage, can negatively impact drivers' perception, decision-making, and control, leading to serious accidents.
(4) Environmental aspects: Lighting conditions are significant factors affecting urban heavy truck traffic accident severity. The probability of fatal accidents under street lighting at night is 1.837 times that of no street lighting. The cause of this phenomenon may be that better nighttime lighting conditions lead to decreased vigilance among heavy truck drivers, resulting in higher speeds and, consequently, increasing the severity of traffic accidents. The probability of fatal accidents with no street lighting at night is 1.174 times that of daytime. This indicates that fatal accidents are more likely to occur at night compared to daytime on urban roads.

The analysis of the mechanism of urban heavy truck traffic accident severity reveals that older driver age, straight driving status, hazardous road sections, and night street lighting are risk factors leading to fatal accidents on urban roads.

5.2. Mechanism Analysis of Highway Accidents

Heavy truck accidents on highways are significantly correlated with six variables: visibility, roadside protection measures, intersection section types, vehicle driving status, inter-vehicle accident types, and road safety attributes. And age, driving experience, accident forms, road surface conditions, physical isolation conditions, alignment, weather, lighting conditions, and violations are not significant factors. The results are shown in Table 7.

(1) Vehicle aspects: The driving status of the vehicle and inter-vehicle accident types are significant factors affecting heavy truck traffic accident severity on highways. When the vehicle is driving straight, the probability of fatal accidents is 1.57 times that of non-straight driving. For accident types, side collisions have the highest probability of causing fatal accidents, being 1.294 times that of non-vehicle accidents. Non-vehicle accidents (i.e., vehicle-pedestrian accidents) have a greater probability of fatal accidents, being 1.241 and 2.571 times that of rear-end and other direction collisions, respectively. In China, many highways pass through villages and towns, leading to numerous minor roads connecting to these main roads. The majority of intersections between main roads and minor roads lack signal control, which increases the probability of serious traffic accidents caused by heavy trucks colliding with vehicles suddenly emerging from minor roads.
(2) Road conditions: Roadside protection measures are significant factors affecting heavy truck traffic accident severity on highways. When there are no roadside protection

measures, the probability of fatal accidents is 1.792 times that of protected roads. If a heavy truck loses control or veers off the road for other reasons, the lack of protective measures on the roadside will fail to absorb impact energy, resulting in a significantly increased force of impact during the collision, which exacerbates the severity of the traffic accident. Furthermore, many rural roads are located near water or cliffs, and the absence of roadside protection measures increases the risk of severe traffic accidents, such as trucks falling into water or off cliffs. For intersection section types, the probability of fatal accidents at road sections is 1.506 times that at intersections. For road safety attributes, the probability of fatal accidents on roads with hazards is 1.57 times that of roads without hazards.

(3) Environmental aspects: Visibility is a significant factor affecting heavy truck traffic accident severity on highways. As visibility decreases, the probability of fatal accidents increases. When visibility is below 50 m, the probability of fatal accidents is 2.732, 3.534, and 5.181 times that of visibility at 50–100 m, 100–200 m, and over 200 m, respectively. As visibility decreases, drivers find it more challenging to observe the road traffic environment and have poorer ability to respond to sudden events, thereby increasing the likelihood of severe traffic accidents.

Table 7. Regression Analysis Results of Heavy Truck Accidents on Highways.

Influencing Factors	β	Standard Error	Wald	df	Significance	Exp (β)
Accident Types			14.59	3	0.002	
1 = Side Collision	0.258	0.23	1.258	1	0.262	1.294
2 = Rear-end Collision	−0.216	0.288	0.561	1	0.454	0.806
3 = Other Collision	−0.943	0.323	8.541	1	0.003	0.389
Visibility			32.838	3	0	
1 = 50–100 m	−1.005	0.302	11.109	1	0.001	0.366
2 = 100–200 m	−1.263	0.321	15.509	1	0	0.283
3 = 200+ meters	−1.646	0.292	31.875	1	0	0.193
Intersection Section Type (1 = Intersection)	−0.44	0.204	4.668	1	0.031	0.644
Roadside Protection Measures (1 = Protection)	−0.583	0.22	7.015	1	0.008	0.558
Road Safety Attributes (1 = Hazard)	0.547	0.195	7.863	1	0.005	1.727
Driving Status (1 = Straight)	0.451	0.215	4.392	1	0.036	1.57
Constant	0.728	0.33	4.862	1	0.027	2.071

The analysis of the mechanism of heavy truck traffic accident severity on highways reveals that straight driving status, side collision accident type, no roadside protection measures, driving on hazardous road sections, and visibility below 50 m are risk factors leading to fatal accidents on highways.

5.3. Mechanism Analysis of Expressway Accidents

Heavy truck accidents on expressways are significantly correlated with four variables: inter-vehicle accident types, driver violations, visibility, and road alignment. And age, driving experience, vehicle driving status, accident forms, road surface conditions, intersection section types, physical isolation conditions, road safety attributes, roadside protection measures, lighting conditions, and weather are not significant factors. The results are shown in Table 8.

(1) Driver aspects: Driver violations are significant factors affecting heavy truck traffic accident severity on expressways. The significance of violations is 0.039 < 0.05, indicating that violations are related to heavy truck traffic accident severity on expressways. Using other reasons (natural disasters, etc.) as a reference, the top three violations with the highest probability of causing fatal accidents are speeding, violating traffic signals (traffic signs, traffic markings), and vehicles not meeting technical standards, with probabilities 2.582, 2.116, and 2.032 times that of other reasons, respectively. Speeding increases the braking distance and the impact force during collisions. Violations of

traffic signals by heavy trucks primarily include crossing solid lines while changing lanes and disregarding lane separation signs for passengers and cargo. Such violations can lead to side collisions or rear-end accidents involving passenger cars, which increases the risk of fatalities among passengers and drivers in these cars. Failure to meet technical standards includes the absence of side and rear under-run protection devices or reflective markings on the body, making heavy trucks difficult to detect and unable to use crash barriers to absorb energy during collisions, increasing the probability of fatal accidents.

(2) Vehicle aspects: Inter-vehicle accident types are significant factors affecting heavy truck traffic accident severity on expressways. Regarding accident types, when the accident type is a non-vehicle accident, i.e., a vehicle-pedestrian accident, the probability of fatal accidents is the highest, being 4.587, 1.575, and 4 times that of side collisions, rear-end collisions, and other angle collisions, respectively. Under expressway conditions, heavy truck collisions with pedestrians who are illegally on the expressway or with occupants of disabled vehicles who have not evacuated in time are the primary types of vehicle-to-person accidents. Additionally, heavy trucks operate at high speeds on expressways, have a heavy load, and require a long braking distance. Consequently, if a collision occurs, the probability of fatalities among those struck is extremely high.

(3) Road conditions: Road alignment is a significant factor affecting heavy truck traffic accident severity on expressways. When the road alignment is curved or sloped, the probability of fatal accidents is 5.228 times that of straight sections. First, curved and sloped road sections can affect the driver's visibility. Second, heavy trucks have notable characteristics such as a high center of gravity and heavy loads, and they travel at high speeds on highways. This makes them prone to overturning when navigating curves and susceptible to brake failure during long descents, which can lead to severe traffic accidents.

(4) Environmental aspects: Visibility is a significant factor affecting heavy truck traffic accident severity on expressways. As visibility increases, the probability of fatal accidents first increases and then decreases. When visibility is below 50 m, the probability of fatal accidents is the lowest. At 100–200 m visibility, the probability of fatal accidents is the highest, being 3.292 times that of visibility below 50 m. The probability of severe traffic accidents is lowest when visibility is below 50 m because, under such conditions, traffic management authorities implement strict control measures, such as speed limits of 20 km/h, traffic restrictions, diversion, guidance, and even highway closures. In contrast, visibility between 100 and 200 m typically corresponds to less stringent traffic control measures, and some drivers may ignore these controls, driving as if visibility were greater than 200 m. This compromised visibility and field of view for heavy truck drivers can lead to severe traffic accidents, such as rear-end collisions.

Table 8. Regression Analysis Results of Heavy Truck Accidents on Expressways.

Influencing Factors	β	Standard Error	Wald	df	Significance	Exp (β)
Accident Types			16.011	3	0.001	
1 = Side Collision	−1.522	0.643	5.607	1	0.018	0.218
2 = Rear-end Collision	−0.454	0.576	0.620	1	0.431	0.635
3 = Other Collision	−1.387	0.595	5.430	1	0.020	0.250
Violations			23.266	13	0.039	
1 = Not Following Lane Regulations	−1.120	0.827	1.834	1	0.176	0.326
2 = Not Maintaining Safe Distance in Same Lane	−0.660	0.689	0.916	1	0.338	0.517
3 = Illegal Parking	0.265	0.743	0.127	1	0.722	1.303
4 = Not Yielding as Required	0.279	1.077	0.067	1	0.795	1.322
5 = Vehicle Not Meeting Technical Standards	0.709	0.761	0.867	1	0.352	2.032
6 = Violating Traffic Signals	0.749	1.001	0.561	1	0.454	2.116

Table 8. *Cont.*

Influencing Factors	β	Standard Error	Wald	df	Significance	Exp (β)
7 = Illegal Overtaking, Reversing, Meeting, U-turning	−0.262	0.866	0.092	1	0.762	0.769
8 = Speeding	0.949	1.301	0.531	1	0.466	2.582
9 = Overload	0.031	0.759	0.002	1	0.968	1.031
10 = Drunk Driving	−0.618	0.739	0.699	1	0.403	0.539
11 = Unqualified Driver	−1.043	1.137	0.843	1	0.359	0.352
12 = Pedestrian or Non-motor Vehicle Violation	−1.038	0.901	1.328	1	0.249	0.354
13 = Distracted Driving	−0.051	0.686	0.005	1	0.941	0.951
Visibility			12.183	3	0.007	
1 = 50–100 m	1.014	0.341	8.861	1	0.003	2.756
2 = 100–200 m	1.192	0.372	10.260	1	0.001	3.292
3 = 200+ meters	0.728	0.338	4.648	1	0.031	2.070
Road Alignment (1 = Curved)	1.654	0.748	4.888	1	0.027	5.228
Constant	0.971	0.773	1.579	1	0.209	2.641

The analysis of the mechanism of heavy truck traffic accident severity on expressways reveals that speeding, violating traffic signals (traffic signs, traffic markings), vehicles not meeting technical standards, curved or sloped road alignment, car-pedestrian accidents, and visibility at 100–200 m are risk factors leading to fatal accidents on expressways.

6. Preventive Measures and Suggestions

Considering the significant differences in the causes of heavy truck traffic accident severity under different road types, traffic management departments should adopt differentiated control measures to effectively reduce the severity of heavy truck traffic accidents.

For urban roads, the key factors include drivers over 50 years old, straight driving status, road hazards, and nighttime with street lighting. Measures can include enhancing education and regular medical check-ups for drivers over 50, restricting truck access on certain sections, addressing poor sight distance, unclear traffic markings, improper sign placement, road surface defects, and intensifying enforcement against speeding and red-light violations by heavy trucks at night.

For highways, the key factors include straight driving status, side collisions between vehicles, lack of roadside protection measures, road hazards, and visibility below 50 m. Measures can include implementing separate lanes for passenger and freight vehicles, adding speed limit and distance warning signs on accident-prone sections, installing stop and yield signs, speed bumps, consolidating closely spaced small entrances, adding guardrails where roadside clear zones are insufficient, and addressing various road safety hazards. Additionally, visibility-related traffic control measures such as speed limits, traffic flow control, and guidance have been crucial in reducing the severity of heavy truck traffic accidents on expressways, and it is recommended that such measures be actively implemented for highways as well.

For expressways, key factors include speeding, traffic signal violations, non-compliance with vehicle technical standards, curved or sloped road sections, vehicle-pedestrian collisions, and visibility of 100–200 m. Measures should include enhancing the detection and warning of driver violations and conducting source supervision starting from the heavy truck companies. For sharp curves, install stepwise speed reduction and rumble strips in advance, and strengthen enforcement against speeding. For long downhill sections, implement enhanced speed control measures for heavy trucks, scientifically set up escape lanes, and use variable message boards to inform passing vehicles of driving precautions. For vehicle-pedestrian collisions, advanced equipment such as drones can be used to quickly identify and remind pedestrians illegally on the expressway and drivers and passengers of broken-down vehicles who have not yet left the area. For visibility, traffic management departments should further strengthen the enforcement of control measures for visibility levels of 100–200 m.

The above measures targeting the three types of roads can yield the following benefits. The results are shown in Table 9.

Table 9. Policy recommendations and benefits.

Road Types	Policy Recommendations	Benefits
Urban roads	Enhancing education and regular medical check-ups for drivers over 50	Enhance safe driving awareness and reduce accidents caused by health issues or slower response times among older drivers
	Restricting truck access on certain sections	Reduce the risk of mixed traffic with smaller vehicles
	Addressing poor sight distance, unclear traffic markings, improper sign placement, and road surface defects	Enhance visibility and clarity of signage assists drivers in earlier recognition of road information, thereby reducing unexpected collision risks
	Intensifying enforcement against speeding and red-light violations by heavy trucks at night	Reduce the frequency of serious traffic accidents caused by these violations significantly, raise awareness for safe driving
Highways	Implementing separate lanes for passenger and freight vehicles	Reduce the likelihood of side and rear-end collisions, and enhance the overall safety and efficiency of traffic flow
	Adding speed limit and distance warning signs on accident-prone sections	Decrease rear-end and loss-of-control accidents caused by excessive speed and insufficient following distance
	Installing stop and yield signs, speed bumps, and consolidating closely spaced small entrances	Reduce collision risks at dense entrances and exits, preventing small vehicles from accidentally entering high-speed traffic
	Adding guardrails where roadside clear zones are insufficient, and addressing various road safety hazards	Prevent vehicles from veering off the road, reducing the severity of rollovers and collisions
Expressways	Enhancing the detection and warning of driver violations	Provide timely warnings to drivers to correct behavior, reducing accident risks caused by violations
	Conducting source supervision starting from the heavy truck companies	Strengthen source control to ensure vehicle maintenance and driver training meet safety standards, enhancing driving safety
	Install stepwise speed reduction and rumble strips in advance, and strengthen enforcement against speeding	Improves road infrastructure to ensure safety, and prevent severe accidents caused by excessive speed
	Implement enhanced speed control measures for heavy trucks, scientifically set up escape lanes, and use variable message boards to in-form passing vehicles of driving precautions	Ensure road safety by controlling vehicle speeds, while dynamic message boards provide real-time road information and driving recommendations, enabling drivers to adjust their behavior promptly in response to changing road conditions
	Advanced equipment such as drones can be used to quickly identify and remind pedestrians illegally on the expressway and drivers and passengers of broken-down vehicles who have not yet left the area	Accelerate identification and warnings preventing secondary accidents caused by unauthorized pedestrians and disabled vehicles, thereby enhancing emergency response times
	Further strengthen the enforcement of control measures for visibility levels of 100–200 m	Maintain safer driving speeds and distances, reducing chain collisions caused by poor visibility

As shown in Table 2, comparing the number of general and fatal heavy truck accidents across three road types reveals that the fatal accident rate is as high as 60% on urban roads, 57% on highways, and 27% on expressways. Therefore, traffic management departments should strengthen control measures and law enforcement for heavy trucks on urban roads and highways. The findings of this study can provide support for the refined and targeted prevention and control of heavy truck traffic accidents, helping to reduce their severity.

7. Discussion

Reducing road accident severity is a central objective of the new "Decade of Action for Road Safety 2021–2030" [29,30]. To address the severity of heavy truck accidents, this study utilized traffic accident data from the past five years in a certain region of China to establish logistic regression models. The study analyzed the factors contributing to accident severity under different road types: urban roads, highways, and expressways. Results indicate that on urban roads, key factors include driver age, vehicle status, road safety features, and lighting. On highways, key factors include vehicle driving status, accident types, roadside protection measures, road safety attributes, and visibility. On expressways, the critical factors influencing accident severity are driver violations, road alignment, accident types, and visibility. These findings demonstrate significant differences in the factors affecting heavy truck accident severity across various road types.

Although accident types and visibility are common factors on both highways and expressways, their specific mechanisms differ. For example, on highways, side collisions between vehicles have the greatest impact on accident severity, whereas on expressways, vehicle-pedestrian collisions are the most critical. This difference arises because highways often have roadside access points, which increase the likelihood of side collisions, while expressways are more isolated, leading to a higher risk of vehicle-pedestrian accidents. Additionally, on highways, the effect of visibility on accident severity is linear—the severity increases as visibility decreases. On expressways, the relationship is non-linear; the severity is lowest when visibility is below 50 m, and highest at 100–200 m. This is primarily due to the stricter visibility-related traffic control measures in place on expressways compared to highways. The above findings underscore the importance of analyzing different road types separately when proposing accident prevention strategies.

In previous studies, scholars also conducted severity analyses of heavy truck traffic accidents based on different road types. Chen et al. [5] conducted a study under urban road conditions, and the results showed that nighttime driving conditions, single-vehicle accidents, vehicle-pedestrian collisions, not following lane regulations, and traffic signal violations significantly influenced the severity of heavy truck traffic accidents. Osman et al. [19] studied heavy truck traffic accidents on highways and found that daytime crashes, lack of access control, higher speed limits, and crashes on rural principal arterials were the most important factors contributing to higher injury severity. Choi et al. [21] conducted a study under expressways, and their analysis showed that weather conditions, lighting conditions, speeding, and bridge/tunnel sections had significant impacts on the severity of heavy truck traffic accidents. We can conclude that the causes of heavy truck traffic accident severity identified in these studies differ significantly from those found in our study. The primary reason for this discrepancy is the different datasets used. Chen, Osman, and Choi's studies were based on foreign traffic accident data, whereas this study is based on Chinese traffic accident data. Different countries have significant differences in terms of laws, road design standards, and driver characteristics. Therefore, when formulating traffic management measures, the primary basis should be research findings based on domestic data, with studies based on foreign data serving as a supplementary reference.

Furthermore, this study has some limitations. First, this study is based on data from heavy truck traffic accidents in a specific region of China, so the findings may not be fully applicable to all regions of China. In the future, data from different regions can be collected for a more comprehensive study. Additionally, the conclusions drawn from the logistic regression model in this study are more qualitative. In the future, quantitative research on heavy truck traffic accidents can be conducted using machine learning or deep learning methods, which will provide better support for formulating traffic management measures aimed at preventing heavy truck traffic accidents.

8. Conclusions

This study, based on five years of heavy truck traffic accident data from a region in China, uses a binary logistic regression model to analyze the factors and mechanisms affecting the severity of heavy truck traffic accidents. Considering that different road types have distinct design standards, control measures, and conflict types, we established separate models for analyzing the severity of heavy truck traffic accidents under urban roads, highways, and expressways. The results indicate significant differences in the causes of severe heavy truck accidents across different road types.

Under urban road conditions, key factors that exacerbate the severity of heavy truck accidents include drivers over 50 years old, vehicles driving straight, road hazards, and nighttime lighting with street lamps. Specifically, the probability of a fatal accident for drivers over 50 years old is 3.832 times higher than for drivers under 30. When the vehicle is driving straight, the probability of a fatal accident is 1.523 times higher than for non-straight driving. When there are hazards on the road, the probability of a fatal accident is 1.987 times higher than on roads without hazards. The probability of a fatal accident at night with street lighting is 1.837 times higher than at night without street lighting.

Under highway conditions, the main factors contributing to increased severity are vehicles driving straight, side collisions between vehicles, lack of roadside protection, road hazards, and visibility below 50 m. Specifically, the probability of a fatal accident when driving straight is 1.57 times higher than when driving non-straight. Side collisions have the highest probability of causing fatal accidents, with a likelihood 1.294 times higher than non-vehicle-related accidents. The probability of a fatal accident occurring in areas without roadside protection is 1.792 times higher than in areas with protection. The probability of a fatal accident on a road section is 1.506 times higher than at intersections. Roads with hazards are 1.57 times more likely to cause fatal accidents than hazard-free roads. As visibility decreases, the probability of fatal accidents increases. The likelihood of a fatal accident at visibility levels below 50 m is 2.732, 3.534, and 5.181 times higher than at visibility levels of 50–100 m, 100–200 m, and over 200 m, respectively.

Under expressway conditions, key factors include speeding, traffic signal violations, non-compliance with vehicle technical standards, vehicles driving on curved or sloped roads, collisions with pedestrians, and visibility between 100 and 200 m. Specifically, the top three violations leading to fatal accidents are speeding, violating traffic signals, and non-compliance with vehicle technical standards, with probabilities 2.582, 2.116, and 2.032 times higher than other factors, respectively. The probability of a fatal accident in non-vehicle-related accidents is the highest, being 4.587, 1.575, and 4 times higher than in side collisions, rear-end collisions, and other angle collisions, respectively. The probability of a fatal accident on curved or sloped road sections is 5.228 times higher than on straight sections. As visibility increases, the probability of fatal accidents first increases and then decreases. When visibility is below 50 m, the likelihood of a fatal accident is lowest, while at 100–200 m, the likelihood is highest—3.292 times that of visibility below 50 m.

Author Contributions: Conceptualization, F.C. and S.M.; Investigation, Z.T. and M.G.; Methodology, Z.T. and F.C.; Formal analysis, F.C.; Visualization, Z.T.; Validation, Z.T. and F.C.; Writing—original draft, Z.T. and F.C.; Writing—review and editing, M.G., F.C. and S.M.; Resources, F.C.; Data curation, F.C.; Supervision, F.C.; Project administration, S.M.; Funding acquisition, F.C. and M.G. All authors have read and agreed to the published version of the manuscript.

Funding: This paper was internally funded by the Double First-Class Innovation Research Project for People's Public Security University of China (No. 2023SYL09).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zuo, D.; Liang, Q.; Zhan, S.; Huang, W.; Yang, S.; Wang, M. Using energy consumption constraints to control the freight transportation structure in China (2021–2030). *Energy* **2023**, *262*, 125512. [CrossRef]
2. Chinese Statistics. *Statistical Bulletin of the People's Republic of China on National Economic and Social Development for 2023*; National Bureau of Statistics of China: Beijing, China, 2024.
3. Wen, H.; Du, Y.; Chen, Z.; Zhao, S. Analysis of factors contributing to the injury severity of overloaded-truck-related crashes on mountainous highways in China. *Int. J. Environ. Res. Public Health* **2022**, *19*, 4244. [CrossRef]

4. Li, C. Research on Safety Management in Highway Freight Transport. *China Shipp. Gaz.* **2024**, *33*, 72–74.
5. Chen, M.; Zhou, L.; Choo, S.; Lee, H. Analysis of risk factors affecting urban truck traffic accident severity in Korea. *Sustainability* **2022**, *14*, 2901. [CrossRef]
6. Schindler, R.; Jänsch, M.; Bálint, A.; Johannsen, H. Exploring European heavy goods vehicle crashes using a three-level analysis of crash data. *Int. J. Environ. Res. Public Health* **2022**, *19*, 663. [CrossRef]
7. Abrari Vajari, M.; Aghabayk, K.; Sadeghian, M.; Moridpour, S. Modelling the injury severity of heavy vehicle crashes in Australia. *Iran. J. Sci. Technol. Trans. Civ. Eng.* **2022**, *46*, 1635–1644. [CrossRef]
8. Habib, M.F.; Motuba, D.; Huang, Y. Beyond the surface: Exploring the temporally stable factors influencing injury severities in large-truck crashes using mixed logit models. *Accid. Anal. Prev.* **2024**, *205*, 107650. [CrossRef]
9. Zhou, T.; Zhang, J. Analysis of commercial truck drivers' potentially dangerous driving behaviors based on 11-month digital tachograph data and multilevel modeling approach. *Accid. Anal. Prev.* **2019**, *132*, 105256. [CrossRef]
10. Hollnagel, E. *Barriers and Accident Prevention*; Routledge: London, UK, 2016.
11. Belin, M.Å.; Tillgren, P.; Vedung, E. Vision Zero–A road safety policy innovation. *Int. J. Inj. Control Saf. Promot.* **2012**, *19*, 171–179. [CrossRef]
12. Yan, M.; Chen, W.; Wang, J.; Zhang, M.; Zhao, L. Characteristics and causes of particularly major road traffic accidents involving commercial vehicles in China. *Int. J. Environ. Res. Public Health* **2021**, *18*, 3878. [CrossRef]
13. Useche, S.A.; Cendales, B.; Alonso, F.; Montoro, L. Multidimensional prediction of work traffic crashes among Spanish professional drivers in cargo and passenger transportation. *Int. J. Occup. Saf. Ergon.* **2022**, *28*, 20–27. [CrossRef]
14. Sun, W. Study on Accident Causes, Mechanism and Preventing Strategy of Heavy Trucks. Master's Thesis, Chongqing Jiaotong University, Chongqing, China, 2014.
15. Li, Z.; Niu, Y.; Fan, Y. Study on characteristics of truck accidents in different regions of expressways. *China Saf. Sci. J.* **2020**, *6*, 121–127.
16. Ma, Z.; Shao, C.; Li, X. Research on the influence factors of traffic accident severity in highway tunnel based on Logistic model. *J. Jilin Univ. (Eng. Technol. Ed.)* **2010**, *2*, 423–426.
17. Zhang, J.; Zhang, M.; Li, H. An analysis of severity of traffic accidents on urban roadways based on binary logistic models. *J. Transp. Inf. Saf.* **2022**, *40*, 70–79.
18. Zhu, X.; Srinivasan, S. A comprehensive analysis of factors influencing the injury severity of large-truck crashes. *Accid. Anal. Prev.* **2011**, *43*, 49–57. [CrossRef]
19. Osman, M.; Paleti, R.; Mishra, S.; Golias, M.M. Analysis of injury severity of large truck crashes in work zones. *Accid. Anal. Prev.* **2016**, *97*, 261–273. [CrossRef]
20. Chen, F.; Chen, S. Injury severities of truck drivers in single-and multi-vehicle accidents on rural highways. *Accid. Anal. Prev.* **2011**, *43*, 1677–1688. [CrossRef]
21. Choi, S.; Oh, C.; Kim, M. Risk factors related to fatal truck crashes on Korean freeways. *Traffic Inj. Prev.* **2014**, *15*, 73–80. [CrossRef]
22. Uddin, M.; Huynh, N. Truck-involved crashes injury severity analysis for different lighting conditions on rural and urban roadways. *Accid. Anal. Prev.* **2017**, *108*, 44–55. [CrossRef]
23. Ahmed, M.M.; Franke, R.; Ksaibati, K.; Shinstine, D.S. Effects of truck traffic on crash injury severity on rural highways in Wyoming using Bayesian binary logit models. *Accid. Anal. Prev.* **2018**, *117*, 106–113. [CrossRef]
24. Qin, X.; Wang, K.; Cutler, C.E. Logistic regression models of the safety of large trucks. *Transp. Res. Rec.* **2013**, *2392*, 1–10. [CrossRef]
25. Yuan, Y.; Yang, M.; Guo, Y.; Rasouli, S.; Gan, Z.; Ren, Y. Risk factors associated with truck-involved fatal crash severity: Analyzing their impact for different groups of truck drivers. *J. Saf. Res.* **2021**, *76*, 154–165. [CrossRef]
26. IBM. SPSS Statistics Software. Available online: https://www.ibm.com/products/spss-statistics (accessed on 1 July 2024).
27. Shrestha, N. Detecting multicollinearity in regression analysis. *Am. J. Appl. Math. Stat.* **2020**, *8*, 39–42. [CrossRef]
28. Akinwande, M.O.; Dikko, H.G.; Samson, A. Variance inflation factor: As a condition for the inclusion of suppressor variable(s) in regression analysis. *Open J. Stat.* **2015**, *5*, 754–767. [CrossRef]
29. World Health Organization. *Regional Approach to the Decade of Action for Road Safety 2021–2030*; World Health Organization: Geneva, Switzerland, 2022.
30. Truong, J.; Ward, D.; McInerney, R.; Smith, G. *Achieving the SDGs for Road Safety in G20 Countries*; iRAP: Bracknell, UK, 2023.