Chinese Journal of Traumatology 20 (2017) 20–26

Contents lists available at ScienceDirect

Chinese Journal of Traumatology

journal homepage: http://www.elsevier.com/locate/CJTEE

Original article

Investigation on occupant injury severity in rear-end crashes involving trucks as the front vehicle in Beijing area, China

Quan Yuan [a,*], Meng Lu [a], Athanasios Theofilatos [b], Yi-Bing Li [a]

[a] State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China
[b] National Technical University of Athens, Athens, Greece

A R T I C L E I N F O

Article history:
Received 30 May 2016
Received in revised form
21 September 2016
Accepted 25 September 2016
Available online 9 November 2016

Keywords:
Rear-end crash
Trucks
Contributing factors
Injury severity

A B S T R A C T

Purpose: Rear-end crashes attribute to a large portion of total crashes in China, which lead to many casualties and property damage, especially when involving commercial vehicles. This paper aims to investigate the critical factors for occupant injury severity in the specific rear-end crash type involving trucks as the front vehicle (FV).

Methods: This paper investigated crashes occurred from 2011 to 2013 in Beijing area, China and selected 100 qualified cases i.e., rear-end crashes involving trucks as the FV. The crash data were supplemented with interviews from police officers and vehicle inspection. A binary logistic regression model was used to build the relationship between occupant injury severity and corresponding affecting factors. Moreover, a multinomial logistic model was used to predict the likelihood of fatal or severe injury or no injury in a rear-end crash.

Results: The results provided insights on the characteristics of driver, vehicle and environment, and the corresponding influences on the likelihood of a rear-end crash. The binary logistic model showed that drivers' age, weight difference between vehicles, visibility condition and lane number of road significantly increased the likelihood for severe injury of rear-end crash. The multinomial logistic model and the average direct pseudo-elasticity of variables showed that night time, weekdays, drivers from other provinces and passenger vehicles as rear vehicles significantly increased the likelihood of rear drivers being fatal.

Conclusion: All the abovementioned significant factors should be improved, such as the conditions of lighting and the layout of lanes on roads. Two of the most common driver factors are drivers' age and drivers' original residence. Young drivers and outsiders have a higher injury severity. Therefore it is imperative to enhance the safety education and management on the young drivers who steer heavy duty truck from other cities to Beijing on weekdays.

Introduction

China is a country with a growing number of registered vehicles and a large number of traffic crashes. Previous studies show that rear-end crashes attribute to a large proportion of traffic crashes and is usually associated with heavy casualties and property losses. In China, rear-end crash ranks the third highest among vehicle crash types.[1] In addition, all types of vehicles are more likely to be involved with serious injury, when in a collision with a large truck (gross weight > 3.5 ton). Heavy vehicle involvement would increase the likelihood of drivers sustaining fatal injuries.[2] Therefore, as a kind of frequent and serious crash, rear-end crashes involving trucks require particular investigation to explore the contributing factors and prevention countermeasure of these crashes. So far, a limited number of studies have been emphasized on rear-end crashes with truck as the front vehicle (FV) in China.

Chang & Mannering[3] studied the crash data from Washington State, and found that trucks-involved crashes significantly increase injury severity of accidents, associated with higher speed limits, crashes occurring when a vehicle is making right or left turn, and

* Corresponding author.
E-mail address: yuanq@tsinghua.edu.cn (Q. Yuan).

Peer review under responsibility of Daping Hospital and the Research Institute of Surgery of the Third Military Medical University.

http://dx.doi.org/10.1016/j.cjtee.2016.10.002

rear-end type of collision. After more than a decade, Washington State data were also used to show the impact of driver distraction, inattention, speeding, seat belt usage, and drowsiness & fatigue on the likelihood of a run-off-road crash among commercial drivers.[4] Due to the serious consequences, trucks and commercial driver factors involving in crashes are the focuses of these studies.

Khattak et al[5] developed binary probit model and ordered probit model path analysis to study the risk factors, e.g., high-risk behavior, vehicle and roadway factors, in large truck rollovers and injury severity. The results indicated that dangerous truck-driver behaviors worsen the injury severity, such as speeding, reckless driving, alcohol and drug use, non-use of restraints, and traffic control violations, truck exposure to roadways with dangerous geometry and trucks with hazardous material.

Using conditional logistic regression model and chi-square test, Bunn et al[6] studied the impact of sleepiness/fatigue and distraction/inattention factors on fatal and nonfatal commercial vehicle driver injuries. The results indicate that drivers' sleepiness/fatigue and inattention/distraction increase a commercial vehicle crash's injury severity. Eluru & Bhat[7] used 2003 US General Estimates System (GES) to estimate the association between seat belt use and injury severity levels in crashes. The results show the selective recruitment hypothesis to explain the seat belt use endogeneity.

Based on crash data in Finnish, Summala & Mikkola[8] studied the human factors (e.g., fatigue, age, and alcohol) affecting fatal accidents with passenger cars and trucks. They indicated that, in terms of fatal accidents, fatigue and alcohol seem to be less influential for truckers than for car drivers.

Aside from driver factors, factors related to vehicle and road may have influence on the crash severity as well. Lemp et al[9] used crash data from United States' Large Truck Crash Causation Study, General Estimates System, and Vehicle Inventory and Use Survey data sets to estimate the impact of vehicle, occupant, driver, and environmental characteristics on injury outcomes of crashes with heavy-duty trucks. The results show that the possibility of fatality and serious injury accident increases with the increasing of the number of trailers, and decreases with the increasing of standard value of truck length and weight.

Zhu & Srinivasan[10] analyzed the empirical factors affecting injury severity of large-truck crashes, based on crash data from the LTCCS released in 2006, and concluded that rear-end crashes and crashes in wet roadways are shown to be least severe, and crashes in higher speed facilities are estimated to be more severe. A similar research on the factors influencing injury severity of single- and multi-vehicle large truck at-fault crashes on rural and urban roadways in Alabama shows that driver characteristics, e.g., gender and fatigue, roadway and weather condition have different effects on injury severity in rural and urban locations, respectively.[11]

There are many statistical methods employed to examine injury severity. However, despite of the variety of approaches and databases, those studies indicate that some similar risk factors have impact on the likelihood of injury severity. For example, using safety constraints factor reduces the likelihood of more severe injuries.[12,13] Speeding significantly increases the likelihood of injurious or fatal crashes.[9] Other driver factors contributing to severe injury and fatality include gender, age, inattention, fatigue and alcohol use. Drivers with alcohol are more likely to be involved in fatal or serious injuries crashes.[14] Older drivers, i.e., drivers older than 65 years, have a higher probability of more severe injuries.[15] Nevertheless, the impact of gender is comparatively complicated. A number of studies indicate that female drivers have a higher probability of increased severity[16]; on the contrary, others show that male drivers have a higher probability in Hong Kong.[17] Furthermore, environment, crash and road factors also play an important role when analyzing accident severity. In the study of Yau et al,[18] older vehicles were involved with a higher proportion of fatal and serious-injury. The likelihood of fatalities and severity injury is estimated to rise with the number of trailers, but fall with the truck length and gross vehicle weight rating.[9] Traffic crashes occurring on rural ways induce more severe injuries than those in urban areas, especially when trucks involved.[19] Higher speed limits increase the likelihood of severe injuries and fatalities.[9,20] Wet roadway surface is observed to decrease crash severity.[21] Higher friction coefficient of road ways result in reduced frequency of crashes during the morning peak hours.[22] A higher proportion of fatal or severe injuries occur with dark but light conditions, and during midnight.[16,18]

Intuitively, one would expect that the likelihood of rear-end crashes are high, but associated studies show that rear-end crashes appear to be the less severe of all crash types observed.[7,10,11,23,24] Within China, there are limited studies focusing on this crash type, and few research work concerning contributing factors involved in accidents, especially for the rear-end crashes involving trucks as the ahead vehicles. Therefore, the aim of the paper is to analyze the significant factors related to occupant injury severity in the specific rear-end crashes of truck as the FV in Beijing. Comparatively speaking, when these rear-end crashes happen, the occupants in the rear vehicle (RV) will suffer more serious injury, who are the concerned objects in this paper.

Materials and methods

The crash samples were from the real-world crash cases analyzed by the Crash Reconstruction Lab of Tsinghua University for the Bureau of Beijing Traffic Security Administration. From 2011 to 2013, 100 rear-end crashes involving trucks as the FV were investigated with required and detailed information. Each rear-end crash involves two vehicles, a FV, which in our study was fixed to be a truck, and a RV of any type. In the 100 cases, there were totally 57 fatal crashes, which included 32 cases with drivers' fatalities. Each sample included basic information of driver, vehicle and incident from police records, and some in-depth data from the researchers' vehicle inspection after crash.

The study utilized two different datasets. In the first dataset, a binary logistic model was used to identify the corresponding driver, vehicle, and environmental factors that contributed to the likelihood to be fatal or non-fatal for a rear-end crash that involved a truck from a three-year perspective. A crash was classified as fatal if it involved at least one fatally injured occupant, while it was classified as non-fatal if there were no fatally injured occupants. Therefore, in the first dataset each row corresponded to a crash case. The first dataset consisted of 100 rear-end crashes.

The second dataset included information about the driver of the RV. A multinomial logistic model was used to predict the likelihood of fatal, severe injury or no injury for the driver in the RV in a rear-end crash. Therefore, each row in the second dataset corresponded to a RV driver (100 drivers). Table 1 illustrates the list of crash related variables. Regarding the crash position of RV, offset crash means not full impact, e.g. only left-front part or right-front part of RV involved in the crash (Fig. 1).

All the corresponding equations of the binary and the multinomial logit models can be found in Washington et al's study.[25] To obtain a better understanding of marginal effects of the variables related to severely injured occupant, elasticities were calculated.[3] In general, the direct elasticity is defined as

$$E_{x_n}^{\Pr_n(i)} = \frac{\partial \Pr_n(i)}{\partial x_n} \cdot \frac{x_n}{\Pr_n(i)},$$

Table 1
List of crash-related variables.

Variables	Categories
Time	
Time of day	Day (7:00–19:00); Night (19:00–7:00)
Day of week	Weekdays; Weekend
Rear vehicle	
Vehicle type	Commercial vehicle; Passenger car
Weight (weight ratio of two involved vehicles)	FV/RV<5; FV/RV>5
Crash position	Offset crash; Full crash
Front vehicle	
Vehicle type	Light truck (<6 t); Medium-duty truck (6–12 t); Heavy-duty truck (>12 t)
Driver of rear vehicle	
Residence	Beijing; Non-Beijing
Gender	Male; Female
Age (years)	18–25; 26–30; 31–35; 36–40; 41–45; 46–50; 51–55
Speeding	Speeding; Not speeding
Alcohol consumption (mg/100 ml)	Low (>20) or high (>80)
Braking action	Brake before crash; Brake after crash; No braking
Injury severity	Fatal; Nonfatal injury; Not injury
Environment	
Weather	Good (clear); Adverse (cloudy, rainy, snowy, foggy, etc)
Visibility	Good; Bad
Area	Urban; Suburban
Road	
Road surface	Dry asphalt, Wet asphalt
Speed limit (km/h)	50; 60; 70; 80; 90; 100; 110; 120
Lane type	Straight; Intersection/crossing/exit/entrance
Road type	Express way; Highway; Others
Number of lanes	1; 2; 3; 4; 5

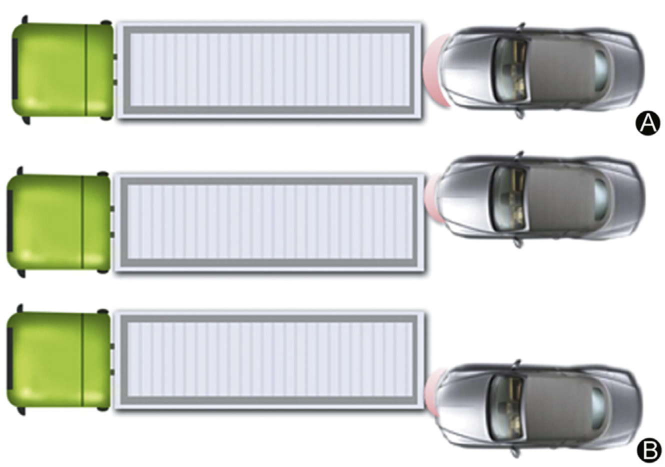

Fig. 1. Crash types between vehicles. A: Full crash; B: Offset crash.

where *E* represents the direct elasticity, $Pr_n(i)$ is the probability of vehicle n having severity category i, and x_n is the variable being considered to have impacts on crash severity i.

Results

Descriptive statistics

The time of crash was observed over a 24 h period in a day (Fig. 2), with the proportion of night time (19:00 to 7:00) encompassing about 72% of total. The peak periods appeared in the range from 4:00 to 5:00, which represented the possibility of driver's fatigue and sleepiness. Fig. 2 also illustrates occupants' injury severity by time. There was one peak for fatalities from 4:00 to 5:00 at dawn. Thus it can be seen that the night time was the crash prone period of the serious rear-end crashes with high injury severity. On the other hand, the least crashes occurred during the morning time (7:00 to 8:00), afternoon time (13:00 to 14:00) and evening time (20:00 to 21:00). The results were consistent with the overall characteristics of traffic crashes in China.[1]

The proportion of sunny days in the crashes observed was 81%, and 19% for non-sunny days (cloudy, rainy and foggy day). Thus adverse weather did not appear to be a prominent influence factor for crash occurrence. The frequency of vehicle occupants recorded in all RVs involved in crashes showed that 36% of all crashes occurred when the vehicle had no passenger and 46% RVs had two occupants. A very small number of cases ($n = 5$) has more than 5 occupants. Fig. 3 shows the injury severity of all the RVs' occupants classified by age. Two remarkable high peaks of age 21–25 and age 31–35 appeared for the fatalities and injured respectively, which basically accorded with the situations of traffic crashes in China.

Some information of RV drivers was examined. Of the total, 22 drivers resided in Beijing and the rest 78 drivers came from other 14 provinces of China; 3% of drivers had alcohol records. According to the analysis of trace information on the crash scene, about 40% of drivers adopted braking measures before collisions.

Table 2 shows the occupant injury severity of RV drivers by gender, including 88 drivers' casualties (88%). And males exceeded females significantly in total. Fig. 4 shows these drivers' injury severity by age, indicating that the age groups of 31–35 and 18–25 had the most quantity and the group of 18–25 had the highest fatality rate.

Table 2
Injury severity of RV drivers.

Gender	Fatal	Non-fatal injured	Not injured	Total
Male	31	56	10	97
Female	1	1	1	3
Total	32	57	12	100

The types of RVs included 53% commercial vehicles and 47% passenger vehicles. In the 100 rear-end crashes, 100 RVs contained 175 passengers. Of these occupants, 35 were fatally injured, including 18 males, 13 females and 2 passengers without gender records. In addition, there was no data record on most injured occupants' gender, so further analysis cannot be performed. Fig. 5 shows injury severity of rear drivers by FV type involved in crashes, indicating that the heavy-duty truck had the most quantity and the highest fatality rate at the same time.

Fig. 6 shows the speed limit in roads, in which the most frequency was 80 km/h (31%) and 75% cases had over 70 km/h speed limit. Obviously, the high speeding limit increased the injury severity of the crashes. According to the distribution of RVs' speeds in 100 rear-end crash cases, the maximum calculated speed was over 140 km/h, at least 42% speed was over 60 km/h, and at least 15% speed was over 80 km/h. Here, the data of vehicle speed were estimated by the basic crash reconstruction methods, containing the theorem of kinetic energy and the law of energy conservation.

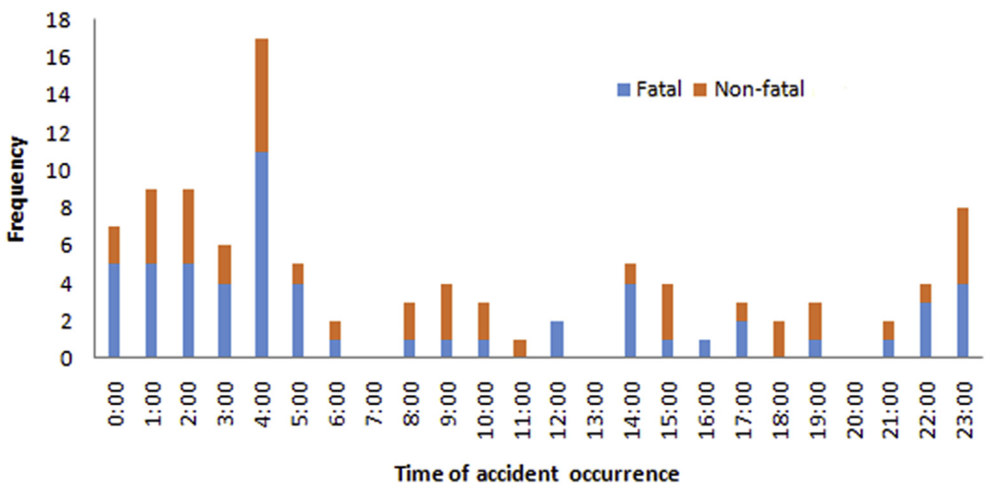

Fig. 2. Occupants' injury severity by time.

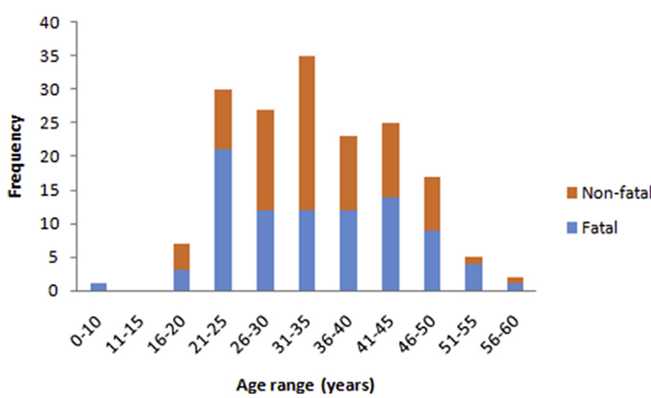

Fig. 3. Occupants' injury severity by age.

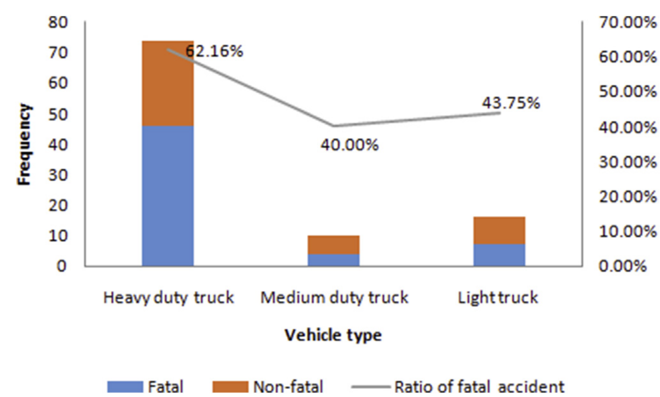

Fig. 5. Injury severities by types of front vehicles.

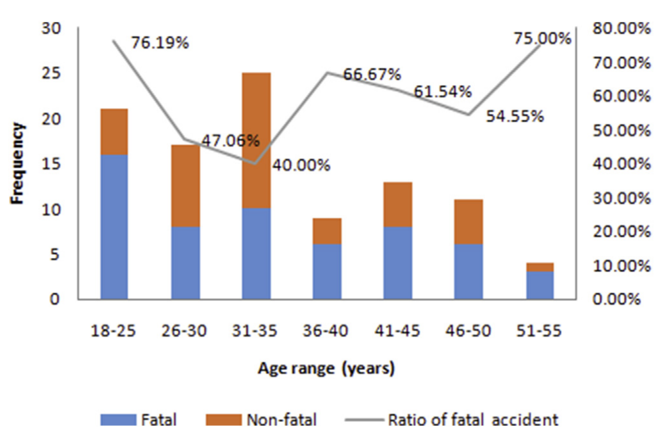

Fig. 4. Age vs. severity of RV drivers.

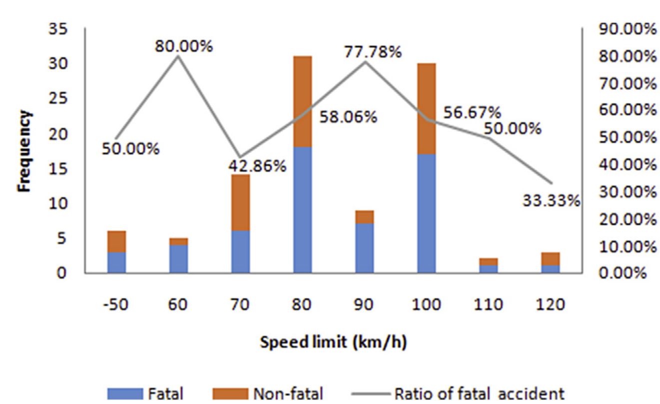

Fig. 6. Speed limits on roads.

Considering the RVs' impact positions, 60% crashes occurred in the full frontal parts and 40% occurred in the offset parts. It was very clear that full frontal collisions led to most casualties of drivers and passengers. The proportion of the damage of engine, front wheel, front door and cab were close to that of fatalities. The data scope of effective plastic deformation of RVs was 0.1–1.7 m and the mean was 0.58 m. The deformation depth of vehicles had the data scope of 0.1–2.2 m and the mean of 0.8 m.

In addition, after a collision between vehicles, 2% vehicles caught fire and 2% vehicles fell into the river or pool; 2% vehicles experienced more than two times of collisions with fixed objects on roads. In terms of road type, 41% of crashes occurred on express ways; 30% took place in ring roads; 28% happened in other suburban roads; 100% of road surface was asphalt. In 100 crashes, 95% were dry road surface, and only 5% road surface were in wet condition when the crashes occurred. As for the line type of road, 87% were straight, and others were 9% crossing and 4% were at exit or entrance of the expressways. Besides, three or more lanes of road in one direction increased the probabilities of injury in crashes.

Based on the data above, a descriptive statistics can be summarized as Table 3. Meanwhile, chi-square tests were performed on individual pairs to evaluate the potential influence of typical variables on crash severity. Results showed that a significantly larger proportion of nonfatal and fatal crashes were related to traveling at night, the age of RV's driver, weight different between FV and RV, FV type and road line type. However, other variables, such as vehicle type, road type and residence of rear driver were under-represented in fatal and nonfatal crashes.

Binary logistic model on occupant injury severity

A binary logistic model was used to predict the likelihood that a rear-end crash was fatal or non-fatal. The resulting regression model is presented in Table 4, which shows that younger drivers (<26 years old) increase the likelihood of a rear-end crash being fatal by 4.1 fold. And weight difference, visibility and lane number also significantly increase the likelihood for severe injury of rear-end crash. In terms of vehicle type and road line type, compared with commercial vehicle and straight road, passenger vehicle and crossing/entrance reduce the likelihood of a fatal crash. No other explanatory variables are observed as remarkable.

Multinomial logistic model on the severity of RV drivers

A multinomial logistic model was used to predict the likelihood of RV drivers of rear-end crashes being fatal, injured or not injured (Table 5), and the change in probability when each factor was altered from one to zero was calculated (Table 6), which was called the average direct pseudo-elasticity of the possibility. The results showed that night time and drivers from other provinces increased the possibility of driver's fatal injury by 40.77% and 198.73%, respectively. And young drivers (<26 years old) had on average a 55.35% decrease in probability of fatal injury, whereas a 41.67% increase in probability of injury. As for the type of RV, passenger vehicle was more likely to be involved in fatal injury, the possibility of which increased on average by 95.56% of driver's fatal injury. When in a collision with a heavy-duty truck, rear driver was more likely to suffer injury, for the average direct pseudo-elasticity was 79.45%. Compared with the weekend, a crash on the weekday had on average a 145.16% increase in possibility of fatal injury.

Discussion

This study examined 100 rear-end crashes involving trucks as the FV in Beijing from 2011 to 2013. In summary, the proportion of night time crashes accounted for 72% and the crash number as well as fatalities peaked at the time period of 4:00 to 5:00, which represented the possibility of driver's fatigue or sleepiness. Thus it can be seen that the night time is a crash prone period of the serious rear-end crashes with high severity casualties. The result is similar to some former research conclusions on the commercial vehicle crash.[6,10]

For the drivers in RVs, the age groups of 31–35 and 18–25 have the most quantity and the group of 18–25 has the highest fatality rate, which basically accord with the situations of traffic crashes and the features of drivers in China.

Considering the types of vehicles, RVs include 53% commercial vehicles and 47% passenger vehicles. When impacting heavy-duty truck as the most quantity of FVs, the RVs have the highest fatality rate, which resembles some previous findings on the large truck crash.[9]

As to the speed limit in roads, the most frequency is 80 km/h (31%). The high speeding limit increases the injury severity of crashes, which is close to the former research results.[3] According to the distribution of RV speed in 100 rear-end crash cases, the maximum calculated speed was over 140 km/h, and at least 42% speed was over 60 km/h. In relation to the RVs' impact positions, 60% crashes occurred in the full frontal parts of RVs and 40% occurred in the offset parts. It is very clear that frontal collisions lead to most casualties of drivers and passengers. Therefore, for preventing the crashes and reducing the injuries of RVs, it is very

Table 3
List of main variables related to crash severity.

Variables	Categories	Fatal (%)	Non-fatal (%)	X^2	*p* value
Time of day	Night (19:00–7:00)	44	28	1.77	0.18
Residence	Other province/city	43	35	0.50	Ns
Drivers' age	Younger driver (<26 years)	16	5	4.00	0.04
Speed limit	>80 km/h	44	31	0.30	Ns
Crash area	Suburban	37	29	0.07	Ns
Crash position	Full frontal	35	26	0.01	Ns
Rear vehicle type	Passenger vehicle	27	20	0.01	Ns
Front vehicle type	Heavy duty truck	46	28	3.10	0.08
Weight difference	>5 ratio	31	17	2.17	0.14
Weather	Bad weather	13	6	1.25	Ns
Visibility	Bad visibility	22	12	1.25	Ns
Road line	Crossing/entrance	4	8	3.12	0.08
Road surface	Wet	4	1	1.36	Ns
Road type	Express way	22	19	0.32	Ns
Day of week	Weekday	43	33	0.02	Ns
Lanes in the same direction	≥3 lanes	31	19	1.01	Ns

Note: Ns = not significant.

Table 4
Parameter estimates for likelihood of more severe injury ($n = 100$).

Variable	Estimate	*SE*	*z* value	*p* value	*OR*	*95% CI*
Intercept	−0.53	1.04	−0.51	0.61	0.59	(−2.64, 1.50)
Night (19:00–7:00)	0.03	0.56	0.05	0.96	1.03	(−1.09, 1.14)
Other province/city	−0.06	0.64	−0.09	0.93	0.94	(−1.35, 1.20)
Younger driver (<26 years)	1.41	0.66	2.15	0.03	4.09	(0.19, 2.80)
>80 km/h	0.84	0.58	1.45	0.15	2.32	(−0.28, 2.02)
Suburban	−0.11	0.56	−0.20	0.85	0.90	(−1.22, 0.99)
Full frontal	0.11	0.49	0.22	0.82	1.12	(−0.86, 1.08)
Passenger vehicle	−0.62	0.60	−1.03	0.30	0.54	(−1.87, 0.53)
>5 ratio W.D.	1.13	0.61	1.86	0.06	3.08	(−0.03, 2.37)
Bad weather	0.13	0.70	0.18	0.86	1.14	(−1.24, 1.56)
Bad visibility	1.08	0.64	1.69	0.09	2.94	(−0.14, 2.38)
Crossing/entrance	−1.21	0.76	−1.61	0.11	0.30	(−2.79, 0.22)
Wet surface	1.99	1.32	1.51	0.13	7.31	(−0.33, 5.23)
≥3 lanes	−1.11	0.57	−1.94	0.05	0.33	(−2.27, −0.02)
Weekday	−0.14	0.54	−0.26	0.79	0.87	(−1.23, 0.92)

Note: SE = standard error; OR = odds ratio; CI = confidence interval. Null deviance = 136.66; residual deviance = 119.06; Akaike information criterion = 149.06.

Table 5
Parameter estimates for likelihood of more severe injury of rear drivers.

Variable	Fatal/Not injured						Injured/Not injured					
	Estimate	*SE*	*t* value	*p* value	*OR*	*95% CI*	Estimate	*SE*	*t* value	*p* value	*OR*	*95% CI*
Intercept	−5.25	2.113	−2.49	0.005	–	–	−1.98	1.654	−1.2	0.11	–	–
Night (19:00–7:00)	−0.06	1.294	−0.04	0.48	0.94	(0.07, 11.91)	0.34	1.177	0.29	0.39	1.40	(0.14, 14.04)
Other province/city	0.25	1.159	0.22	0.42	1.28	(0.13, 12.44)	1.53	1.060	1.44	0.07	4.62	(0.58, 36.91)
Younger driver (<26 years)	1.60	1.439	1.11	0.14	4.95	(0.30, 83.02)	0.44	1.352	0.33	0.37	1.56	(0.11, 22.09)
>80 km/h	0.80	1.213	0.66	0.25	2.23	(0.21, 24.00)	−0.90	1.094	−0.83	0.21	0.41	(0.05, 3.46)
Suburban	−0.04	1.199	−0.04	0.49	0.96	(0.09, 10.02)	−0.34	1.148	−0.30	0.38	0.71	(0.07, 6.73)
Full frontal	1.94	1.174	1.65	0.05	6.94	(0.70, 69.3)	1.25	1.069	1.17	0.12	3.49	(0.43, 28.55)
Passenger vehicle	0.81	1.416	0.58	0.28	2.26	(0.14, 36.22)	1.62	1.148	1.26	0.11	5.08	(0.41, 63.88)
Heavy-duty truck	1.53	1.225	1.25	0.11	4.64	(0.42, 51.15)	−0.95	1.069	−0.95	0.17	0.39	(0.06, 2.73)
>5 ratio W.D.	2.11	1.427	1.48	0.07	8.24	(0.50, 135.07)	1.23	1.288	0.96	0.17	3.44	(0.28, 42.92)
Bad weather	0.69	1.774	0.39	0.35	2.00	(0.06, 64.76)	0.21	1.732	0.12	0.45	1.23	(0.04, 36.66)
Bad visibility	1.40	1.339	1.05	0.29	4.07	(0.30, 56.11)	1.27	1.232	1.03	0.15	3.57	(0.32, 39.99)
Crossing/entrance	0.58	1.556	0.37	0.35	1.78	(0.08, 37.63)	0.51	1.371	0.37	0.36	1.66	(0.11, 24.42)
Wet surface	0.33	1.829	0.19	0.43	1.40	(0.04, 50.55)	−1.80	1.931	−0.93	0.18	0.17	(0, 7.32)
Express way	−0.46	1.170	−0.39	0.35	0.63	(0.06, 6.26)	0.35	1.048	0.33	0.37	1.42	(0.18, 11.05)
Weekday	0.99	1.147	0.86	0.30	2.70	(0.28, 25.53)	2.09	1.066	1.96	0.03	8.10	(1.00, 65.37)
≥3 lanes	1.93	1.209	1.60	0.06	6.92	(0.65, 73.99)	0.66	1.156	0.57	0.29	1.94	(0.20, 18.70)

Note: SE = standard error; OR = odds ratio; CI = confidence interval; "–" = not applicable. Number of observations = 100; residual deviance = 134.0663; Akaike information criterion = 202.0663.

Table 6
Average direct pseudo-elasticity of variables for all outcomes in the injury severity model of rear drivers.

Variable	Elasticity (%)		
	Not injured	Injured	Fatal
Night (19:00–7:00)	0.65	−4.99	40.77
Other province/city	−35.36	−17.07	198.73
Younger driver (<26 years)	−71.38	41.67	−55.35
>80 km/h	−37.33	39.71	−74.61
Suburban	11.75	6.89	−20.73
Full frontal	−82.90	18.73	−40.40
Passenger vehicle	−61.47	−12.99	95.56
Heavy-duty truck	−61.28	79.45	−84.99
>5 ratio W.D	−84.70	26.11	−47.43
Bad weather	−44.45	11.11	−31.65
Bad visibility	−74.73	2.86	−9.69
Crossing/entrance	−43.05	1.54	−5.27
Wet surface	6.15	48.92	−82.37
Express way	32.52	−16.31	87.78
Weekday	−69.71	−18.34	145.16
≥3 lanes	−78.91	45.94	−59.11

urgent to increase the installation of efficient safety systems and driver assistance systems in vehicles, and the speed limit of road should be considered to adjust correspondingly.

In terms of road type, 41% crashes occurred in express way roads; 30% took place in ring roads and 28% happened in other suburban roads. In terms of the line type of road, 87% were straight, and others were crossing and at exit or entrance of express way. Three or more lanes in one direction increased the probabilities of injury in crashes, alike to the result of some recent analysis.[11] Thus it is momentous to consider the collision avoidance in the express way and ring road of the city.

Moreover, chi-square tests were applied to evaluate the potential influence of typical variables on crash severity. Results indicated that time of day (traveling at night or day), age of RV's driver (<26 years or>25 years), weight ratio between front and RV (<5 or>5), FV type (Heavy duty truck or not) and road line type (straight or crossing/entrance) were significant related to nonfatal and fatal crashes. The binary logistic model showed that drivers' age increased the overall crash severity by more than four fold in accord with the relevant research findings in US.[24] And weight difference between two vehicles, visibility condition and lane number of road also significantly increased the likelihood for severe injury of rear-end crash.

A multinomial logistic model and the average direct pseudo-elasticity of variables showed that night time, drivers from other provinces, and passenger vehicles significantly increased the likelihood of rear drivers being fatal. Furthermore, younger drivers (<26 years) and collision with a heavy-duty truck had a higher likelihood of RV driver's injury. In addition, crashes occurring on weekdays were associated with an increase likelihood of the RV drivers being fatal. Crashes happening at wet road surface even reduced the likelihood of RV drivers being fatal, in accordance with a previous research finding.[10,21]

All these remarkable factors mentioned above should be concerned to improve, such as the conditions of lighting and the layout of lanes on roads. Two of the most common driver factors in rear-end crashes are drivers' age and drivers' original residence. Young drivers and outsiders have higher casualty. Therefore, it is very imperative to increase the safety education and relevant guidance to the young drivers, especially for novice drivers. And it is also crucial to enhance the management on the drivers who steer heavy duty truck from other cities to Beijing on weekdays.

In summary, this paper showed that there are many factors that contribute to rear-end crashes with trucks in Beijing, China. Typical variables are explored and linked with the severity of traffic crashes. It is hoped that the current findings contribute to our understanding of the main factors involved in crashes and provide guidance for the research of traffic safety. In the long term, more in-depth data in China will be collected and more useful analysis could be carried out.

Fund

This work was supported by the Open Project of Key Laboratory of Ministry of Public Security for Road Traffic Safety (2016ZDSYSKFKT10), China and partly supported by Science Foundation of China under grant No. 51675295.

Acknowledgements

The authors gratefully acknowledge Professor Linda Ng Boyle at University of Washington for her insightful comments on the manuscript. And the authors also acknowledge Beijing Traffic Management Bureau, which provided the crash data for the study.

References

1. Traffic Management Bureau of the Ministry of Public Security of China. *Annual Statistical Report of China Road Traffic Collisions (2012), Beijing.* 2013.
2. Chen C, Zhang G, Yang J, et al. An explanatory analysis of driver injury severity in rear-end crashes using a decision table/Naïve Bayes (DTNB) hybrid classifier. *Accid Anal Prev*. 2016;90:95–107. http://dx.doi.org/10.1016/j.aap.2016.02.002.
3. Chang LY, Mannering F. Analysis of injury severity and vehicle occupancy in truck- and non-truck-involved accidents. *Accid Anal Prev*. 1999;31:579–592. http://dx.doi.org/10.1016/S0001-4575(99)00014-7.
4. Peng Y, Boyle L. Commercial driver factors in run-off-road crashes. *Transp Res Rec J Transp Res Board*. 2012;2281:128–132. http://dx.doi.org/10.3141/2281-16.
5. Khattak AJ, Schneider RJ, Targa F. Risk factors in large truck rollovers and injury severity: analysis of single-vehicle collisions. In: *Presented at 82nd Annual Meeting of the Transportation Research Board. Washington, D.C*; 2003. TRB Paper 03–2331 http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.463.4047.
6. Bunn TL, Slavova S, Struttmann TW, et al. Sleepiness/fatigue and distraction/inattention as factors for fatal versus nonfatal commercial motor vehicle driver injuries. *Accid Anal Prev*. 2005;37:862–869. http://dx.doi.org/10.1016/j.aap.2005.04.004.
7. Eluru N, Bhat CR. A joint econometric analysis of seat belt use and crash-related injury severity. *Accid Anal Prev*. 2007;39:1037–1049. http://dx.doi.org/10.1016/j.aap.2007.02.001.
8. Summala H, Mikkola T. Fatal accidents among car and truck drivers: effects of fatigue, age, and alcohol consumption. *Hum Factors*. 1994;36:315–326.
9. Lemp JD, Kockelman KM, Avinash U. Analysis of large truck crash severity using heteroskedastic ordered probit models. *Accid Anal Prev*. 2011;43:370–380. http://dx.doi.org/10.1016/j.aap.2010.09.006.
10. Zhu X, Srinivasan S. A comprehensive analysis of factors influencing the injury severity of large-truck crashes. *Accid Anal Prev*. 2011;43:49–57. http://dx.doi.org/10.1016/j.aap.2010.07.007.
11. Islam S, Jones SL, Dye D. Comprehensive analysis of single- and multi-vehicle large truck at-fault crashes on rural and urban roadways in Alabama. *Accid Anal Prev*. 2014;67:148–158. http://dx.doi.org/10.1016/j.aap.2014.02.014.
12. Shankar V, Mannering F, Barfield W. Statistical analysis of accident severity on rural freeways. *Accid Anal Prev*. 1996;28:391–401. http://dx.doi.org/10.1016/0001-4575(96)00009-7.
13. Ulfarsson GF, Mannering FL. Differences in male and female injury severities in sport-utility vehicle, minivan, pickup and passenger car accidents. *Accid Anal Prev*. 2004;36:135–147. http://dx.doi.org/10.1016/S0001-4575(02)00135-5.
14. Padmanaban J, Moffatt EA, Marth DR. *Factors influencing the likelihood of fatality and serious/fatal injury in single-vehicle rollover crashes*. SAE Technical Paper 2005-01-0944. 2005. http://dx.doi.org/10.4271/2005-01-0944.
15. Newgard CD. Defining the "older" crash victim: the relationship between age and serious injury in motor vehicle crashes. *Accid Anal Prev*. 2008;40:1498–1505. http://dx.doi.org/10.1016/j.aap.2008.03.010.
16. Abdel-Aty M. Analysis of driver injury severity levels at multiple locations using ordered probit models. *J Saf Res*. 2003;34:597–603. http://dx.doi.org/10.1016/j.jsr.2003.05.009.
17. Yau KK. Risk factors affecting the severity of single vehicle traffic accidents in Hong Kong. *Accid Anal Prev*. 2004;36:333–340. http://dx.doi.org/10.1016/S0001-4575(03)00012-5.
18. Yau KK, Lo HP, Fung SH. Multiple-vehicle traffic accidents in Hong Kong. *Accid Anal Prev*. 2006;38:1157–1161. http://dx.doi.org/10.1016/j.aap.2006.05.002.
19. Chen C, Zhang G, Tian Z, et al. Hierarchical Bayesian random intercept model-based cross-level interaction decomposition for truck driver injury severity investigations. *Accid Anal Prev*. 2015;85:186–198. http://dx.doi.org/10.1016/j.aap.2015.09.005.
20. Lee J, Mannering F. Impact of roadside features on the frequency and severity of run-off-roadway accidents: an empirical analysis. *Accid Anal Prev*. 2002;34:149–161. http://dx.doi.org/10.1016/S0001-4575(01)00009-4.
21. Nassar SA, Saccomannaon FF, Shortreed JH. Road accident severity analysis: a micro level approach. *Can J Civ Eng*. 2011;21:847–855. http://dx.doi.org/10.1139/l94-090.
22. Das A, Abdel-Aty M. A combined frequency–severity approach for the analysis of rear-end crashes on urban arterials. *Saf Sci*. 2011;49:1156–1163. http://dx.doi.org/10.1016/j.ssci.2011.03.007.
23. Qin X, Wang K, Cutler CE. Analysis of crash severity based on vehicle damage and occupant injuries. *Transp Res Rec J Transp Res Board*. 2013;2386:95–102. http://dx.doi.org/10.3141/2386-11.
24. Donmez B, Liu Z. Associations of distraction involvement and age with driver injury severities. *J Saf Res*. 2015;52:23–28. http://dx.doi.org/10.1016/j.jsr.2014.12.001.
25. Washington S, Karlaftis M, Mannering F. *Statistical and Econometric Methods for Transportation Data Analysis*. New York: Chapman & Hall/CRC; 2003. http://dx.doi.org/10.1057/palgrave.mel.9100102.