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An investigation on fatality of drivers in vehicle-fixed object accidents using multinomial logistic regression model

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Abstracts:

Background: As the development of expressway construction speeds up in recent years in China, appeared many accidents between vehicle and object on expressways. This study investigated the factors influencing fatality of drivers in vehicle-fixed object accidents on expressways in Chang-Zhu-Tan district of Hunan Province in China by developing multinomial logistic regression models of fatality for drivers.

Objective: The objective of this paper is to provide deeper insight into significant factors that affect fatality of drivers involving fixed objects.

Method and materials: For this purpose, 121 crashes involving fixed objects from 2011-2017 were included in the modeling process. Firstly, descriptive statistical analysis were made to understand the main characteristics of the vehicle-fixed object crashes. Then 18 explanatory variables were selected and correlation analysis of all the independent variables were conducted to decide the variables to be concluded. Finally, five multinomial logistic regression models with different independent variables were compared, and the model with best fitness was chosen as the final model.

Results: The results showed that the turning direction in avoiding fixed objects can raise the death possibility of drivers. Drivers are inclined to death when they met a bad weather on the expressway. And drivers with less driving experience were found to (<10 years) be easier to die in the accidents. Also, fatigue or distraction of drivers is a significant factor attributing fatality of drivers.

Conclusion: Findings from this research provided an insight into the prevention of fatality for drivers and development of active protection system for vehicle-fixed object accidents. Suggestions for preventing vehicle-fixed object crashes were put forward.

Key words: fatality of drivers, fixed object, expressway, contributing factors, collision avoidance action

1. Introduction

As the development of expressway construction speeds up in recent years in China, appeared many accidents between vehicle and object on expressways. According to the report of the transportation bureau of Ministry of Public Security, nearly one third of the fatal accidents were vehicle-fixed object accidents. Also in the United States, the percentage of accidents between vehicle and fixed objects or accidents without collision is 19%. However, 44% of all fatal accidents were caused by them.[1] Vehicle-fixed object accidents can bring enormous casualties and property losses of society. Therefore, deep investigations of characteristics of accidents and factors affecting fatality or injury severity of occupants were needed to give some insight on reducing the accident severity.

Many researchers focused on a variety of characteristics of vehicle collisions with all kinds of fixed objects. Boufous et al. compared trends, circumstances and outcomes of single- versus multi-vehicle bicycle on-road crashes.[2] Lori et al. investigated the object characteristics, the vehicle characteristics and the occupant characteristics of side-impact accidents with fixed roadside objects using the FARS and the NASS data bases. The guardrail ends were found to cause more serious injuries than midsections and young drivers are more susceptible of collisions at night.[3] J. L. GATTIS et al. explained that turned-down guardrail ends cause more serious injuries for they are easier to cause vehicle rolling and vaulting than exposed ends by studying the reports of guardrail-end accidents on highways.[4] The similar conclusion was drawn by Wlliam et al.[5] The driver has a higher risks of serious injury when the vehicle hits the blunt and turn down end treatment than a barrier length of need. Bryden and Fortuniewicz concluded that, in terms of injury severity, vehicle containment and secondary collisions, traffic barriers perform better for midsize passenger automobiles than for vans and light trucks.[6] M. H. Ray et al. found that occupants are rarely injured severely in a collision with a longitudinal barrier that smoothly redirects the vehicle.[7, 8] Most severe accidents and injuries are due to the second collision which is more critical than the first collision with longitudinal barrier, rather than poor quality of barriers. According to analyzes of the data base of secondary collision established by Hunter et al., factors including vehicle redirection velocity, redirection angle, damage condition and stability of the vehicle all have effects on the redirection path of the vehicle.[7] Some run-off-roadway accident studies have examined particular roadside features and their effect on the frequency and severity of accidents. Jinsun et al. showed that avoiding cut side slopes, shorter distance from outside shoulder edge to guardrail, less isolated trees along roadway sections and longer distance from outside shoulder edge to light poles can effectively reduce the run-off-roadway accident frequencies.[9] Sunanda et al. identified the factors influencing severity of injury to older drivers in passenger car collision with fixed object. Factors like travel speed, restraint device usage, use of alcoholic and drugs are responsible for making a different injury severity between old drivers.[10] Other characteristics like road conditions and vehicle conditions were considered in analysis of the injury severity of drivers and occupants.[11-14]

Researchers have used a wide range of methodological tools to assess the impact of factors including vehicle, roadway and human on injury severity data. Ordered probit model was used to identify specific characteristics greatly influencing injury severity in several studies.[15-18] Also logistic regression models were used to assess the influence of gender and age on injury severity in head-on collisions in rural highways[19] and were used to estimate the effect of changing vehicle factors to reduce mortality.[20] Considering the heterogeneous effects of age and gender, a mixed logit model for driver injury severity was developed by Joon-Ki Kim et al.[21] Logit and ordered probit/logit models have their own model assumptions and predefined underlying relationships between dependent and independent variables, while the classification and regression tree don’t need to meet those conditions. Li-Yen Chang et al. used a CART model to establish the relationship between injury severity and characteristics of drivers, vehicles and environment.[22] Besides, quadratic regression models are also used to assess the factors attributing to severity of head injury.[23] Artificial neural networks[24, 25] were used far less than ordered logit and ordered probit model, while the frequencies of multinomial logistic regression model[26-30] and Nested logit model[31-33] being used in studies are very close.

In most of the former researches, only some characteristics of vehicle-fixed object accidents like type of the guardrails, condition of the road were investigated. However, the impact avoidance actions taken by drivers were not included, which may cause a big difference to the fatality of drivers. Besides, many researches only study the correlation between factors and fatality of drivers using a typical regression model without considering whether the collinearity between explanatory variables can cause some inaccuracy to the modeling results.

The present paper intends to investigate the factors significantly influencing the fatality of drivers in vehicle-fixed object accidents on the expressway. A total of 121 vehicle-fixed object accidents provided by police office from 2011-2017 were accepted and sorted out. The descriptive statistical analysis were made to investigate the characteristics of the accidents. Besides, correlation analysis of 18 explanatory variables were conducted and five multinomial logistic regression models were established and compared to find the model with the best fitness of the real accidents. A single logistic model was also adopted to study the relationship between vehicle speeds and the fatality rate of drivers. This study provide some insight on casualty prevention in vehicle-fixed object accidents.

2. Data and Methods

2.1 The dataset

For the model building process in this study, the vehicle-fixed object accident data were selected from the traffic accident database established by the traffic police department of Hunan province of China. Once there is an accident happened on the expressway, the detailed information about the road environment, the characteristic of drivers and passengers including injury severity of them, and the vehicle condition will be recorded and saved in the traffic accident database. All the crash related variables are recorded in materials covering accident file, person file and inquiry record. Accident file contains the general crash characteristics describing the environmental and roadway conditions at the time of the crash. Person file consists of driver file, passenger file and other related person file. Apart from information about drivers like age and sex, the accident assertion and some vehicle information are also include in the driver file.

The accident data used in this study are limited on expressways in districts of Changsha, Zhuzhou and Xiangtan, the three major city in Hunan province, from 2011 to 2017. Since it was required to consider the factors only associated with vehicle-fixed object accidents, single vehicle crashes in the database were searched and accidents between vehicle and non-fixed object were rejected. Also accidents like vehicle sliding and turning over itself without impact with any object are excluded from the selected data. Finally, a total of 120 vehicle-fixed object accidents were selected. The response variable, injury severity of driver, is coded as: no injury, injury and fatal, while the explanatory variables were defined and categorized in Table 1. Apart from the variables directly related to crashes, variables considered to be related to the accidents were selected out. The explanatory variables were divided into four large categories covering driver-related, vehicle related, roadway-related and environment-related. All of the independent variables were set as 0 or 1 except the travel speed. In all of the cases, the medium value of the speed interval estimated by a professional traffic accident expertise organization was set as the actual vehicle speed at the time of collision with fixed object. And some other explanatory variables including Second Impact (SI), Emergency Turning Only (ET) and Emergency Turning with Emergency Breaking (ETEB) were all carefully extracted from the inquiry record file of participants and witnesses. Especially, the different impact circumstances of vehicle and fixed object were illustrated in Figure 1. Picture a shows the scratch caused by side impact between central barrier and vehicle. Picture b and c represents the truck turning over after impacting with central concrete barrier.

Table 1 List of the selected explanatory variables for the first time

Category	Variable	Description
Driver-related	FOD	Fatigue or Distracted (1 if true;0 otherwise)
	BREAK	Breaking (1 if true; 0 otherwise)
	TURN	Turning (1 if true; 0 otherwise)
	FP	Having a front passenger(1 if true; 0 otherwise)
	DAGE	Driver age (1 if over 55; 0 otherwise)
	DSEX	Driver sex (1 if male; 0 otherwise)
	DYEAR	Driving year (1 if over 10; 0 otherwise)
Roadway-related	DRY	Dry road (1 if true; 0 otherwise)
	SDRCT	Impacting Fixed object in same direction (1 if true; 0 otherwise)
Vehicle-related	ROFF	Running off the road (1 if true; 0 otherwise)
	ROLL	Rolling or turning over (1 if true; 0 otherwise)
	SIMP	Vehicle having second impact(1 if true; 0 otherwise)
	VCON	Vehicle condition (1 if bad; 0 otherwise)
	ABU	Air bag unfold (1 if true; 0 otherwise)
	FRONT	Front impact point (1 if true; 0 otherwise)
Environment-related	SEAS	Season (1 if spring; 2 if summer; 3 if autumn; 4 if winter)
	DAY	The rash happening during day (1 if true, 0 otherwise)
	WEAT	Fine (1 if it’s sunny; 0 otherwise)

a b c

Figure 1 The scene of a vehicle-fixed object accident

2.2 Multinomial logistic regression modeling

The purpose of the model development was to identify the expressway, environment, vehicle and driver related characteristics that are more likely to cause severe injury for drivers involved in vehicle-fixed object accidents. Also as the explanatory variables except Vehicle Velocity in table 1 are all categorical variables rather than continuous numerical variables, logistic regression model is more suitable than linear regression model here in this study. Logistic regression model was widely used in study of relationship between multiple variables and injury severity of occupants in traffic safety research, where the probability of different rank of injury severity is predicted by using a set of independent variables. The fatality of driver is always naturally divided into two categories: non fatality and fatality. These two ranks were also coded respectively as 1 and 0. The multiple logistic regression model can be described in following formula:

$$\mathrm{logit}(p_i) = \log[\frac{p_i}{1-p_i} - \alpha + \beta' X_i]$$

where p_i is the probability of y_i equaling to y_1 when given the value ofX_i, the vector of explanatory variables. And y_i is the first order level of$y$; α is the intercept parameter; β' is the regression coefficient to be estimated in maximum likelihood method. A positive β' means more tendency to get a severe injury, while a negative β' means less.

The Odds Ratio (OR) is used to describe how probability of fatality for driver changes as vehicle speed changes in this study. The OR can be expressed as following:

$$\mathrm{OR} = e^{\beta}$$

it represents the change in injury severity of driver when increasing one unit of corresponding vehicle speed with other variables fixed as the variable vehicle speed is continuous. With an OR over/under 1, injury odds increase/decrease as vehicle speed increase/decrease. However, if the independent variable is discrete, it represents the ratio of probability of dependent variable with different independent variable.

3. Results

3.1 Description statistics results

A total of 121 cases were included in this study to investigate the relationship between injury severity of drivers and variables of environment, driver, expressway and vehicle. These cases have a time span of 7 years (2011-2017). In the year of 2011, there is only one vehicle-fixed object case in the whole districts of Changsha, Xiangtan and Zhuzhou, which is far from less than that in other years. An explanation to this phenomenon is that the expressway extension project in Hunan Province have proceeded very rapidly after 2011, but before that time, it progress in a relatively lower speed. Among all the vehicle-fixed object cases, cases causing fatality of drivers accounted for 18.2%. Compared with the fatality of drivers in rear-end crashes [34], it has a lower percentage. In most of the vehicle-fixed object accidents, the fixed object vehicle impacted with are guardrails containing W-beam guardrails, concrete barriers and defending mound. Apart from the guardrails, other fixed objects like revetments, plantings, and lamp poles are also included but with a much lower frequency. The lower fatality for drivers of vehicle-fixed object accidents compared with rear-end crashes shows most of the guardrails can effectively reduce the fatality of the drivers involved a crash. If the first object impacted by a vehicle is fixed, then the case was included in this study. However, it doesn't mean that the vehicle only impacted with one object. After the first impacting, about 24.8% of the vehicles have a second impact with some other objects, none of which is another vehicle, for the traffic density was told to be low. In some cases, vehicle running off the road was not defined as having a second impact, but separately defined as running off the road, which make up about 19% of overall cases. In about 52.1 % of the cases, vehicles had collisions with fixed objects in same direction as the driving direction of vehicles. Unfolded air bags were found in 33.1% of the involved vehicles, while the other 66.9% were recorded as no airbags, folded airbags. And more males were involved in the accidents than females with a percentage of 94.2 %.

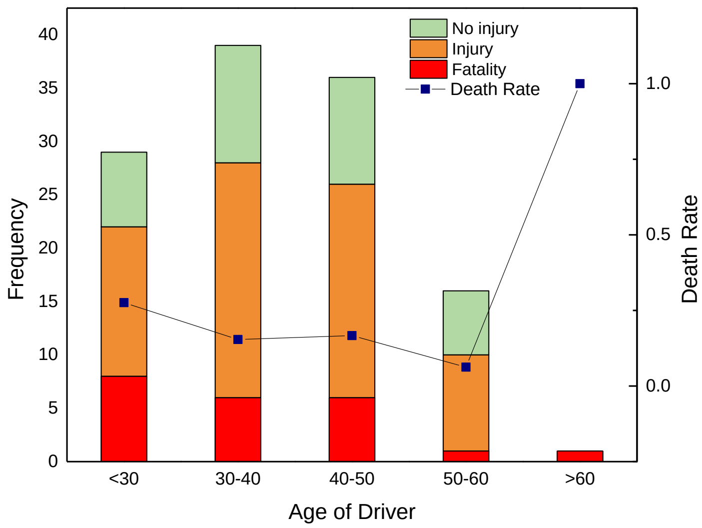

Figure 2 Drivers' fatality distribution of different age of drivers

For the reason that citizens in China can only drive vehicles and get their driving licenses after 18 years old, age of drivers in adopted cases ranges from 19 to 69. The age of drivers were divided into five groups to show the statistical characteristics of injury severity for drivers in figure 2. The age groups of 30-40 and 40-50 covered over one half (75 in 121) of the overall cases. In china, most of the people under 30 owns less property than that of the age between 30 and 50. Buying a car is rather more difficult for those under 30, so they have a lower accident frequency than people age 30-50. While compare with people over 50, people under 50 are more active than those "old" people, which means they might travel more. As for the groups under 60, drivers with injury outcomes take a large part of the whole groups. And the death rate curve shown in the figure2 demonstrates that those under 30 or over 60 have a higher risk of death than other groups, while group of 50-60 has the lowest death risk. Different driving experiences and different physical qualities may be responsible for this result.

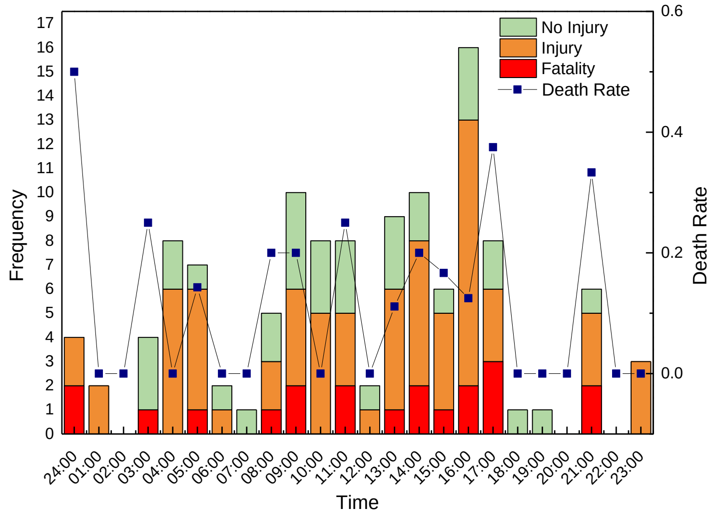

Figure 3 Drivers' fatality distribution of different time ranges

The relationship between the injury of drivers and the time of accidents happening is shown in figure 3. Crashes happening in the day account for 70.2% (85 in 121) of all the cases, while the crashes happening in the evening only account for 29.8%. Traveling time by expressway between any two cities in the district of Chang-Zhu-Tan only costs about 1 hour, which is very convenient for communication. So in the day, there are more vehicles from these three cities, which may cause more crashes happening. At around 09:00 and 16:00, there are more accidents for time periods around these two moments are the so-called morning rush hours and evening rush hours. At 24:00 appearing the peak value of the death rate 50%, and at 23:00, 24:00 and 01:00, the injury severity of drivers is either injury or fatality. As it's shown in the figure 3, accidents happening at around these three times are relatively less, which may indicate a lower traffic density and a more relaxed driving status of drivers.

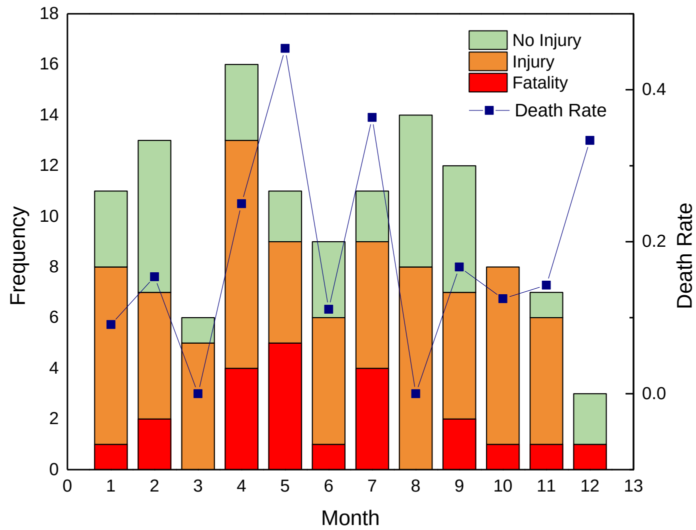

Figure 4 Drivers' fatality distribution of different month

To investigate the relationship between the outcomes of vehicle-fixed object accidents and twelve months, the distribution of fatality, injury and no injury together with the frequency of the accidents happening in each month were included in figure 4. Between April and July, a higher average value of death rate may be attributed to the rainy season of Hunan Province, which resulted in a lower friction coefficient of road, dim sight and an unknown road surface.

Table 2 Drivers' fatality distribution of different avoiding actions

Avoiding action	All case	Fatality		Non-fatality	
	Frequency	Frequency	Percentage	Frequency	Percentage
Braking	12	0	0.00%	12	100.00%
Turning	30	1	3.33%	29	96.67%
Braking and Turning	36	2	5.56%	34	94.44%
No avoiding action	43	19	44.19%	24	55.81%

The avoiding actions taken by drivers and distribution of fatality for drivers under different avoiding actions are included in table 2. Among whole of the 121 cases, drivers only taking braking actions account for 9.92%; drivers only taking turning direction actions account for 24.79%; drivers taking actions of braking and turning direction at the same time account for 29.75% and drivers don't take any avoiding actions account for 35.54%. Drivers taking actions of braking and turning at the same time have a higher fatality rate than those only taking either of these two actions. Because of the smaller sample size of action braking, it's hard to tell whether this higher fatality is caused by turning or braking. But turning may have a higher possibility to make drivers closer to fatality for they can be threw out vehicle due to the large rotatory inertia of the vehicle. Among those taking no actions before the collision, most of them said in the inquiry record that they were frightened at that moment or it's too late to take any avoiding action. And taking no avoiding actions resulted in more fatalities.

Table 3 Drivers' fatality distribution of different fixed objects

Fixed object type	All case	Fatality		Non-fatality	
	frequency	Frequency	Percentage	Frequency	Percentage
W-beam guardrail	73	13	17.81%	60	82.19%
Concrete guardrail	10	0	0.00%	10	100.00%
Others	38	9	28.57%	29	71.43%

The fixed object having collision with vehicle are various. But according to the table 3, the top two frequent being impacted fixed object are W-beam guardrails and concrete guardrails. The death rate caused by impacting with W-beam guardrail is 17.81%, while that caused by impacting with concrete is 0%. This is because in many crashes involving W-beam guardrails, vehicles always impacted with the exposed guardrail end, which cause a much higher death rate. All of the other fixed objects without any protecting function caused a higher death rate of drivers as 28.57%. For example, in one case, a truck impacted a lamp pole and the driver dead because the heavy and tall lamp pole fall down to crush the driver's cab.

Table 4 Drivers' fatality distribution of different speed ranges

Vehicle speed (km/h)	All case	fatality		Non-fatality	
	frequency	Frequency	percentage	frequency	percentage
<40	3	1	33.33%	2	66.67%
40-60	4	3	75.00%	1	25.00%
60-80	25	5	20.00%	20	80.00%
80-100	44	9	20.45%	35	79.55%
100-120	43	4	9.30%	39	90.70%
>120	2	0	0.00%	2	100%
Total	121	22	18.18%	99	81.82%

The vehicle speeds were divided to several groups and the distribution of fatality and non-fatality of each group is concluded in table 4. The speed limit of the expressway is over 60km/h and less than 120km/h. But the speed limit always change to 40km/h for vehicle on the ramp. In the cases group of vehicle speed under 40km/h, there only one fatal accident for driver's over-speed behavior. And what's interesting is that all of these three vehicles involved in the accidents were heavy truck, which suggests the angle and the gradient of the ramp may be not so appropriate for big heavy truck to get through. What's more, those drivers with driving speed over 120km/h all avoided the result of death. Check the detailed information about these cases and compare the results with those speed under 120km/h just to find the air bag did work under high vehicle velocity in protecting driver's life safety.

3.2 Multinomial regression model results

3.2.1 Correlation analysis of explanatory variables

Distance analysis were used to decide whether there is similarity between cases or variables. Because all of the explanatory variables were sorted out firstly according to the integrity degree of the information recorded by police office, it's unclear if there is any multicollinearity between the sorted out variables. If there is, the results of the multinomial regression modeling will be less accurate, which may cause the significant variables insignificant as the results shows.

Table 5 Euclidean distances between all variables

Variables	SEAS	DAY	ROFF	ROLL	SDRCT	SIMP	WEAT	DRY	VCON
SEAS	0.000	22.869	27.221	23.896	24.718	27.350	24.658	23.388	28.018
DAY	22.869	0.000	8.485	7.746	7.483	8.307	6.557	6.633	8.718
ROFF	27.221	8.485	0.000	7.746	6.928	6.557	8.062	8.485	6.000
ROLL	23.896	7.746	7.746	0.000	7.348	8.185	7.416	6.782	8.246
SDRCT	24.718	7.483	6.928	7.348	0.000	7.681	8.185	8.000	8.246
SIMP	27.350	8.307	6.557	8.185	7.681	0.000	7.746	8.544	6.245
WEAT	24.658	6.557	8.062	7.416	8.185	7.746	0.000	***3.873***	7.550
DRY	23.388	6.633	8.485	6.782	8.000	8.544	***3.873***	0.000	8.246
VCON	28.018	8.718	6.000	8.246	8.246	6.245	7.550	8.246	0.000
BREAK	25.652	7.681	7.416	7.416	8.062	7.071	7.483	8.307	6.856
TURN	24.372	7.000	7.681	7.000	7.681	7.348	7.483	7.550	8.185
ABU	26.115	7.810	6.083	8.307	7.810	7.071	7.746	8.426	6.708
FRONT	22.068	6.782	8.832	7.746	8.246	9.220	7.550	7.071	9.274
FP	24.474	7.616	7.746	7.746	7.348	8.185	8.307	8.246	8.367
DSEX	20.640	6.245	9.747	7.141	7.681	9.165	7.616	6.557	10.050
DYEAR	27.459	8.888	5.916	7.550	7.550	6.782	7.874	8.185	5.568
DAGE	28.705	9.000	5.000	8.307	7.810	5.657	7.746	8.660	***3.873***
FOD	26.439	7.746	7.348	8.367	7.348	7.550	7.000	7.483	7.211

Continued From Table 5 Euclidean distances between all variables

Variables	BREAK	TURN	ABU	FRONT	FP	DSEX	DYEAR	DAGE	FOD
SEAS	25.652	24.372	26.115	22.068	24.474	20.640	27.459	28.705	26.439
DAY	7.681	7.000	7.810	6.782	7.616	6.245	8.888	9.000	7.746
ROFF	7.416	7.681	6.083	8.832	7.746	9.747	5.916	5.000	7.348
ROLL	7.416	7.000	8.307	7.746	7.746	7.141	7.550	8.307	8.367
SDRCT	8.062	7.681	7.810	8.246	7.348	7.681	7.550	7.810	7.348
SIMP	7.071	7.348	7.071	9.220	8.185	9.165	6.782	5.657	7.550
WEAT	7.483	7.483	7.746	7.550	8.307	7.616	7.874	7.746	7.000
DRY	8.307	7.550	8.426	7.071	8.246	6.557	8.185	8.660	7.483
VCON	6.856	8.185	6.708	9.274	8.367	10.050	5.568	***3.873***	7.211

BREAK	0.000	6.481	7.616	8.544	7.416	8.485	7.348	6.633	7.810
TURN	6.481	0.000	7.874	8.062	7.681	7.483	8.246	8.246	8.307
ABU	7.616	7.874	0.000	8.426	7.280	8.832	7.348	6.164	6.708
FRONT	8.544	8.062	8.426	0.000	7.616	5.916	8.888	9.539	8.485
FP	7.416	7.681	7.280	7.616	0.000	7.550	8.185	8.307	8.718
DSEX	8.485	7.483	8.832	5.916	7.550	0.000	9.381	10.488	8.888
DYEAR	7.348	8.246	7.348	8.888	8.185	9.381	0.000	5.292	7.280
DAGE	6.633	8.246	6.164	9.539	8.307	10.488	5.292	0.000	6.083
FOD	7.810	8.307	6.708	8.485	8.718	8.888	7.280	6.083	0.000

The Euclidean distances between all variables were listed out in table 5. Smaller the Euclidean distances between two variables, the more possibility of linear correlation existing between them. As the table 5 shows, there may be linear correlation between variables WEAT and DRY, also between variables VCON and DAGE. Five multinomial regression models which separately containing different independent variables were established and the detailed information of the selected variables of each model were listed below in table 6.

Table 6 Models with different independent variables

Model	Removed variables [a]		Explanations
Ⅰ	none		
Ⅱ	WEAT	VCON	WEAT: fine (1 if it's sunny; 0 otherwise) VCON: vehicle condition (1 if bad; 0 otherwise) DAGE: driver age (1 if over 55; 0 otherwise) DRY: dry road (1 if true; 0 otherwise)
Ⅲ	WEAT	DAGE	
Ⅳ	DRY	VCON	
Ⅴ	DRY	DAGE	

a: the variables were removed from variables listed in Table 1

3.2.2 Modeling results for fatality of drivers

Table 7 Comparison of fitness of models with different explanatory variables

Model	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ
Cox&Snell	0.440	0.360	0.421	0.372	0.438
Nagelkerke	0.718	0.587	0.686	0.607	0.716
McFadden	0.612	0.470	0.575	0.490	0.608
Prediction accuracy	92%	88%	91%	87%	93%

Multinomial logistic modelling processes were run by using SPSS software. Cox&Snell, Nagelkerke R2, McFadden R2 together with prediction accuracy were used to assess the fitness of different model. The comparison of fitness of models with different variables were demonstrated in table 7.For model Ⅱ and Ⅳ, only the value of Nagelkerke R2 is over 0.5 and the values of Cox&Snell are all far from 0.5. For model Ⅰ, Ⅲ and Ⅴ, the Nagelkerke R2, McFadden R2 are all over 0.5, which represents over 50% of fatality for drivers in the whole cases can be fitted effectively. And the modeling results including significance of the variables and the OR were listed in table 8 and table 9.

Table 8 Modeling results of model Ⅰ

Variables	Significance	OR	95% confidence interval of OR	
			Lower limit	Upper limit
Defined for fatality				
Constant	0.985	---	---	---
SEAS	---	---	---	---
Spring	0.868	0.804	0.044	14.615
Summer	0.870	0.785	0.053	11.560

Autumn	0.806	0.944	0.056	14.599
Winter	Reference	---	---	---
DAY	0.691		0.164	9.797
ROFF	0.132		0.522	73.404
ROLL	0.512	1.828	0.289	11.550
SDRCT	0.604	1.358	0.238	7.739
SIMP	0.323	0.195	0.012	3.141
WEAT	0.091	38.895	0.561	2696.989
VCON	---	<.001	<.001	<.001
BREAK	0.291	0.236	0.016	3.452
TURN	0.001	0.002	6.849E-5	0.089
ABU	0.719	0.705	0.105	4.739
FRONT	0.073	0.037	0.001	1.363
FP	0.414	2.407	0.293	19.795
DSEX	0.239	0.178	0.010	3.160
DYEAR	0.061	9.184	0.899	93.813
FOD	0.009	0.032	0.002	0.428

Modeling results of model Ⅰ was shown in table 8. According the significance value listed, only variable TURN (turning; 1 if true, 0 otherwise) and variable FOD (fatigue of distracted; 1 if true, 0 otherwise) were found to be significant related to injury severity of drivers in vehicle-fixed object accidents. There are more probability of 99.8% (1-0.2%=99.8%) leading to the death of driver when the driver turning the direction before collision according to the OR results. And if the driver was fatigue or distracted, he would be closer to death compared with those didn't fatigue or distracted with a percentage of 96.8% (1-3.2%=96.8%).

Table 9 Modeling results of model Ⅴ

Variables	Significance	OR	95% confidence interval of OR	
			Lower limit	Upper limit
Defined for fatality				
Constant	0.000	---	---	---
SEAS	---	---	---	---
Spring	0.987	1.026	0.047	22.578
Summer	0.997	1.005	0.052	19.582
Autumn	0.902	1.200	0.066	21.977
Winter	reference	---	---	---
DAY	0.629	1.684	0.204	13.902
ROFF	0.149	6.188	0.522	73.404
ROLL	0.574	1.717	0.261	11.283
SDRCT	0.593	0.549	0.061	4.946
SIMP	0.249	0.322	0.176	0.006
WEAT	0.013	27.245	2.012	368.996
VCON	---	<0.001	<0.001	<0.001
BREAK	0.234	0.214	0.017	2.706
TURN	0.001	0.003	8.474E-5	0.092
ABU	0.660	0.656	0.100	4.298
FRONT	0.054	0.045	0.002	1.058

FP	0.363	2.581	0.335	19.907
DSEX	0.208	0.161	0.009	2.767
DYEAR	0.048	9.248	1.015	84.280
FOD	0.007	0.028	0.002	0.370

In model Ⅴ, the included variables are all contained by model Ⅰ, but model Ⅰ has two more variables that model Ⅴ without. These two variables are DRY and DAGE. In theory, model with more independent variables always better fit the real cases. However, too many independent variables could result in large inaccuracy of the model results, if there is multicollinearity existing between independent variables, which make the results hard to explain. Modeling results of model Ⅴ were demonstrated in table 9. When considering the significance between explanatory variables and dependent variable, more variables were found to have a significant relationship with fatality of drivers. Except from the two variables in model Ⅰ, DYEAR and WEAT were also significant to the fatality of drivers, though they were not so significant as the other two variables with significance 0.048 and 0.13 respectively. When the driver take the action of turning direction, he will have more probability of 99.7% (1-0.3%=99.7%) facing death. If a driver driving with fatigue or distracted, he will also be more inclined to death (more 72%). Drive years under 10 years and a bad weather correspond more probability of death with almost 8 times and 26 times.

4. Discussion

In this study, 121 vehicle- fixed object accidents were included to discover the relationship between several explanatory variables and fatality of drivers. Characteristics of vehicle, driver, expressway and environment were sorted out to be explanatory variables. Because of the inaccuracy of police report about injury level, only fatality was considered in this study, about which information is definitely accurate in police record. A descriptive statistics were used to visualize some characteristic of the overall accidents and the significance of the relationship between explanatory variables and fatality of drivers were figured out by multinomial logistic regression modeling and single logistic regression modeling.

4.1 Turning

The avoiding action of turning direction has a significant effect on fatality of drivers as concluded from table 9. Turning direction and turning direction with braking at the same time are two kinds of typical collision avoidance actions taken by most drivers on expressway. However, these two kinds of actions have different outcomes. The results of multinomial regression modeling indicate that turning direction leads to death of drivers. It can be explained that when drivers driving vehicles at the same speed, which is always over 100km/h on the expressway, drivers taking actions of braking suffered a slightly lower acceleration than taking actions of turning. And because of the high rotatory inertia of the vehicle during turning direction, drivers can be easily threw out of the vehicle, which may causing more serious injury. Also most of the turning action happens under emergencies with a small distance between fixed objects or other vehicles, so the turning speed is much higher than that when driving normally or avoiding objects on other roadways with lower speed limits.

4.2 Weather

The factor weather also found to be significantly related to fatality of drivers. Bad weathers can contribute to death of drivers. The definition of the bad weather in this study including windy, cloudy, rainy, snowy etc. Most of the fatal accidents between vehicle and fixed objects happened on rainy days. Except from a lower friction coefficient of road caused by bad weather, dim sight should also be responsible for the accidents. Inquiring the detailed description from drivers and participants in fatal accidents, “unexpected pit or hole” appearing in a high frequency. The unknown condition of road surface caused by bad weather not only increases the frequency of the accident, but also aggravate the outcome. Besides, bad weather always increase the rescue time and difficulty, which may cause the wounded getting the treatment too late. What's more, some drivers always drive in a fast speed even in a bad weather, though they're told to low down the speed in traffic law.

4.3 Driving experience

In some literatures, driving experience was found not having a significant influence to fatality or injury severity of drivers. However, in this study, less driving year is indicated to have an effect on fatality of drivers. Driving years under 10 years correspond more probability of death about 8 times. Among some of the literatures mentioned above, many accidents happened between vehicles. Compared with vehicle-fixed object, vehicle-vehicle accidents involves at least two participants, and the action taken by drivers always effected by other drivers. Under such complicated circumstances, the differences between driving experience may not lead to big different results of the accidents. However, in vehicle-fixed object accidents, there are not so many other human factors included. And different driving experiences may make great differences in results. When two drivers drive a same vehicle with the same speed, facing the totally same emergency condition (almost going to impact a fixed object), turning action of the experienced drivers may be more effectively than that with a driving year under 10.

4.4 Fatigue or distraction

Fatigue or distracted driving are very common in expressway. This kind of behavior has been reported in many literatures to have a great effect on fatality and injury severity of drivers. As expected, fatigue or distraction was also found to have a bad effect on injury severity of the drivers in this research. Fatigue and distraction can cost drivers more time reacting and taking avoiding actions. And the sensitivity of drivers about the nearby environment can be low under this circumstances. According to the descriptions of the survivors in the accidents, some of those drivers with fatigue or distraction were driving without any feeling about deviation of the vehicle and any avoiding actions, while the other found it's too late to tale any avoiding actions. And according to table 2, there are over 44% of those taking no actions before impacting with fixed objects died during the accidents.

4.5 Driving speed

The driving speed remains as one of the most important parameters capable of leading different results of the accidents. According to the previous research, those variables related to speed like speed limit have the most statistically prominent effect on injury severity of drivers in different type of accidents. According to the results of the descriptive statistics, the fatality percentage reach the highest when the vehicle speed ranges from 40-60km/h. And all of these three fatal accidents happened on ramps with heavy trucks involved. Compared with relatively small and lighter passenger cars, heavy trucks always have long and big “tails”, which make them easier to turn over and impact with the guardrails along the roads. What's different from impacting fixed objects on relatively straight roads, on the ramp, extra space for drivers to turning the direction is smaller and the only way to avoid the collision is breaking. However, those large trucks have big masses, the braking action can't effectively stop the vehicles. In this way, if a driver driving a big heavy truck on the ramp doesn't control the direction and his speed well at the beginning of the ramp, he or she will have more possibility of fatality even taking emergency braking in time.

4.6 Other factors

Except from those factors discussed above, which have significant influences on fatality of drivers in vehicle-fixed object accidents, factors including ROFF, SIMP, FRONT and DSEX all have some influence on the results, which is not so significant as factors mentioned above. In the regression modeling process, two variables, DRY and DAGE were removed for affecting the fitness and accuracy of the final model. However, it doesn't mean that these two variables don't have any influence on the fatality of drivers. Through correlation analysis, VCON and DAGE, also DRY and WEAT are found to have a smaller Euclidean distances than that between any other two explanatory variables, which means the high possibility of collinearity between them. The influence of the two remaining variables on the result of the accidents can represent that of the two removed variables in some degree. However, replacing remaining variables with those two removed, the results of the regression modeling changed a lot and the R-square will be under 0.5.

5 Conclusion

The study investigates the impacts of factors including driver characteristics, vehicle characteristics, roadway characteristics and environment characteristics on fatality of drivers in vehicle-fixed object accidents. Descriptive statistics were conducted to describe the distribution characteristics of all accidents. Five multinomial logistic regression models were established and compared. The model without variables DAGE and DRY was finally chosen to represent the relationship between explanatory variables and fatality of drivers. According to the results of regression model, the avoiding action of turning direction increases the possibility of death for drivers. To reduce the fatality of drivers caused by turning direction in emergency, the automatic collision avoidance system fit for vehicles should take vehicle-fixed accidents into consideration. The problem of lacking driving experience can also be resolved in this way, for drivers with driving experience under 10 years were found to be easier to die in this research. Accordingly, the restraint apply to drivers should be updated to protect drivers from throwing out of the vehicle when turning direction too fast under emergency. Bad weather is another important factor resulting in the death of drivers. For drivers, more attention should be paid when driving in bad weather and a lower travel speed is necessary to avoid collision with fixed object. Besides, definite travel speed range in specific weather need to be specified in traffic law and the management of the road service should be strengthen. Fatigue and distraction of drivers cause the injury of drivers more severe. As for those personal owner of the vehicles, it's hard to ask all of them having a good rest before starting off. But more emphasis of the severe outcome caused by fatigue and distraction should be included in the drive education. As for the professional drivers, the companies or institutions they belonging to should require them to rest as planned and responsible for their fatigue driving.

There was tremendous room for improvement in future study, and how the speed of turning direction of drivers under emergency affecting the dynamic response of the human body will be studied later. Overall, this study provides some insights of vehicle-fixed object accidents, which may help with the management of roads and education for the drivers.

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