Single Vehicle Traffic Accidents in Shanghai River-crossing Tunnels

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Abstract. This study attempts to evaluate the injury risk of single-vehicle accidents in fourteen Shanghai river-crossing tunnels and identify the factors that contribute to mortalities and severe injuries. The traffic accident data was obtained from the Shanghai Transport and Port Authority. The driver, environmental, vehicle and tunnel characteristics of 508 single-vehicle accidents in 2011 were examined by an ordered logit model. The results show that driver's gender, the time of accident, road surface condition, vehicle types, speed limits, accident location, the number of lanes, tunnel length, maximum gradient, and least horizontal radius are significant factors influencing the injury severity.

Introduction

As the increasing traffic volume and growing demands for land because of urban construction and development, cities in China are beginning to utilize urban underground space for various uses to enhance the capacity and accessibility for road transport systems. Road tunnels are one of these cost-effective underground infrastructures which provide passageways for motorists and commuters, especially in densely populated cities like Shanghai. However, recent histories have shown that accidents occurred in the tunnels would result in disastrous consequence due to the enclosed structure nature of tunnel systems. This had been demonstrated by several road tunnel fire disasters. For example, 12 people lost their lives in a fire disaster that happened in the Tauern Tunnel of Austria in 2008 [1]; and another disaster happened in Yanhou Tunnel of China in 2014 resulted in 31 fatalities [2]. Thus, these accidents have not only raised awareness of government to improve tunnel safety, but also drawn more and more attentions from scholars and specialists.

Amundsen et al. [3-5] carried out a series of tunnel traffic accidents analysis on Norwegian road tunnels from 1994 to 2009. They found that vehicle accident risk in tunnels was lower than on open roads, but the severity of accidents was substantially higher. Subsequently, they divided the tunnels into four zones and found that vehicle accident risk and severity varies greatly in different zones.

Using data from police accident database, Lemke [6] analyzed tunnel accidents that occurred in for 68 German tunnels and found that material damage accident rates are highest in tunnel freeways without shoulder lanes while injury accident rates are highest in bidirectional tunnel highways.

Based on data from police database, Nussbaumer [7] have studied accidents in 50 Austrian tunnels and also found accidents severity in tunnels was greater than on open roadways.

Using data derived from police records, Ma et al. [8] analyzed traffic accidents that occurred in four freeway tunnels of China from 2003 to 2004. They divided each tunnel into four zones (refer to table 1). Ma et al. found that accident severity is somewhat higher in freeway tunnels than in freeway in general, especially the case for zones 3 and 4. They also found that highest accident and casualty rates are both in zone 3.

Yeung and Wong [9] analyzed tunnel traffic accidents that occurred in the three Singapore expressway tunnels over 2009–2011, using incident records provided by the Land Transport Authority. Each road tunnel was divided into three zones and accident characteristics were analyzed for each zone. The analysis revealed that tunnel accident rates are higher in transition zones (zone 1 and zone 2, refer to table 1) compared to interior zones (zone 3). Furthermore, upon disaggregation by travel direction, it was found that traffic accidents are more likely to occur when entering the tunnel than exiting.

A few studies on tunnel accidents have been conducted by researchers from Norway, Austria, China, Germany and Singapore. The results of these studies have been inconsistent to some extent in traffic accidents rates and severities in different tunnel zones. This is probably due to different accident records requirements in different countries. However, these studies are mostly based on rural road tunnels and paid little attention on urban road river-crossing tunnels. Therefore, this study aims at identify risk factors affecting injury severity of tunnel single vehicle accidents. An ordered logistic model will be estimated to examine the influence of human elements, environment factors, vehicle attributes and tunnel features on single vehicle accidents in Shanghai river-crossing tunnels. Statistical analyses of all single vehicle traffic accidents in 2011 were conducted.

Table 1 Definition of tunnel zones by three studies

Author	Zone 1	Zone 2	Zone 3	Zone 4
Amundesen and Ranes (2000)	First 50m in front of tunnel	First 50m inside tunnel	Next 100m inside tunnel	Remainder of tunnel
Ma et al. (2009)	First 100m in front of tunnel	First 100m inside tunnel	Next 300m inside tunnel	Remainder of tunnel
Yeung et al. (2013)	First 250m in front of tunnel	First 250m inside tunnel	Remainder of tunnel	-

Some short tunnels may not consist of all zones.

Materials and methods

Database. Conventionally, police accident records can be fairly reliable sources of accident data. Past studies on tunnel traffic accidents in China were conducted based on police accident database [8,10]. In this study, the traffic accident data obtained from incident records provided by Shanghai Transport & Port Authority. Tunnel accidents data considered in this study were extracted from the police database. The data contain 508 accident samples in 2011, and each sample contains driver information, vehicle characteristics, accident site, crash time and environmental conditions. Table 2 shows the descriptive statistics of variables considered in the study.

Table 2 Descriptive Statistics of Variables

Variables	Codes	Share
Driver's gender	0 – male	65.0%
	1 – female	35.0%
Driver's age	1 – ≤25	15.1%
	2 – 26-44	43.2%
	3 – 45-64	26.8%
	4 – ≥65	14.9%

Quarter of the day	1 – January-March	24.9%
	2 – April-June	25.9%
	3 – July-September	24.4%
	4 – October-December	24.8%
Time of accident	1 – 00:00–06:59	17.0%
	2 – 07:00–09:29	13.6%
	3 – 09:30–16:29	37.1%
	4 – 16:30–18:59	16.6%
	5 – 19:00 - 23:59	15.8%
Day of week	0 – Weekends	64.1%
	1 – Weekdays	35.9%
Vehicle types	1 – Small passenger car	68.4%
	2 – Large passenger car	10.5%
	3 – Good vehicle	21.1%
Road surface condition	0 – Dry	48.5%
	1 – Wet	51.5%
Tunnel length	0 – 3000≥L>1000m	63.3%
	1 – L>3000m	36.7%
Speed limit	1 – <50km/h	46.4%
	2 – 50-79km/h	32.9%
	3 – ≥80km/h	20.7%
Number of lanes (unidirection)	1 – Two lanes	45.8%
	2 – Three lanes	25.6%
	3 – Four lanes or more	28.6%
Accident location	1 – Zone 1	49.1%
	2 – Zone 2	13.0%
	3 – Zone 3	37.9%
Maximum gradient	Continuous variable	
Least horizontal radius	Continuous variable	

* Accident locations are grouped into three zones, see Figure 1.

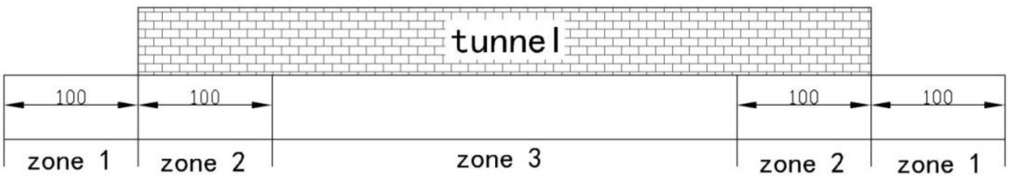

Figure 1 Tunnel Zones

Statistical analysis. In this study, injury severity is divided into three levels: no injury, slight injury and serious or fatal injury. It is explicitly clear that the dependent variable is categorical and ordered in the nature in which no injury, slight injury, serious or fatal injury can be coded as 1, 2, 3, respectively. In order to deal with an ordered dependent variable, an ordered logit model is more appropriate [11-13].

An important task in developing the model is selection of appropriate factors from driver, environment, vehicle and environment characteristics that could reasonably be expected to influence single vehicle accidents in tunnel. In this study, variables selection and collinearity test were computed using a stepwise regression model in which all factors were initially included, and insignificant factors are subsequently removed by the stepwise procedure. Entry and removal probabilities for the stepwise procedure were set at 0.05 and 0.1, respectively.

The odds ratio tells the relative amount by which the odds of the outcome increase (OR greater than 1.0) or decrease (OR less than 1.0) when the value of the predictor value is increased by 1.0 units [14]. It was usually used to estimate the likelihood of the injury severity for different predictor variables conditional on the occurrence of an accident.

Discussion of results

Before going into the detailed data analysis results, preliminary findings point to an important conclusion. The result of variables selection and collinearity test are shown in Table 3. Several factors such as driver's age, quarter of the day and day of week were found to be no significant and should be removed from the model. The collinearity test among the explanatory variables suggested that no variables were highly correlated.

The ordered logit model was estimated with various combinations of the explanatory variables in the data section. Table 4 shows model test of parallel lines and Table5presents the best estimation results. It is clear from the TABLE 4 that results of model satisfy the test of parallel lines (Sig.>0.05).From Table 5, a number of factors are found to be significant. Drivers' gender had a significant impact on accident severity. Male drivers are more likely to increase probability of single accident severity in river-crossing tunnel accidents. This result is in line with previous studies [15-22].A number of studies had identified the effects of different age categories on various aspects of traffic accidents severity [17-29, 23-31]. However, in our study, the effect of drivers' age is not found to be significant on accident severity.

As one of environment factors, time of the accident is found to be significant in the model. Single accidents have the highest risk at the time after midnight (00:00–06:59), with the lowest risk period being morning peak time (7:00-9:30).This result may be caused by drowsy driving and speeding during this period [23]. In addition, lower traffic volume in nighttime could be related with higher speeds that more often lead to severe crashes [32].

In addition to driver and environment characteristics, vehicle type was also found to be significant affect single accident severity in river-crossing tunnel accidents. In comparison with passenger cars, goods vehicles exhibit significantly lowest risk of accident severity. This finding can be explained by the difference in the structure and speed of heavy vehicles compared to passenger cars.

Seven tunnel characteristics (road surface condition, number of lanes, speed limits, accident location, tunnel length, maximum gradient and least horizontal radius) are found to affect single crashes in the river-crossing tunnels. Wet road surface increases the probability of injury severity. This finding may imply that drivers seem more affected by the relatively reduction in and friction in the transition zones due to wet road surface, compared with dry road surface. The model's results indicate that crashes in tunnel with more lanes increase the severity levels of accidents. It is probably because of conflict points arising when lane-changing to overtake in the tunnel with more lanes, which would result in high speed and high accident risk. Model results also show that the location of accidents at zone 3 resulted in higher injury risk propensity than transition zones (zone 1 and zone 2), while accident rate in transition zones is obviously higher than zone 3. This finding is consistent with findings in other studies mentioned above [8-9].

As expected, our results show that high (over 79km/h) speed limits have a higher injury severity propensity than middle (50-79km/h) and low (under 50km/h) speed limits. Higher speed limits usually imply higher speeds of vehicles. Thus, it is obviously that high speed limit naturally aggravates accident severity.

Tunnel length has a significant effect on injury severity levels. Longer tunnel leads to higher severity injuries. This result is consistent with a number of previous studies that have shown that crash severity is higher in long tunnels, presumably due to the drivers' diminishing concentration with increasing tunnel length [33-34].

Finally, both maximum gradient and least horizontal radius are found to be significant factors which have an adverse effect on accident severity. While overheating or speeding because of large gradient may increase injury risk propensity, in the case of small horizontal radius the result possibly drives from the increase of horizontal force and driver's visual blind spot.

Table 3 Results of collinearity test

Model	Standardized Coefficients	t-stat	Collinearity Diagnostics	
			Tolerance	VIF
Constant		5.236		
Driver's gender*	-0.092	-2.199	0.972	1.029
Driver's age	0.051	1.232	0.987	1.013
Quarter of the day	0.072	1.733	0.981	1.019
Time of the accident*	-0.094	-2.274	0.993	1.007
Day of week	0.060	1.436	0.971	1.029
Vehicle types*	-0.082	-1.858	0.882	1.134
Road surface condition*	0.090	2.178	0.990	1.010
Number of lanes*	0.126	2.913	0.904	1.106
Speed limit*	0.215	3.760	0.518	1.931
Accident location*	0.117	2.722	0.914	1.094
Tunnel length*	0.178	3.966	0.840	1.190
Maximum gradient*	0.127	2.465	0.640	1.563
Least horizontal radius*	-0.250	-3.969	0.428	2.338

Note: * Significant at 5% level.

Table 4 Test of Parallel Lines

Model	-2 Log likelihood	Chi-Square	df	Sig.
Null hypothesis	346.750			
General	343.860	2.890	17	1.000

Table 5 Model estimation and odds ratios for significant independent variables

	Estimates	Wald	odds ratios	95% Wald confidence limits	
Driver's gender					
Female vs. male *	0.893	7.114	2.442	1.267	4.707
Time of the accident					
00:00-06:59 vs. 19:00 - 23:59*	0.972	5.217	2.643	1.148	6.092
07:00-09:29 vs. 19:00 - 23:59*	-1.545	5.961	0.213	0.062	0.737
09:30-16:29 vs. 19:00 - 23:59	-0.799	3.315	0.450	0.190	1.063
16:30-18:59 vs. 19:00 - 23:59	-0.979	3.094	0.376	0.126	1.119
Vehicle types					
Small passenger cars vs. good vehicles *	1.158	4.980	3.183	1.151	8.802
Large passenger cars vs. good vehicles *	1.178	2.975	3.248	0.851	12.391

Road surface condition					
Dry vs. wet*	-0.943	8.301	0.389	0.205	0.740
Number of lanes					
Two vs. four or more *	-1.515	7.153	0.220	0.072	0.667
Three vs. four or more *	-1.250	4.554	0.287	0.091	0.903
Speed limit					
<50 vs. ≥80 km/h *	-2.186	13.959	0.112	0.035	0.354
50-79 vs. ≥80 km/h *	-1.367	4.428	0.255	0.071	0.910
Accident location					
Zone 1 vs. zone 3*	-0.949	7.290	0.387	0.194	0.771
Zone 2 vs. zone 3*	-0.242	0.273	0.785	0.318	1.943
Tunnel length					
Long tunnel vs. extra-long tunnel *	-0.919	5.359	0.399	0.183	0.868
Maximum gradient (continuous variables)					
-*	0.626	4.189	1.870	1.046	3.343
Least horizontal radius(continuous variables)					
-*	-0.117	9.427	0.890	0.825	0.959

Note: * Significant at 5% level.

Conclusion and pertinent countermeasures

This study evaluates the injury risk of single-vehicle accidents in fourteen Shanghai river-crossing tunnels and identifies the factors that contribute to mortality and severe injury by the ordered logit model, using a large and disaggregate set of traffic accidents data retrieved from Shanghai Transport & Port Authority. The effect of drivers' information, environment conditions, vehicle factors and tunnel characteristics on injury severity of a single vehicle accident was examined. All single-vehicle accidents (N= 508) occurring during 2011 in Shanghai river-crossing tunnels are considered in this study.

In this study, it is recognized that there is a multiplicity of factors that affect single traffic accidents in river-crossing tunnels. The factors resulting in high severe crashes have been found to be male driver, accident time from midnight to dawn, passenger cars, four or more lanes, high speed limits (over 79 km/h), zone 3, extra-long tunnel (over 3000m), maximum gradient and least horizontal radius of tunnel. The driver's age, quarter of the day and day of week are found to be insignificant.

Traffic accidents are mostly unexpected and random. However, scientific analysis of accident data and the implementation of relevant safety measures could prevent traffic accident occurrence and reduce injury severity [35]. The current study has shown that high speed limit is a major threat to tunnel safety. Thus, variable speed limit could be considered for tunnel areas, in order to effectively control the entering speed.

Passenger cars that are found to be unsafe and drunk driving/speeding should be heavily punished. Drivers need to raise the safety awareness that they should be more carefully driving in tunnels on wet road surface.

Corresponding to the adverse environment factors, appropriate geometric design need to be considered to help reduce the tunnel accident rate. From the perspective of the tunnel design and operation, improvement of geometrics conditions may contribute to eliminating motorist vision confusion. It is suggested to avoid designing transition zones located on a horizontal curve and vertical curve if possible. In addition, in order to reduce the accident rates at the transition zones (i.e.

zone 1 and zone 2), lightings need to be carefully designed to avoid the effect of "black hole" in tunnel entrances and "white hole" in tunnel exits.

Severe accidents happened in road tunnels would lead to economic loss, and more importantly, loss of lives. Thus, the identification ofthe risk factors could provide a better understanding of tunnel safety and valuable information for developing effective safety countermeasures.

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