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Analysis of Influencing Factors of Traffic Accidents in Undersea Tunnel

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Authors' contributions

This work was carried out in collaboration between both authors. Author YYZ designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors YYZ and YM managed the analyses of the study. Author YM managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

This study aims to study the influencing factors of traffic accidents in undersea tunnels and establish a prediction model of undersea tunnel traffic accidents. Through face-to-face inquiry and telephone survey, the relevant information of drivers who had traffic accidents in Jiaozhou Bay undersea tunnel from 2018 to 2019 was obtained, and the relevant information of citizens passing through Jiaozhou Bay undersea tunnel was obtained by posting questionnaires on the Internet. Based on whether there were traffic accidents in undersea tunnel, the drivers with undersea tunnel driving experience were divided into accident group and control group. Through the single factor analysis of the data, it is found that drinking, bad driving habits, having traffic accident experience, speeding and other thirteen factors have an important impact on the occurrence of traffic accidents undersea tunnel. Multivariate analysis was carried out on thirteen factors with significant influence, and a model for predicting the probability of accidents in undersea tunnels was established. Five influencing factors of speeding, the following distance is too small, carelessness, illegal lane change and having traffic accidents experience entered the model, with OR values of 7.11(2.94-

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18.90), 2.35(1.17-4.08), 3.99(1.23-7.45), 2.68(1.15-6.39) and 3.95(1.78-6.11). The occurrence of accidents in undersea tunnel is related to the length of the tunnel and the traffic flow. For an undersea tunnel with a length of 7 km and an average daily traffic flow of 50000 vehicles, the number of daily traffic accidents is 1.96. The driver's violations and the driver's carelessness are the main factors in undersea tunnel traffic accident. In order to improve the traffic safety of undersea tunnel, government departments should step up enforcement against traffic violations. In addition, the undersea tunnel management department needs to consider taking measures to improve the harsh and monotonous environment in the tunnel. This study provides an empirical basis for the prevention of traffic accidents in undersea tunnels.

Keywords: Undersea tunnel; traffic accidents; influencing factors; multivariate analysis; traffic accident probability model.

1. INTRODUCTION

Undersea tunnels are mostly built in economically developed coastal cities, which are submarine structures connecting the two sides of the strait 1. They have the characteristics of large traffic flow, high traffic strategic position and poor resilience to traffic accidents [2,3,4]. Compared with ordinary roads, the undersea tunnel is deeply buried below the sea level, with limited height, long depth and relatively closed space 5. The air is polluted, the noise is large, and the environment is monotonous, which makes drivers feel tired easily. In addition, the undersea tunnel cannot get natural light, only artificial lighting can provide the necessary light intensity for driving [6,7]. This feature will lead to a "bright-dark-bright" visual change process when driving through the tunnel during the day, and the driver will have a lag phenomenon of visual adaptation 8. This change process and related phenomena will directly affect the driving ability and driving behavior 9. At the same time, the undersea tunnel needs to penetrate into the seabed from the land first, then pass under the seabed, and then pass out to the land. This special physical structure will inevitably make the undersea tunnel have complex and varying slope 10. As the undersea tunnel is a strategic transportation facility, it plays a vital role in urban traffic. In the event of a traffic accident, it will easily cause the functional paralysis of the undersea tunnel, which in turn will cause local large-scale regional traffic congestion at both ends of the tunnel, Which poses a major threat to the production and life of citizens 11.

At present, many scholars have done a lot of research on the influencing factors of traffic accidents from different perspectives. Ma et al. 12 analyzed the traffic accidents in the long tunnel and found that improper operation and illegal lane changes are the main causes of the accident. Sun et al. 13 analyzed the spatiotemporal characteristics of traffic accidents in Chinese road tunnels from 2011 to 2019, and found that the Spring Festival and other special festivals are more likely to cause traffic accidents, and the locations of accidents are mostly at the entrance and exit sections of tunnel. Zhang et al. 14 established a road tunnel safety warning model based on the characteristics of road tunnel traffic flow. Through simulation experiments, it was found that the road tunnel safety warning model can effectively reduce the occurrence of secondary accidents. Zhao et al. 15 believed that trucks and the time of the accident had a significant impact on the severity of the accident, and established an analysis model of the severity of road tunnel traffic accidents.

At present, the research on the influencing factors of traffic accidents is mostly focused on highway or road tunnel. Due to the late appearance of undersea tunnel and the small number, there is a lack of research on the influencing factors of traffic accidents in undersea tunnel. Compared with highway and road tunnel, undersea tunnel has special illumination, slope and traffic control 16. In this paper, based on the particularity of the undersea tunnel, the influence of different factors on the traffic accident of the undersea tunnel is analyzed, and the accident probability model of the undersea tunnel is established.

2. METHODS

The investigation site is located in Qingdao. Qingdao is the third largest city in northern China, bordering the ocean, with a developed economy and a dense population. Jiaozhou Bay undersea tunnel is located between the main urban area of Qingdao and Huangdao economic development

zone. It is the main channel connecting the two regions, with huge traffic volume. The Jiaozhou Bay undersea tunnel was opened to traffic in 2011. The main tunnels in both directions are single three-lane, with a total length of 7.8 km and a design speed of ≤80 km/h 17.

This paper investigates the drivers who have had traffic accidents in the undersea tunnel through face-to-face and telephone inquiries, and distributes questionnaires to the citizens through the Internet to obtain the situation when they drive through the undersea tunnel. The content of asking the driver of the accident is the same as that of the questionnaire issued to the public. According to whether there has been traffic accident in undersea tunnel, the respondents are divided into an accident group and a control group. The accident group was drivers who had traffic accidents in undersea tunnel from 2018 to 2019; the control group was drivers who drove through the undersea tunnel without any traffic accidents in the same period of time. In the process of investigation, the purpose of the investigation is explained to the investigated person, and the personal information is not leaked to ensure the accuracy of the investigation results. After collecting and screening the investigation data, 256 valid data were obtained, including 85 in accident group and 171 in control group.

In order to ensure the accuracy of the results and reduce the impact of errors on the results, it is necessary to ensure the number of sample and check whether the sample size satisfies the requirements, which can be determined by the following formula 18:

$$N = \frac{Z^2 p_0 (1 - p_0)}{E^2} \quad (1)$$

In the formula, N is the minimum number of sample; Z is the confidence coefficient, which is used to characterize the reliability. When the confidence is 90%, Z = 1.65; E is the maximum allowable error, the smaller the allowable error, the larger the sample size required; p_0 is the ratio of the sample size of the survey to the total sample size. For the accuracy of the investigation, when the total sample size is unknown, p_0 is taken as 0.5. In this paper, the maximum allowable error is 10%. After the calculation, the minimum sample size is 68. The sample size of this paper is much larger than the minimum sample size, so the sample size of this paper satisfies the requirements.

2.1 Single Factor Analysis

Based on the characteristics of the undersea tunnel and the current research results, this paper forms a questionnaire on the influencing factors of traffic accidents in undersea tunnel. The investigation content includes the driver's basic information, habits and experiences, and driving behavior.

2.1.1 Driver's basic information

In order to reduce the difference in sample size between the accident group and the control group, and to reduce random errors, the control group was divided into two groups according to the order of investigation time. The basic information of drivers is shown in Table 1 and Fig. 1.

It can be seen from Table 1 that there are significant differences between the accident group and the overall control group in five factors: gender, actual driving age, body mass index, whether a professional driver and average annual pass times. This is basically the same as the conclusion of Fig. 1.

Table 1. Basic information of drivers

Group	Total	A1.Gender		A2.Age (years)			A3.Actual driving age (years)		
		Male	Female	<30	30-45	>45	<5	5-10	>10
Accident group	85	62	23	38	45	2	32	24	29
Control group (Control group 1/ control group 2)	171 (85/ 86)	90 (42/ 48)	81 (43/ 38)	68 (36/ 32)	89 (41/48)	14 (8/6)	43 (24/19)	92 (44/48)	36 (17/19)
χ2-value/ P-value		10.436/0.01		4.583/0.33			16.892/0.00		

A4 Body mass index		A5.Whether a professional driver		A6.Average daily driving time (min)			A7.Average annual pass times		
Normal	**Abnormal**	**Yes**	**No**	**<20**	**20-40**	**>40**	**<12**	**12-24**	**>24**
57	28	19	66	27	30	28	13	25	47
133	38	16	155	62	58	51	74	48	49
(62/71)	(23/15)	(7/9)	(78/77)	(26/36)	(26/32)	(33/18)	(42/32)	(21/27)	(22/27)
5.476/0.04		8.305/0.02		7.082/0.13			26.751/0.00		

Note: Body mass index: BMI=18.5-23.9 is normal, BMI<18.5 or BMI>23.9 is abnormal.

The proportion of male drivers in the accident group was 72.9%, which was significantly higher than the proportion of male drivers in the control group 1(49.4%) and control group 2(55.8%), indicating that male drivers are more likely to have accidents in undersea tunnel.

From the actual driving age of drivers, the proportion of high driving age and low driving age drivers in the accident group is significantly higher than that of the control group, which indicates that the drivers with high driving proficiency are not necessarily low in traffic accident probability, and some drivers with high driving age are full of confidence in their own driving skills, thus increasing the probability of traffic accidents [19,20].

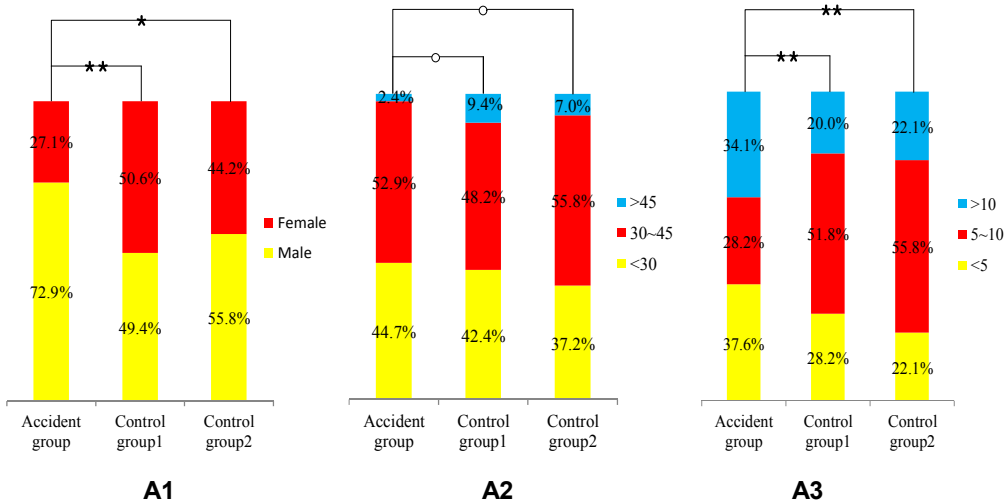
The proportion of professional drivers in the accident group was 22.4%, which was significantly higher than the proportion of professional drivers in the control group 1(8.2%) and control group 2(10.5%), indicating that professional drivers are more likely to have accidents in undersea tunnel. This may be related to the number of times professional drivers pass through the undersea tunnel.

2.1.2 Driver's habits and experiences

The habits and experiences of drivers are shown in Table 2 and Fig. 2.

It can be seen from Table 2 that there are significant differences between the accident group and the overall control group in terms of whether to smoke, whether have bad driving habits, and whether have traffic accident experience. This is the same as the conclusion of Fig. 2.

In the accident group, the proportion of drivers with drunk driving experience was 17.6%, which was much higher than the proportion of drivers with drunk driving experience in control group 1(5.9%) and control group 2(2.3%), which means that drivers who have drunk driving behaviors have a higher probability of traffic accidents when driving in undersea tunnel 21. Drivers who have drunk driving tend to be more aggressive, careless and do not follow the rules than ordinary drivers 22.



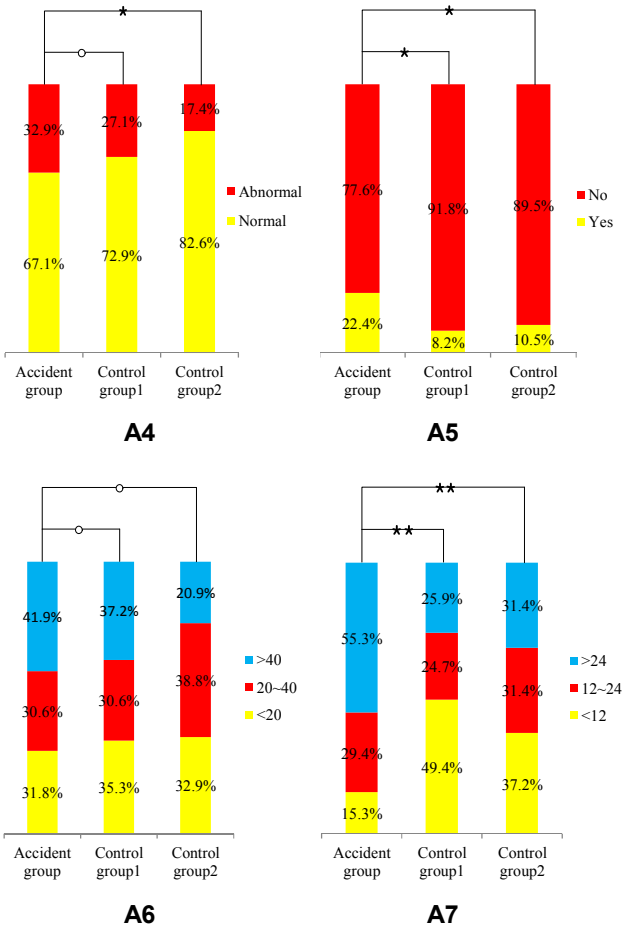


Fig. 1. Distribution of driver's basic information (°p>0.05，*p=0.05，p=0.01)**

In the accident group, the proportion of drivers who had traffic accidents is 31.8%, while in control group, the proportion of drivers who had accidents is about 10%. This shows that drivers who have had traffic accidents are more likely to have accidents again. Combined with the relationship between actual driving age and traffic accidents in Table 1, it can be inferred that after the drivers master the driving skills, the driving experience cannot play a positive role in traffic safety effect 23.

2.1.3 Driving behavior

The driving behavior of the driver when driving in undersea tunnel is shown in Table 3 and Fig. 3.

From Table 3, it can be seen that there are significant differences between the accident group and the overall control group in six aspects: speeding, emergency braking, illegal overtaking, illegal lane change, the following distance is too small and carelessness. This is the same as the conclusion of Fig. 3.

The emergency braking behavior is an important influencing factor of traffic accidents in undersea tunnel. The proportion of drivers who have emergency braking behavior in accident group is 17.6% higher than that in control group. The traffic flow in the undersea tunnel is dense. Once the front vehicle emergency braking, it is easy to cause the rear vehicle to have no time to react, which will lead to the occurrence of rear-end collision. The traffic accidents in tunnel are mainly rear-end collision 24.

In tunnel traffic accidents, side collision accident is another frequent accident besides rear-end collision accident. Most of the sections in the undersea tunnel are not allowed to change lanes. Drivers' illegal lane change and illegal overtaking behavior are important causes of side collision

accidents. In accident group, the proportion of drivers with illegal lane change and illegal overtaking behavior is much higher than that of the control group, which is 40% and 45.9%. This trend is in line with the actual situation 25.

2.2 Multivariate Analysis

Filter out the factors that have significant differences in the accident group at the same time as the overall control group, control group 1, and control group 2. The selected 13 factors were assigned (Table 4) and multivariate logistics regression analysis was performed. Finally, a total of six factors entered the model. The results are shown in Table 5.

It can be seen from Table 5 that speeding, the following distance is too small, carelessness, illegal lane change, whether have traffic accident experience *OR* value and the lower limit of 95%CI are all greater than 1, so the above factors are dangerous factors during the process of driving in the undersea tunnel. The influence effects from large to small are speeding, carelessness, whether have traffic accident experience, illegal lane changing, and the following distance is too small.

Table 2. Habits and experiences of drivers

Group	Total	B1.Whether to smoke		B2.Whether to drink		B3.Whether have fatigue driving experience		B4.Whether have drunk driving experience	
		Yes	No	Yes	No	Yes	No	Yes	No
Accident group	85	20	65	55	30	65	20	15	70
Control group (Control group 1/ control group 2)	171 (85/ 86)	38 (22/ 16)	133 (63/70)	118 (61/57)	53 (24/29)	107 (54/53)	64 (31/33)	7 (5/2)	164 (80/84)
χ2-value/ P-value		1.347/0.51		1.158/0.56		5.044/0.08		13.966/0.00	

B5.Whether sleep well and get enough		B6.Whether check the condition of the car before driving		B7.Whether have bad driving habits		B8.Whether have traffic accident experience	
Yes	No	Yes	No	Yes	No	Yes	No
64	21	16	69	43	42	27	58
126	45	39	132	55	116	18	153
(69/57)	(16/29)	(15/24)	(70/62)	(30/25)	(55/61)	(7/11)	(78/75)
5.053/0.08		3.202/0.20		8.859/0.01		18.289/0.00	

Table 3 Driving behavior of drivers

Group	Total	C1.Speeding		C2.The speed is too slow		C3.Emergency braking		C4.Illegal overtaking	
		Yes	No	Yes	No	Yes	No	Yes	No
Accident group	85	62	23	21	64	34	51	39	46
Control group (Control group 1/ control group 2)	171 (85/ 86)	47 (25/ 22)	124 (60/ 64)	59 (34/ 25)	112 (51/61)	41 (19/22)	130 (66/64)	49 (23/26)	122 (62/60)
χ2-value/ P-value		48.24/0.00		4.914/0.08		7.253/0.02		7.661/0.02	

C5.Illegal lane change		C6.Rapid lane change		C7.The following distance is too small		C8.Carelessness		C9.Tension leads to errors	
Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
47	38	22	63	32	53	49	36	19	66
54	117	32	139	35	136	42	129	51	120
(28/26)	(57/60)	(14/18)	(71/68)	(19/16)	(66/70)	(22/20)	(63/66)	(29/22)	(56/64)
13.499/0.00		2.264/0.32		8.983/0.01		27.256/0.00		3.163/0.21	

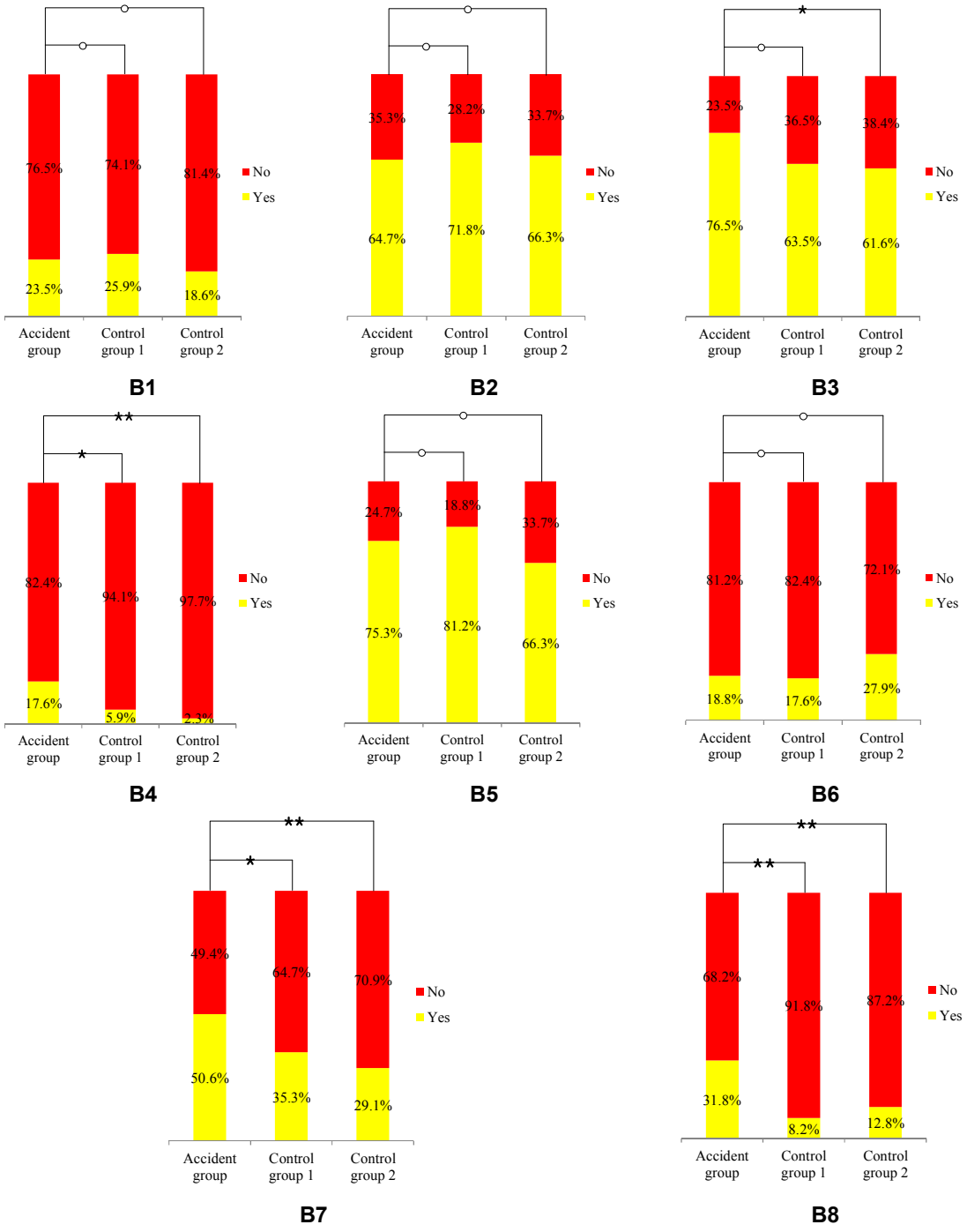


Fig. 2. Distribution of driver's habits and experiences

Speeding is the biggest influence factor of traffic accidents in undersea tunnel. The probability of traffic accidents of drivers with speeding behavior is 7.11 times higher than that of drivers without speeding behavior. Speeding behavior is an important inducing factor of traffic accidents. From a macro perspective, speeding behavior will interfere with the traffic flow and make the traffic order disordered. For individual drivers, speeding will greatly reduce the reaction time of drivers and increase the braking distance 26. Every time the speed increases, the braking

distance will increase by 3 times. Speeding will increase the probability of traffic accidents and increase the severity of the accident 27.

Carelessness is the second major influencing factor of traffic accidents in undersea tunnel. The probability of traffic accidents of drivers with

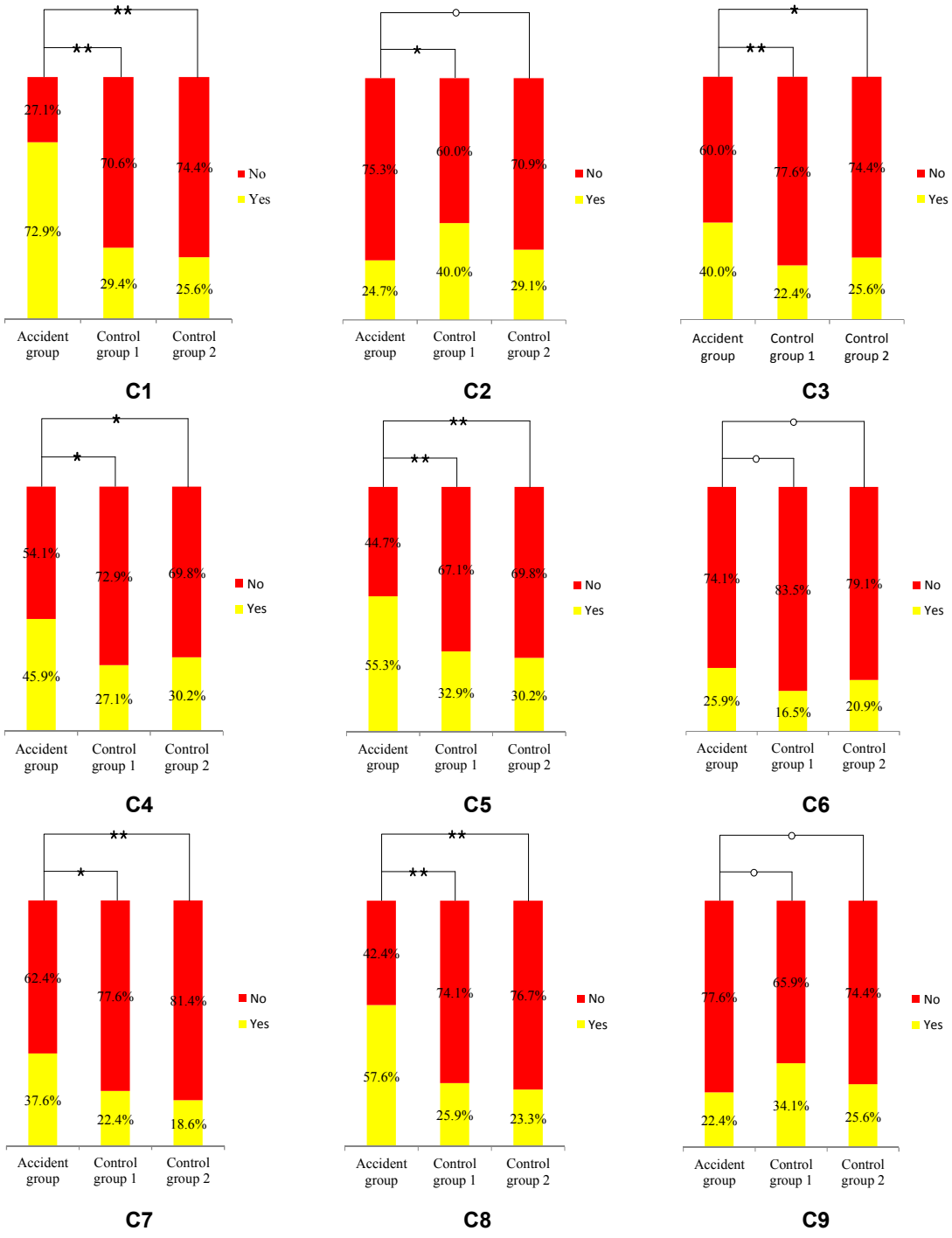


Fig. 3. Distribution of driver's driving behavior

carelessness behaviors is 3.99 times higher than that of drivers without carelessness. The driver is the executor of driving behavior. When the driver is manipulating a high-speed car, a brief distraction may cause a traffic accident. The undersea tunnel is relatively closed, dark in light, noisy, turbid air, monotonous environment, it is easy to make drivers feel tired, which also aggravates the traffic accidents caused by carelessness to a certain extent 28.

The following distance is too small is also an important cause of traffic accidents in undersea tunnel. The probability of traffic accidents of drivers with too small following distance is 2.35 times of that of drivers without too small following distance. When an accident occurs to the front vehicle, the rear vehicle may be unable to complete the braking process due to the small following distance 29, which will lead to traffic accidents, especially rear-end collision accidents.

Table 4. Influencing factors assignment table

Factor	Assignment
Gender	Male=1; Female =0
Actual driving age	High=2; Medium=1; Low=0
Whether a professional driver	Yes=1; No=0
Average annual pass times	>24 =2; 12-24 =1; <12 =0
Whether to drink	Yes =1; No =0
Whether have bad driving habits	Yes =1; No =0
Whether have traffic accident experience	Yes =1; No =0
Speeding	Yes =1; No =0
Emergency braking	Yes =1; No =0
Illegal overtaking	Yes =1; No =0
Illegal lane change	Yes =1; No =0
The following distance is too small	Yes =1; No =0
Carelessness	Yes =1; No =0

Table 5. Multivariate r logistics regression analysis table

Factor	θ	*OR* (95%CI)	P-value
Constant term	-2.02	-	-
Speeding	1.96	7.11 (2.94-18.90)	0.01
The following distance is too small	0.85	2.35 (1.17-4.08)	0.00
Carelessness	1.38	3.99 (1.23-7.45)	0.00
Illegal lane change	0.99	2.68 (1.15-6.39)	0.02
Whether have traffic accident experience	1.37	3.95 (1.78-6.11)	0.04

3. MODELING

Multivariate logistics regression analysis is a linear regression model, mostly used for risk factor identification, probability prediction, etc.

$$Y = \theta_1 x_1 + \theta_2 x_2 + \theta_3 x_3 + \theta_4 x_4 + ... + b \quad (2)$$

In the formula, x_1, x_2, x_3…are independent variables; θ_1, θ_2, θ_3…are regression coefficients;

b is a constant term; *Y* is the dependent variable, The value of variable *Y* is 1 (with traffic accident) or 0 (without traffic accident). When studying the relationship between the probability of traffic accidents and its independent variable, the dependent variable is the probability of traffic accidents.

Transforming the dependent variable, we can get the following results:

$$\ln(\frac{p}{1-p}) = \theta_1 x_1 + \theta_2 x_2 + \theta_3 x_3 + \theta_4 x_4 + ... + b \quad (3)$$

$$\frac{p}{1-p} = e^{\theta_0 X+b}, \theta_0 X = \theta_1 x_1 + \theta_2 x_2 + \theta_3 x_3 + \theta_4 x_4 + ... \tag{4}$$

$$p(Y=i) = \frac{\frac{p}{1-p}}{1+(\frac{p}{1-p})} = \frac{e^{\theta_0 X+b}}{1+e^{\theta_0 X+b}}, i \in \{0,1\} \tag{5}$$

It can be seen from Table 5 that the regression coefficients of the five influencing factors for speeding, the following distance is too small, carelessness, illegal lane change, and whether have traffic accident experience are 1.96, 0.85, 1.38, 0.99, 1.37, and the constant term is -2.02, therefore:

$$p(Y=i) = \frac{e^{1.96x_1+0.85x_2+1.38x_3+0.99x_4+1.37x_5-2.02}}{1+e^{1.96x_1+0.85x_2+1.38x_3+0.99x_4+1.37x_5-2.02}} i \in \{0,1\} \tag{6}$$

The exposure rate of a driver in the environment of a undersea tunnel is:

$$\mu = \frac{t}{365T_0} = \frac{nl}{365T_0 v_0} \tag{7}$$

In the formula, t is the total driving time in the undersea tunnel in a year; T_0 is average daily driving time; l is the length of the undersea tunnel; v_0 is the average speed when driving in undersea tunnel.

Therefore, the probability model of traffic accidents in undersea tunnel is as follows:

$$P = \frac{nle^{1.96x_1+0.85x_2+1.38x_3+0.99x_4+1.37x_5-2.02}}{365T_0 v_0 + 365T_0 v_0 e^{1.96x_1+0.85x_2+1.38x_3+0.99x_4+1.37x_5-2.02}} \tag{8}$$

If a driver with traffic accident experience has an average driving time of 1 h, during a driving process in undersea tunnel, he has speeding behavior, the following distance is too small, carelessness behavior, and illegal lane change behavior. Suppose the length of the undersea tunnel is 7 km, the average speed in undersea tunnel is 70 km/h. Then the probability that the driver has a traffic accident during the driving process is:

$$P_1 = \frac{1\times 7e^{1.96+0.85+1.38+0.99+1.37-2.02}}{365\times 1\times 70(1+e^{1.96+0.85+1.38+0.99+1.37-2.02})} = 2.71\times 10^{-4} \tag{9}$$

If a driver with no traffic accident experience has an average driving time of 1 h, during a driving process in undersea tunnel, he has no speeding behavior, the following distance is too small, carelessness behavior, and illegal lane change behavior. Suppose the length of the undersea tunnel is 7 km, the average speed in undersea tunnel is 70 km/h. Then the probability that the driver has a traffic accident during the driving process is:

$$P_2 = \frac{1\times 7e^{0-2.02}}{365\times 1\times 70(1+e^{0-2.02})} = 3.21\times 10^{-5} \tag{10}$$

If the length of a undersea tunnel is 7 km, the average daily traffic flow is 50000, and the average speed in the undersea tunnel is 70 km/h, assuming that the situation of the driver passing through the

undersea tunnel is the same as the driver in the control group of this paper, then the average daily number of vehicles that have accidents in undersea tunnel is:

$$P_3 = 50000 \times \frac{7e^{1.96\times40\%+0.85\times26\%+1.38\times34\%+0.99\times46\%+1.37\times12\%-2.02}}{365\times0.55\times70(1+e^{1.96\times40\%+0.85\times26\%+1.38\times34\%+0.99\times46\%+1.37\times12\%-2.02})} = 3.91 \quad (11)$$

It can be seen from equation 11 that for the undersea tunnel with an average daily traffic flow of 50000 vehicles, the daily average number of vehicles with accidents is 3.91. There are 2 accident vehicles in an average traffic accident, then the average daily number of traffic accidents is 1.96, which is equivalent to 25510 vehicles/time.

4. CONCLUSION

This paper investigates the drivers who have driving experience in undersea tunnel, compares and analyzes the basic information, habits and experiences, driving behavior of drivers with or without traffic accidents in undersea tunnel, and obtains the following conclusions:

1. There was a significant difference between the accident group and the control group. The drivers in the accident group had a higher risk driving tendency in the undersea tunnel.
2. Speeding, the following distance is too small, carelessness, illegal lane change and have traffic accident experience are the risk factors of traffic accidents in undersea tunnel. Among them, speeding is the biggest influence factor of traffic accidents in undersea tunnel, and the probability of traffic accidents of drivers with speeding behavior is 7.11 times of that of drivers without speeding behavior.
3. During a driving process in undersea tunnel, the probability of a driver having a traffic accident is 2.71×10^{-4}-3.21×10^{-5}.

The main influencing factors of traffic accidents in undersea tunnel are driver's dangerous driving behavior and driver's carelessness. In order to reduce the occurrence of traffic accidents in undersea tunnel, the management department must increase law enforcement. Secondly, government departments must strengthen traffic safety education so that drivers have a deep understanding of the hazards of dangerous driving behavior. At the same time, the management department needs to take necessary measures to improve the environment in undersea tunnel, for example, use sound-absorbing materials to reduce the noise in the tunnel; strengthen ventilation to reduce air pollution in the tunnel; set up a reasonable background wall to change the subsea tunnel monotonous environment 30.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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