ACCIDENTS CHARACTERISTICS OF FIRE AND DANGEROUS GOODS VEHICLES IN CHIINA HIGHWAY TUNNELS

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ABSTRACT

China has become the country with the largest number of tunnels and the longest total mileage in the world. The two basic indicators of tunnel scale and car ownership, as well as the large-scale manufacturing industry, determine the greater probability and serious consequences of road tunnel operation accidents, especially tunnel fire and dangerous goods accidents. In order to understand the macro laws of China's highway tunnel fire / dangerous goods accidents, 130 fire accidents and 40 dangerous goods transport accidents in the past 10 years were collected, and the characteristics of the collected accident cases were statistically analyzed. Finally, the current measures taken to control the risk of tunnel fires and dangerous goods vehicle accidents are introduced.

Keywords: Road, tunnel, accident characteristics, risk control

1. INTRODUCTION

In the past five years, China's tunnel construction has developed rapidly. By the end of 2018, 17738 road tunnels have been built, totaling 17,240 kilometers. Among them, there are 4315 tunnels with a length of more than 1,000 m, 1,058 tunnels with a length of more than 3000 m, and 25 road tunnels with a length of more than 10000 m under operation and construction. The growth trend of road tunnels in the past 15 years is shown in Figure 1.

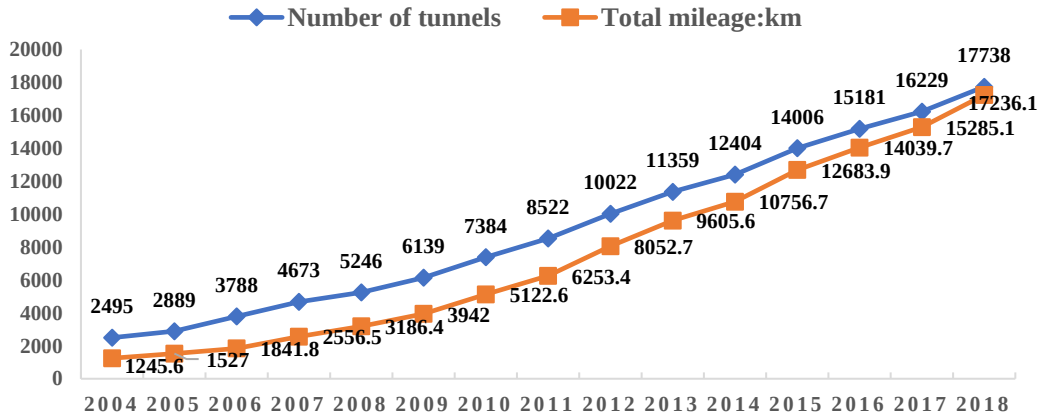

Figure 1: The growth trend of China's highway tunnels in recent years

In the next few years, the number and mileage of China's highway tunnels will still maintain an annual growth rate of about 10%. By the end of 2019, there were 260 million cars in China, with a total of 397 million car drivers, of which trucks accounted for about 10% of the total number of cars. However, the number of vehicles per thousand-persons is only 173, which is only one-fifth of the United States. Therefore, with the improvement of the economic level, the number of Chinese cars will increase in the future, as shown in Figure 2.

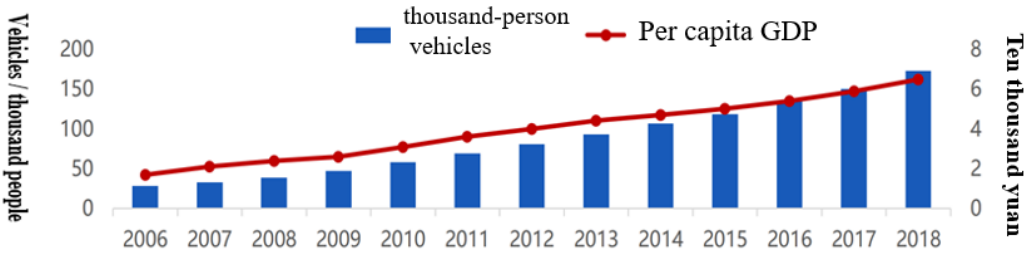

Figure 2: Correlation between China's car ownership and GPD per capita

In terms of traffic volume, some tunnels close to urban areas and traffic trunk lines have far exceeded their designed traffic volume, as shown in Table 1.

Table 1: Daily average traffic volume and design daily traffic volume of some tunnels

Tunnel name	AADT	Design traffic volume	Tunnel name	AADT	Design traffic volume
Zhongnanshan Tunnel（2019）	20500/veh	25000veh/d	Xiangshan Tunnel（2018）	23100/veh	20000veh/d
Xiang'an Tunnel（2016）	51000/veh	50000veh/d	Dabaoshan Tunnel（2018）	22822/veh	41558veh/d
Zhenwu Mountain Tunnel（2018）	48000/veh	not in details	Nanjing Changjiang Tunnel（2019）	44916/veh	45000veh/d
Zhongliangshan Tunnel（2015）	40000/veh	24000veh/d	Nanjing Yangtze River Tunnel（2019）	43290/veh	50000veh/d

Typical cases of tunnel fires or dangerous goods accidents that have occurred in recent years are as follows: For example, a truck fire accident at Maoerling Tunnel in Zhejiang Province on August 27, 2019; March 1, 2014, a fire broke out in Yanhou tunnel on several dangerous goods transport vehicles; April 8, 2011 Xinqidaoliang Tunnel tanker truck explosion; May 23, 2017 a truck caught fire in Futuyu # 5 tunnel; May 4, 2008, a rear-end accident of a chemical tanker truck in Dabaoshan Tunnel.

To sum up, the characteristics of China's highway tunnels are as follows: (1) The number and the mileage of tunnels is large; (2) The number of vehicles is large; (3) The traffic volume in the tunnel is large, and the proportion of trucks is high. The above three characteristics determine that the operation risks of China's highway tunnels are relatively high and the management is difficult.

2. ANALYSIS OF STATISTICAL RESULTS

Collected 130 tunnel fire accidents and 40 tunnel dangerous goods transport accidents in recent years, recorded the time of the accident, the place of occurrence, the vehicle and the cause of the accident, and comprehensively analyzed the characteristics of these accidents.

2.1. Accident area statistics

Each tunnel accident in the case is labeled according to geographical location and classified according to China's regional division (see Figure 3). The distribution of the number of highway tunnel fire / dangerous goods accidents in each region is shown in Figure 4. According to the statistical results, it is found that the number of accidents has a certain relationship with the

economic conditions and geographical conditions of the place.

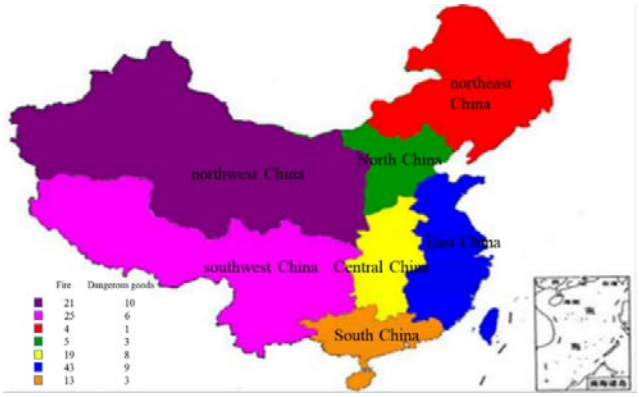

Figure 3: Division of fire / dangerous goods accidents in tunnels

As can be seen from Figure 4, fire accidents in highway tunnels in China are mainly concentrated in east China, southwest China, and central China, accounting for 33.1%, 19.2%, and 16.2% respectively. Dangerous goods accidents in tunnels are concentrated in northwest, east and central China, accounting for 25%, 22.5% and 20% respectively.

Further analysis shows that accidents in East China are mainly concentrated in Zhejiang, Fujian and other provinces. The main reason is that these provinces are economically developed and their traffic volume and vehicle flow are much higher than in other regions, so there are more tunnel fire / dangerous goods accidents caused by vehicle conflict in the tunnel.

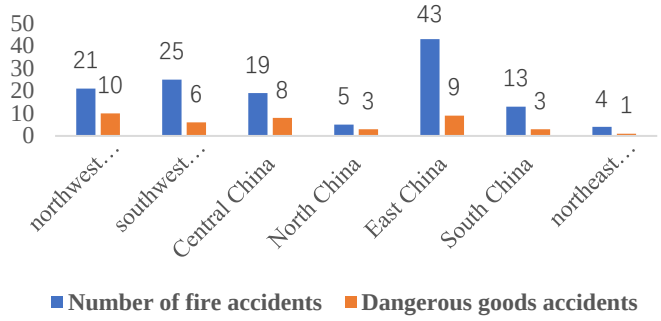

Figure 4: Regional distribution of fire / dangerous goods accidents

2.2. Accident month statistics

Due to the differences in weather and other factors throughout the year, the number of fire / dangerous goods accidents in different months also varies, and there is a certain law to follow. Statistics of accident cases by month are shown in Figure 5:

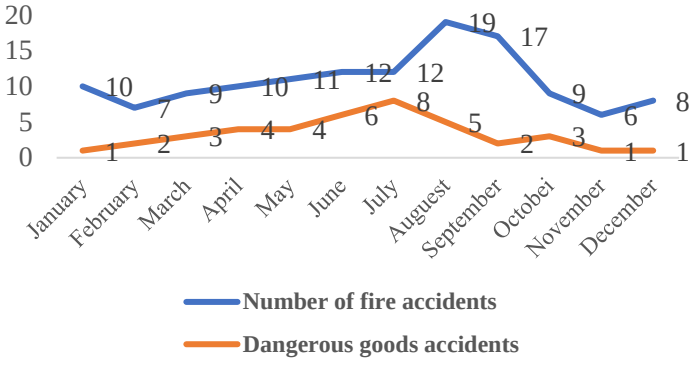

Figure 5: Monthly distribution of tunnel fire / dangerous goods accidents

From the trend line in Figure 5, it can be seen that the peak months of tunnel fires and dangerous goods accidents are all in summer. The reason is that the summer is hot and the heat load of vehicles in high temperature environments increases, resulting in frequent spontaneous combustion. Under the influence of hot and humid summer climate, various types of chemical dangerous goods are more active, and the storage containers of dangerous goods transport vehicles are more susceptible to corrosion, thereby increasing the possibility of leakage.

2.3. Accident Hour Statistics

In order to reflect the regularity of highway tunnel transportation activities throughout the day, the 24h of the day are divided into 12 time periods and the accident statistics are analyzed. The results are shown in Figure 6:

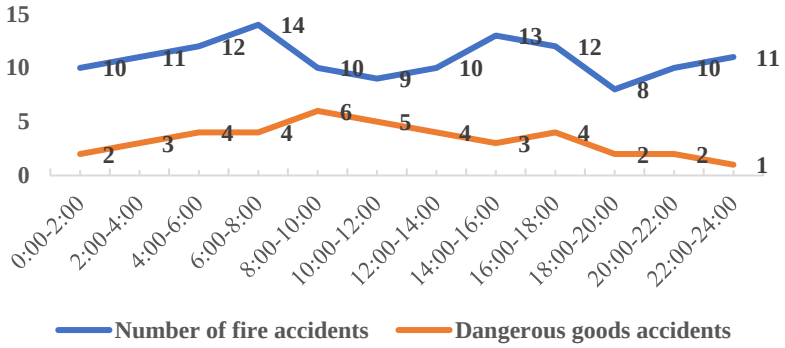

Figure 6: Hour distribution of tunnel fire / dangerous goods accidents

It can be seen from Figure 6 that the frequency of the two types of accidents increased in the early morning and both reached a peak in the morning. The reason may be, that the driver feels tired under poor lighting conditions for a long time. At the same time, the traffic volume in the morning is usually large and the traffic condition on the road is complex, which results in the high accident rate in this period. The second peak of the tunnel fire accident occurred in the afternoon. The reason may be that during this period, especially in summer, the light strongly affects driving and the high road temperature increases the possibility of vehicle accidents and spontaneous combustion.

2.4. Accident cause statistics

There are many causes of tunnel fire / dangerous goods accidents. Through case analysis, they are mainly classified into the following six categories: vehicle spontaneous combustion, dangerous goods leakage, vehicle rear-end collision, vehicle side collision, vehicle rollover, other reasons (incidental events, man-made damage, etc.) The distribution chart is shown in Figure 7:

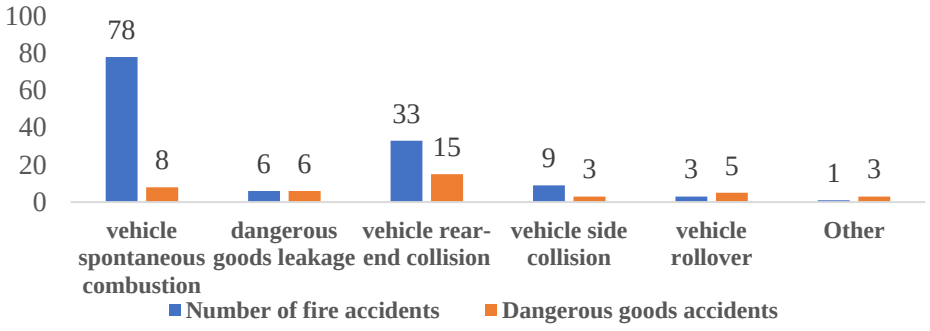

Figure 7: Causes of tunnel fire / dangerous goods accidents

As can be seen from Figure 7, tunnel fire accidents are mainly caused by vehicles spontaneous combustion, accounting for 55.7%; tunnel dangerous goods accidents are mainly caused by vehicle rear-end collisions, accounting for approximately 37.5%. By reviewing the accident cases, it was found that 11 of the 40 tunnel dangerous goods accidents had combustion explosions, and 8 of these 11 accidents were directly caused by spontaneous combustion of vehicles. The remaining 3 dangerous goods accidents were caused by rear-end collisions and rollovers. It is believed that the spontaneous combustion of vehicles is the most adverse event that may cause a tunnel fire. Then the 86 accidents (including both fire and dangerous goods accidents) caused by the spontaneous combustion of the vehicle were further analyzed according to the fire location, as shown in Figure 8:

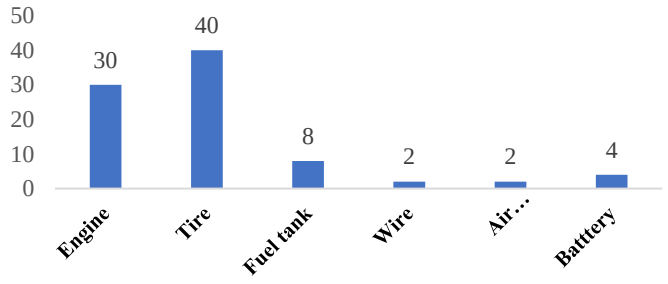

Figure 8: Spontaneous combustion and fire location statistics

It can be seen from Figure 8 that the proportion of spontaneous combustion of tire and engine is 46.51% and 34.9% respectively. Most of the tire fires occurred in the long and steep downhill sections, mainly caused by long-time braking; while most of the engine fires occurred in the uphill sections, especially in trucks.

2.5.Accident Vehicle Statistics

The main types of vehicles corresponding to each accident are classified and statistically analyzed, including cars (cars, vans, etc.), trucks, buses, tankers and other vehicles. The statistical results are shown in Figure 9:

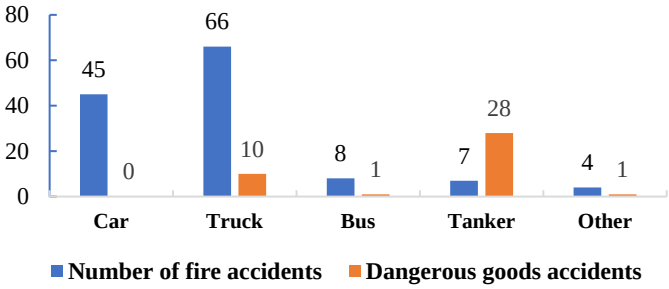

Figure 9: Statistical distribution of accident vehicles

It can be seen from Figure 9 that the main types of vehicles in tunnel fires are trucks and cars, accounting for 47.7% and 30.8% respectively; the types of vehicles for tunnel dangerous goods accidents are mainly tankers and trucks, accounting for 70%, 28%. In order to further investigate the severity of accidents in different vehicle types, the number of casualties was calculated by vehicle type. The results are shown in Table 2:

Table 2: Statistics of accident casualties

Vehicle Type	Tunnel fire accident				Tunnel dangerous goods accident			
	Death	Injured	Average death	Average injured	Death	Injured	Average death	Average injured
Car	14	117	0.31	2.6	0	0	0	0
Truck	78	190	1.18	2.88	42	55	4.2	5.5
Bus	32	43	4	5.38	0	0	0	0
Tanker	16	32	2.28	4.57	28	96	1	3.43
Other	2	5	0.5	1.25	0	0	0	0
Total	142	387			70	151		

From the casualty data in Table 1, it can be seen that the number of car fires is slightly less than that of trucks, but because of the small scale of the fire, the average number of casualties per car is low. The number of bus accidents is small, but due to the dense internal personnel, it is more likely to cause group casualties in the event of a fire, so the average number of casualties per bus is highest. Due to its large fuel tank capacity, coupled with trucks and tankers carrying flammable or dangerous goods, the consequences of a fire are quite serious, so its average number of casualties is also at a high level.

3. PROPHYLACTIC-THERAPEUTIC MEASURES

(1) Speed limit: The vehicle speed in the tunnel should be 20km / h lower than the general road section. The vehicle speed of highway tunnel in Shanxi province is not allowed to be higher than 70km / h.

(2) As shown in Figure 10, regulation of driving behavior: Lane changing is not allowed in the tunnel to reduce the probability of rear-end collisions and side collisions. Video image analysis technology is used to identify and analyze the trajectory of vehicles passing through the tunnel.

Figure10: Lane-changing snapshot system

(3) As shown in Figure 11, asphalt pavement or anti-slip thin layer is laid on the surface of the original cement pavement in the tunnel to improve the frictional performance of the tunnel pavement, which has a significant effect on reducing the accident rate in the tunnel in rainy days.

Figure11: Anti-sliding performance of pavement in tunnel

(4) Tunnels longer than 3000 meters are staffed at the entrance and inspected daily. The tunnel should be closed as soon as possible after an accident occurs to prevent vehicles from entering the tunnel, reduce the casualty rate and prevent secondary accidents.

(5) A remote electric railing is set 300-500 meters in front of the tunnel entrance. The lateral position of the railing is on the side of the road, which will not cause any impact on traffic. When the accident occurs, the remote controlled railing will be rotated 90 degrees horizontally to prevent the vehicle from entering the tunnel.

(6) Dangerous goods transportation vehicles are not allowed during limited time and holidays. According to the "Administrative Measures for the Safety of Road Transport of Dangerous Goods", dangerous goods vehicles are prohibited from passing through expressways between 00:00 and 6:00. During major holidays, such as the Spring Festival, National Day, etc., dangerous goods transportation vehicles (except liquid chlorine transportation vehicles for tap water production) are prohibited from passing through the highway all day to reduce the probability of leakage and explosion of dangerous goods vehicles in the tunnel.

(7) Real-time risk assessment system for tunnel operation. A video image analysis system is arranged at the entrance, the middle part and the exit of the tunnel to dynamically identify the number of vehicles entering and exiting the tunnel and the types of vehicles, evaluate the traffic state of the tunnel and the number of person in the tunnel in real time, and issue early warning in time.(Figure 12)

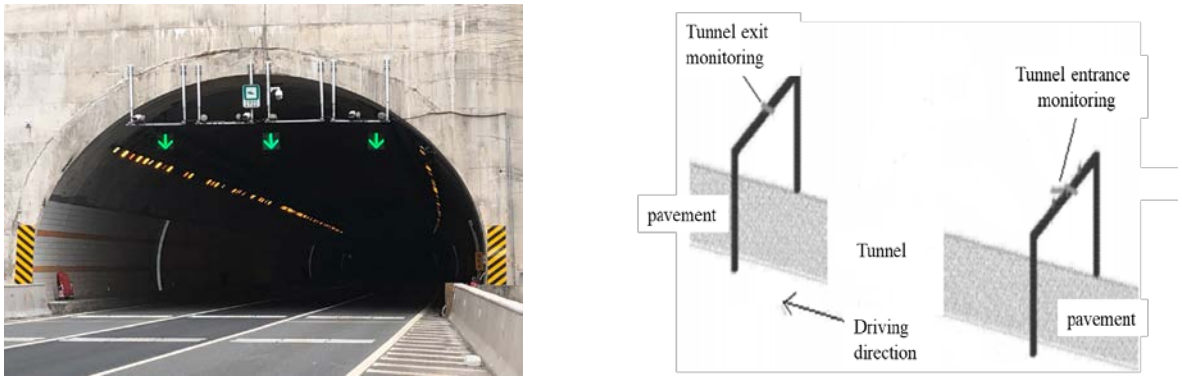

Figure 12: Real-time risk assessment system for tunnel operation

4. CONCLUSION

Statistical analysis and research on the above accidents show that:

(1) China's economically developed areas and mountainous areas are high incidence areas of tunnel fires / dangerous goods accidents; summer in each year and the morning of each day are

the high incidence periods of two types of accidents.

(2) The main cause of the tunnel fire accident is the spontaneous combustion of the vehicle, and the most important cause of the dangerous goods accident is the rear-end collision of the vehicle.

(3) The main vehicles for tunnel fires are trucks and cars, and the main vehicles for tunnel dangerous goods accidents are trucks and tankers. The two types of accidents mostly occur in long tunnels and extra-long tunnels, but the average number of casualties per accident occurring in long tunnels is the highest. The combination of the two types of accidents shows that the consequences are most serious when the fire accident involves dangerous goods.

(4) Regulating driving behavior, controlling driving speed, and improving anti-sliding performance of the road can greatly reduce the probability of traffic accidents in the tunnel.

(5) After a traffic accident occurs in the tunnel, traffic control measures can be taken as soon as possible to effectively control the scale of the accident and reduce the loss consequences of the accident.

(6) Limited time (such as holidays and periods of heavy traffic) on highways for dangerous goods vehicles can reduce the probability and consequences of tunnel accidents.

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