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Research on Traffic Safety at Tunnel Entrance and Exit

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Abstract: Highway tunnel entrances have a high rate of expressway traffic accidents. In this paper, the reasons for the high incidence of traffic accidents at highway tunnel entrances are analyzed in detail, and corresponding solutions are proposed, hoping to provide some reference to relevant parties.

Keywords: Expressway; Tunnel entrance and exit; Traffic safety; Improvement measures

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1. Introduction

Expressway construction duration and operation safety are important standards that measure the development of a country's infrastructure. After the reform and opening-up, the construction of highways in China has undergone rapid development in recent years, especially in the middle and western regions. In the process of highway construction in Central and Western China, due to the complexity of landforms, tunnels have become a channel for highways to cross mountains. However, with the increasing number of tunnels, the frequency of traffic accidents at tunnel entrances and exits is also increasing [1]. Therefore, this is an issue that traffic engineering departments need to focus on and investigate, in particular the reasons that lead to the high incidence of traffic safety accidents at the entrance and exit of expressway tunnels so as to formulate reasonable and effective traffic management methods for the traffic operation at the entrance and exit of tunnels as well as provide security for traffic safety at these locations.

2. Influencing factors of traffic safety at the entrance and exit of expressway tunnels

A detailed analysis of the factors that affect the traffic safety at the entrance and exit of expressway tunnels can provide useful reference for solving the relevant problems and improving traffic operation efficiency.

2.1. Driver factors

2.1.1. Vision

At the entrance of highway tunnels, there are changes to the traffic environment, which have a significant influence on drivers. Using the visual characteristics of drivers for monitoring and control of the change of different indicators, it is possible to analyze the change in visual characteristics of drivers at the tunnel entrances and exits. By monitoring, it has been found that, at tunnel entrances and exits, there are changes to several indicators, including the driver's watching time and number of fixation (to the attention of a region), the number of scanning and scanning speed (pilot area) to access information, blink frequency, and eyes closure time (driver's fatigue) [2]. It should be emphasized that the speed of vehicles on the highway

is relatively fast, and the vehicles will advance a long distance in a very short time. When a driver's eye closure time continues to increase, traffic accidents occur easily (such as rear-end collision, hitting the guardrail, *etc*.).

The poor visual characteristics of drivers when they pass through the tunnel entrance and exit lead to visual fatigue, thus threatening driving safety. According to the survey, the anti-fatigue ability of drivers decreases with advanced age, and the change in eye closure time is most evident when drivers of different ages pass through the tunnel entrance and exit [3]. Therefore, when formulating relevant traffic management policies, it is necessary to fully consider the influence of age factor on eye closure time, so as to ensure sufficient distance for restoration of normal driving sight.

2.1.2. Bad driving behavior

Bad driving behavior will lead to a lot of traffic safety hazards, endangering traffic safety. Major violations at the entrance and exit of tunnels include overloading, speeding, drunk driving, illegal overtaking, insufficient safe distance from the vehicle in front, violation of traffic signs and lines, illegal parking, driving without following the lane, fatigue driving, *etc*. These reasons account for traffic safety accidents at tunnel entrances and exits (**Figure 1**).

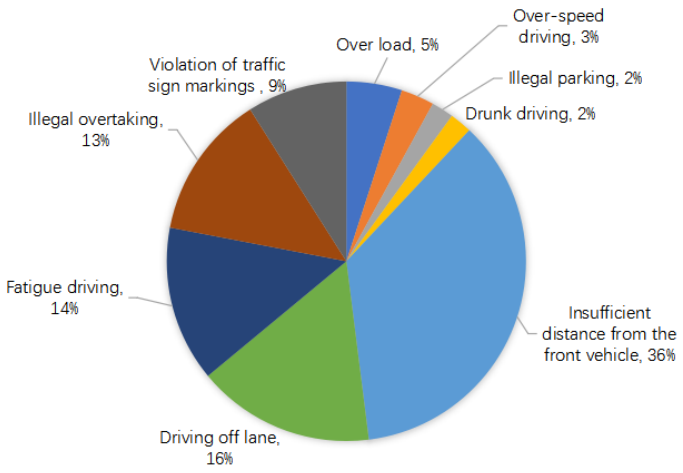

Figure 1. Statistical chart of proportion of different driving violations

Several inferences can be made from **Figure 1**.

(1) Driving without following the lane, insufficient safe distance, illegal overtaking at the tunnel entrance, and fatigue driving account for 79% of safety accident rates. Among them, insufficient safety distance between the vehicle in front accounts for the highest proportion and is the major cause of tunnel exit accidents. This also explains why rear-end collision tends to occur at tunnel exits.

(2) The proportion of traffic accidents caused by drunk driving is relatively low, which may be attributed to the implementation of strict drink-driving laws and regulations. Therefore, appropriate and strict laws and regulations are of great benefit to reducing the occurrence of traffic accidents.

(3) Fatigue driving accounts for a high proportion of traffic accidents. Drivers need to adapt to the changes of the surrounding landscape especially when passing through tunnels. Coupled with the tunnel entrance and exit as well as the environment in the tunnel, drivers may easily experience visual and physical fatigue, which may in turn cause serious traffic accidents.

2.2. Linear factors

2.2.1. Plane linear elements

Plane linearity is the basic element of road linear composition and is mainly composed of three parts: straight line, circular curve, and gentle curve. Different linearity will have different influences on driving.

(1) Straight line

Straight lines are widely used in road design because they save route length. Furthermore, the design is convenient, and the construction is relatively simple. When a car is going in a linear motion, the force of the vehicle is simple, and the driver can easily control his or her vehicle. In contrast, drivers are more likely to experience driving fatigue with excessively long curves. A straight line that is too short between curves will make the curves incoherent, which will bring optical illusion to drivers and easily cause driving errors. In tunnel construction, a straight line can shorten the length of the tunnel, thus reducing the additional fatigue experienced by the driver in the tunnel.

(2) Flat curve

When a vehicle is running on a flat curve, a centrifugal force is produced by the vehicle, which would easily lead to skidding. As a result, the driver may operate erroneously, thus further leading to safety accidents. The angle and radius of the flat curve are two basic linear indexes that can affect traffic safety at the entrance of tunnels. In tunnel engineering design, the horizontal alignment with long straight lines can shorten the construction period and make the construction more convenient; however, in order to maintain the direction of the road, a flat curve tends to be inevitable at the entrance of tunnels. This has raised the safety risk at tunnel entrances and exits. According to statistics, 79.91% of traffic accidents at the entrance of tunnels occurred at a flat curve. Therefore, the issue of adjusting the flat curve at the tunnel entrance in order to reduce the risk of safety accidents is crucial.

2.2.2. Longitudinal curve elements

Longitudinal curve elements include longitudinal slope and vertical curve. Longitudinal curve elements have a significant impact on traffic safety. Going uphill, the speed of any vehicle will decrease; however, the rates at which the speed decreases vary for different models; thus, accidents are likely to occur. When a vehicle passes through a large, longitudinal slope, the continuous climbing will cause the temperature of the car to peak, overload the engine, *etc*., all of which are very dangerous. Going downhill, the speed of the vehicle is often fast. It is easy to lose control and run off the road. Continuously going downhill will lead to overheated brake pad and brake failure, resulting in traffic safety accidents [4]. In the tunnel area and the tunnel entrance and exit, hedging lanes and climbing lanes cannot be set up, thus intensifying the danger. Traffic accidents easily occur when tunnel slopes are large, coupled with the complex external conditions at tunnel entrances.

The smaller the slope at the entrance and exit of tunnels, the greater the traffic safety. In the actual design of tunnels, it is necessary to design a slope in consideration of the drainage demand. According to the highway tunnel design code, in order to meet the basic drainage requirements, its longitudinal slope should be greater than 0.3%. In a word, in order to prevent tunnel entrance safety accidents from occurring, the longitudinal slope at the tunnel entrance cannot be too large or too frequent.

2.3. Environmental factors

The environmental factors at the entrance and exit of expressway tunnels include weather, light, noise, and air quality. The different environments inside and outside the tunnel have an impact on traffic safety. The sudden change in the external environment, especially at the entrance of the tunnel, requires drivers to adjust and adapt quickly. This will undoubtedly distract the driver's concentration, which would in turn affect traffic safety.

2.3.1. Weather

Different weather conditions will have different adverse effects on highway pavement performance, driver's sight, vehicles, and so on, thus affecting traffic safety. According to statistics of highway safety accident in China, the proportion of accidents caused by bad weather is as high as 50%, of which the proportion of major traffic accidents is as high as 71% [5]. Extreme weather factors include rain, snow, fog, hail, and so on. Tunnels are mostly built in mountainous areas, which are prone to bad weather, especially rain and fog. **Table 1** lists the proportion of traffic accidents in different weather conditions at the entrances and exits of tunnels in a year:

Table 1. Proportion of traffic accidents at the entrances and exits of tunnels in different weather conditions

Weather conditions	Sunny	Cloudy	Rainy	Foggy	Snowy
Proportion	32.55%	23.75%	25.63%	15.32%	2.75%

According to statistical data, traffic accidents at tunnel entrances and exits caused by adverse weather conditions account for nearly 70%, among which the proportion of rainy weather is 49.38%. This may be attributed to the fact that rainy weather significantly affects road adhesion coefficient. In the case of sunny weather, the adhesion coefficient of dry asphalt pavement is about 0.75, while in a wet state, the adhesion coefficient decreases to about 0.45–0.6, while the variation range of the adhesion coefficient of concrete pavement is smaller [6]. At the exit, the humidity inside and outside the tunnel will be different due to weather factors, resulting in differences in road adhesion coefficient. When drivers pass through the entrance and exit of tunnels, such differences will easily lead to accidents. This phenomenon is most apparent on snowy days. The proportion of accidents caused by snow, as shown in the statistics, is relatively low. On the one hand, the data in **Table 1** are derived from the statistics of Shaanxi Province, where snowy days are infrequent; on the other hand, there is no fundamental circumstance for traffic accidents to occur since the highways are closed when there is heavy snow. In spite of this, the adverse impact of heavy snow on traffic safety should be paid attention to. In addition, cloudy and foggy days will reduce visibility and affect the driver's sight, thus increasing the risk of traffic accidents.

2.3.2. Sound and light

An important factor affecting traffic safety at the entrance and exit of tunnels is light. This is because lights have a direct impact on the driver's vision. When driving, drivers need to continuously perceive the environmental information around their vehicles via vision to make reasonable driving operations to maintain smooth and safe operations and ensure the safety of their vehicles. At the entrance of tunnels, both the "black hole effect" and the "white hole effect" are likely to occur due to the sudden changes from bright to dark and vice versa. As a result, drivers are unable to normally acquire and perceive external traffic information as easily due to visual interference, thus causing traffic accidents [7]. In addition, when noise is produced by vehicles in a tunnel, noise cannot be transmitted outward due to the enclosed nature of tunnels; thus, the noise will be repeatedly transmitted in the tunnel, which creates more noise. This will, in turn, interfere with the judgment and response ability of drivers and raise the possibility of traffic accidents [8].

3. Safety improvement measures for tunnel entrances and exits

Based on the causes of accidents as discussed above, several measures that can reduce the probability of traffic accidents at the entrance and exit of tunnels and ensure highway safety are proposed.

3.1. Traffic signs

By setting sound traffic signs at tunnel entrances and exits, drivers are guided in such a way to correct their driving operations, thus reducing the probability of accidents. The specific setting can be carried out in the following aspects: (1) place signs that indicate the tunnel's name and length as well as for turning on one's car lights [9] 100 m before the entrance; (2) set up "speed limit," "no overtaking," and "no parking" signs 200 m in front of the tunnel entrance to regulate drivers' driving behavior before entering the tunnel; (3) set up a "recommended speed" sign 1 km away from the combined "speed limit, no overtaking, no parking" sign before the entrance to remind drivers that they are about to enter the tunnel and should maintain a reasonable speed; (4) according to the speed limit of different expressways, design two "recommended speed" signs; they should be placed within 1 km of the "speed limit," "no overtaking," and "no parking" signs before the entrance; the interval between the two "recommended speed" signs should be 500 m; (5) remove the "speed limit," "no overtaking," and "no parking" signs within 1 km of the useless interference signs; (6) lift the "no overtaking" and "speed limit" signs at the exit of the tunnel 100 m away from the entrance.

Through a series of signs, drivers will be reminded to abide by traffic rules when driving through tunnels. Moreover, these signs will help enhance their awareness, increase their concentration and seriousness, and reduce their visual fatigue, thus reducing the safety risk at the entrance and exit of tunnels.

3.2. Traffic line marking

Vibration marking is a traffic marking line composed of a series of grooves or convex grooves set on both sides of the expressway [10]. When a vehicle deviates and drives on the marking line, the vibration marking and vehicle tires will generate sounds or noises due to friction to remind the driver that the vehicle has deviated from the lane and that the direction of the vehicle needs to be corrected immediately. In continuous downhill or curve sections, anti-skid lateral deceleration marks can be set before the slopes and curves to remind drivers to reduce their speed and control their vehicles in such a way that they are in the correct lane [11]. Several methods can be used to set the marking positions of tunnel entrances and exits.

(1) Within the range of 150 m before the tunnel entrance to 20 m inside the tunnel, and from 20 m before the tunnel exit to 100 m outside the tunnel, white hot melt reflective vibration solid lines can be laid on the edge line and dividing line of the lane, with a width of 20 cm and 15 cm at the edge line and the dividing line, respectively.
(2) Visual transition yellow zebra crossing (hot melt reflective vibration marking) can be set at the right hard shoulder within 120 m before the tunnel entrance and 50 m after the tunnel exit. The line width should be 45 cm, with an interval of 100 cm and an angle of 45° against the driving direction, and outer line width should be 20 cm with white vibration marking.
(3) Two-component yellow anti-slip pavement can be set at the tunnel entrance and exit, extending 20 m into the tunnel and 30 m out of the tunnel. Nine sets of two-component yellow horizontal anti-slip marking lines can be laid 50 m from the tunnel entrance [12].

3.3. Protruding road sign

In order to enhance drivers' driving line of sight in poor weather conditions, such as rain, snow, and fog, protruding road signs can be set up on the basis of matching the edge line and the dividing line of the lane. Specifically, it can be placed on the carriageway dividing line within 150 m before the tunnel entrance and 20 m in the tunnel, and 20 m before the tunnel exit and 100 m outside the tunnel, with a spacing of 10 m [13].

3.4. Strengthen the management of tunnel entrances and exits

Strict management can effectively improve the traffic safety at the entrance and exit of tunnels. Several measures can be adopted.

(1) Ensure regular road maintenance. Road signs, lines, guardrail, and other safety facilities should be inspected and maintained in a timely manner to ensure that they are functioning well.

(2) Strengthen the patrol and inspection of traffic violations at the entrance and exit of tunnels; strictly deal with illegal driving behaviors, such as random parking, speeding, and random lane change at the entrance and exit of tunnels; and maintain the basic driving norms at the tunnel entrance and exit.

(3) Make use of modern internet information technology to understand the traffic conditions at the tunnel entrance and exit in real time and release timely information to passing vehicles so as to realize real-time dynamic road information exchange and improve the basic service level of expressways.

4. Conclusion

Highway tunnel entrances have many safety problems, thus endangering road traffic safety. Through a careful analysis of the causes of safety accidents and the corresponding measures to prevent accidents, it is possible to reduce traffic safety risk at the entrance and exit of highway tunnels and provide a safe driving environment for drivers, both of which are conducive to the sustainable and healthy development of highway construction.

Disclosure statement

The author declares no conflict of interest.

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