Research on Highway Tunnel Safe Speed Limit Setting Method Considering Energy Conservation and Emission Reduction

Hao Li, Yuanyong Wen
Yunnan Institute of Transportation Planning and Design, Kunming 650000, China

*Corresponding author e-mail: 1750081846@qq.com

Abstract. Highway tunnel sections are prone to accidents. In order to reduce safety risk factors generated by tunnels, strict speed limit is implemented in highway tunnels. At present, there is still a lack of research on speed limit standards for expressway tunnel sections. Firstly, this paper analyzes the general situation of highway speed limit in China and abroad, the influencing factors of highway tunnel speed limit setting, and the driving process into the tunnel. Then a speed limit setting model of highway tunnel considering the constraint conditions of energy saving and emission reduction is proposed, based on the serial influencing factor model, the highway tunnel speed limit setting model is determined by taking the road conditions, traffic conditions, energy consumption and emission factors and environmental conditions into comprehensive consideration and combining with the analytic hierarchy process. Finally, the speed limit scheme of highway tunnel section with the consideration of energy consumption conservation and carbon emission reduction is put forward, and some suggestions for setting conditions and constraints of the speed limit scheme are put forward. The results show that the method can be operated and the results obtained are reliable, which can be used as an effective method for the implementation of energy conservation, emission reduction and safety scheme in the field of highway.

1. Introduction
China's first expressway was opened to traffic in 1988. By 2018, the total length of China's expressways had reached 143,000 kilometers, ranking first in the world and about 30,000 kilometers ahead of the United States, which ranked second [1]-[2]. With the implementation of the "traffic power" strategy, China's investment in the field of transportation infrastructure will be further increased, and its advantage in highway mileage will be further expanded. At the same time, energy consumption and pollutant emission are also hot spots in the field of transportation in recent years. How to further save energy and reduce emissions in the field of transportation is also the focus of global scholars [3]-[4].

As one of the black spots of accidents, there have been many traffic accidents in highway tunnel in recent years. In order to reduce the safety risk factor caused by the tunnel, the expressway tunnel imposed strict speed limits, and vehicles in the tunnel to change lanes are also strictly restricted. Some tunnel accidents in recent years show that the probability of accidents at the tunnel entrance is high, so it is imperative to implement reasonable speed limit in the road near the tunnel. However, with the
improvement of road infrastructure and vehicle manufacturing technology, as well as the application of some new science and technology to roads and vehicles, road users are not satisfied with the current speed limit standards [5].

In the United States, there is no specific highway class. Generally, interstate highway is the default highway. The speed limit varies from state to state. But in China, it is almost the same. (Fig.1)

![Figure 1. An example of speed limit in highway tunnel in China](image)

In addition, with the rapid development of expressway mileage in China in the past few years, the length of expressway tunnel section is getting longer and longer, and traffic accidents in tunnel section are attracting more and more attention from traffic management workers [6]. At present, there are many studies on the analysis of road traffic accidents and the safety of rail transit, but studies on the speed limit standards of highway tunnel sections are still lacking. At the same time, the existing models and methods, the lack of energy conservation and emission reduction [7]-[10]. In this paper, based on the serial influencing factor model, the road conditions, traffic conditions, energy consumption and emission factors and environmental conditions are comprehensively considered, and the expressway tunnel speed limit setting model is determined by combining AHP. Finally, the speed limit scheme of expressway tunnel section is put forward, and some Suggestions for setting conditions and constraints of the speed limit scheme are put forward.

2. Tunnel Conditions that Affect Tunnel Speed Limits and Energy Consumption
Highway speed limit management needs to balance the will of drivers and law enforcement. For example, when considering driving safety, drivers and passengers want to minimize travel time, which is reflected in speed, that is, to maximize speed within a controlled range. However, excessive speed will produce noise pollution and reduce energy efficiency. Tunnel sections occupy a low proportion of all expressways, and the excessive pursuit of high speed and high efficiency in tunnel sections will not pay the price. Therefore, safety factors are the key factors to be considered in the speed limit of tunnel sections. Compared with the non-tunnel section, the tunnel section environment is relatively closed, which mainly has the following characteristics.

Tunnel light intensity difference inside and outside the existence, the light intensity difference gap is more obvious in the daytime, due to the change in the outside light intensity people visual reaction time, so the driver in the fast into the tunnel or use tunnel happens when the tunnel effect of "black hole" and "white hole effect" when the car drove up to the tunnel, because the light in the tunnel condition is worse than the outside world a lot, driving people cannot adapt to illumination change, so that unable to identify the road conditions, can't even find obstacles effect into a black hole. The white hole phenomenon is the opposite of the black hole effect. When the driver drives in the tunnel for a long time, the weak light conditions in the tunnel cause the driver's pupils to dilate. When the driver drives out of the tunnel, the external brightness is too high, which leads to glare in the vision. Black hole effect and white hole effect are important risk factors for highway tunnel traffic accidents.
In addition, due to the poor air mobility in the tunnel, the exhaust produced by motor vehicles cannot be effectively diffused, resulting in low environmental illumination and serious air pollution in the tunnel. These are the risk factors that may affect the traffic safety of expressway tunnel.

The determination of the distance between the speed limit sign and the tunnel entrance is strongly related to road condition, traffic flow condition, speed limit of non-tunnel section, vehicle type and other factors. According to the institute of psychology, Chinese academy of sciences, a field experiment was conducted on the relationship between the distance and speed of a driver's identification of a traffic sign. The results are shown in the following table:

### Table 1. The influence of speed on traffic sign recognition.

| Type of Label | Warning | Forbid | Indicate |
|---------------|---------|--------|----------|
| Speed (Km/h)  | walk    | 60     | 100      | walk    | 60     | 100      |
| Average distance of recognizing | 316     | 212     | 390      | 337     | 277     | 239      | 496     | 410     | 326     |
| Lapse rate of recognizing distance | 0       | 23      | 43       | 0       | 20      | 39       | 0       | 17      | 34      |
| Perspective (°) | 4.35    | 5.78    | 7.66     | 4.32    | 4.40    | 4.49     | 3.52    | 5.8     | 2.79    | 3.35    | 4.21    |

3. The Speed Limit Model Considering Energy Saving and Emission Reduction

In addition to the above mentioned risk factors affecting highway tunnel traffic safety, both at home and abroad also need to consider when determining the limit value of the influence factors are: traffic conditions (including the size of traffic flow and traffic flow composition, etc.), road conditions (including the lane width and lane number, if there is a plane curve, and the road conditions, etc.) that holds a store and environmental conditions (including precipitation, average temperature, average wind speed, etc.). The speed limit on a highway is usually set at 85%. The study shows that 85% speed can effectively balance traffic efficiency and traffic accident rate.

![Figure 2. Schematic diagram of the effect of the string factors on the speed limit](image)

Therefore, the speed limit model can be established as follows:

\[ V = V_0 \times \prod_{i=1}^{n} x_i w_i \]  \hspace{1cm} (1)

Where, \( V_0 \) is the speed limit value under ideal conditions, \( x_i \) is the influencing factor, and \( w_i \) is the weight value of each influencing factor.

The weight value of each influencing factor can be determined by AHP or single factor method. Different tunnel conditions are different, so the weight value is different.

According to the analysis of existing studies, it is found that the driver’s real-time surroundings will have an impact on the choice of driving speed, but when the surrounding environment is the same, the economic development level of different regions will also have an impact on the driver’s expected driving speed. The main performance is that economic level will have an impact on vehicle performance and highway construction quality in the traffic flow composition. In addition, drivers with different economic conditions and income levels also have different driving skills, physiological and psychological factors, the intensity of their reactions to the surrounding environment and the importance they attach to safety, which affects their speed selection and speed limit command execution ability under different road conditions.
Different speed limit values have different effects on the driver’s speed selection. After receiving the speed limit instruction, the driver will adjust the driving speed rapidly according to the speed limit value, and the speed distribution of traffic flow will also change at the issuing point of the speed limit instruction. It is generally believed that the speed limit value which can minimize the variance of traffic flow speed and maximize the mean speed is the optimal speed limit value.

Suppose $V_1$ is the driving speed of the vehicle when it encounters the speed limit instruction, and $V_t$ is the driving speed adjusted according to the speed limit instruction after the driver receives the speed limit instruction. Then, the speed selection model can be expressed as:

$$V_t = \frac{V_1}{1 + c \times d^2}$$

(2)

$$z = \frac{V_t}{V_o}$$

(3)

In the actual situation, $V_1$ can be the median speed when the traffic flow is free flow before the speed limit instruction is issued. $V_t$ can be the median speed when the traffic flow is free flow after the speed limit instruction is issued. $V_g$ is the speed limit value issued by the speed limit instruction. And, $c$, $d$ are the parameters of the model.

4. **Speed Limit Setting Scheme with the Consideration of Energy Saving and Emission Reduction**

At present, the commonly used speed limit method has deceleration speed limit warning sign and deceleration ridge. Speed limit sign method is the most basic method of speed limit on expressway. For specific speed limit scheme, the variable information board can be used to prompt according to different models and weather. For example, speed limits for small passenger cars, buses and lorries can be differentiated, and speed limits can be adjusted for different day or night and different weather conditions.

In addition, using the speed limit sign method, the more commonly used domestic highway speed limit scheme also includes lane speed limit and section speed limit. However, as for the length of the section with speed limit by section, there is no relevant regulation in China to limit it. According to the Australian traffic control implementation manual, the minimum section length of the section with speed limit by section shall be specified.

Many studies have shown that for low-grade roads, decelerating ridges are an effective means of decelerating, thus reducing the number and severity of accidents significantly. However, for the expressway, the setting of the deceleration ridge should be very careful, because the deceleration ridge which has a significant effect on the reduction of vehicle speed will have a big safety hidden trouble. According to experience, the setting of deceleration ridge should be arranged in full section to avoid traffic accidents caused by lane change. Drivers should also be warned in advance of the layout of the deceleration ridge to prevent drivers from braking hard or quickly through the deceleration ridge accident risk.

For the speed limit of highway tunnel section, try to use (1) lane limit to effectively reduce traffic delay; (2) the variable information board outside the tunnel entrance shall be used in advance to determine the speed limit value according to different weather conditions and traffic conditions to adjust the running state of vehicles; (3) timely and conditional selection of reduction ridge to assist speed limit.

5. **Conclusion**

As one of the black spots of accident, there have been many traffic accidents in recent years. As one of the effective means to reduce traffic casualties, the speed limit of highway tunnel should be paid enough attention by traffic safety researchers and traffic managers. It is imperative to develop a
reasonable speed limit strategy for expressway. For the speed limit sign of expressway tunnel section, the speed limit scheme should first be formulated under the framework of China's "road traffic safety law" and relevant regulations on expressway speed limit. In addition, space factors, time factors, energy consumption and pollutant emission factors as well as traffic flow factors should also be considered to determine the speed limit sign speed limit scheme for expressway tunnel sections by time, segment and vehicle type. The scheme proposed in this paper is scientific and feasible, and the results are relatively objective, which can be used as a reliable method in the research field of expressway tunnel speed limit.

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