31-317 Study on Variable Speed Limit Effect of Tunnel Section of Mountainous Expressway Based on VISSIM Simulation

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Abstract: With the construction of a large number of mountainous expressways, the number of tunnel sections has also increased. But the tunnel group speed limit has caused many traffic accidents. In order to ensure the traffic safety of the tunnel section, the expressway management department have adopted the variable speed control strategy. In this paper, VISSIM simulation method is used to construct the contrast experiment, and the effect of variable speed limit is studied from the perspective of traffic safety. The results show that the variable speed limit can effectively reduce the congestion degree of the tunnel group accident and improve the driving safety effect.

Keywords: Road traffic safety, Tunnel group, Variable speed limit，simulation

1. INTRODUCTION

Highway tunnels due to their special environment, often influenced the driver's traffic safety, easily lead to traffic accidents(*1*, *2*). The expressway tunnel group is composed of multiple tunnels and connecting lines, and the driving environment is changing, which causes great danger to traffic safety. After a traffic accident, the rescue and evacuation are very difficulty. In addition, the impact of tunnel traffic accidents have two characteristics: "chain effect" and "radiation effect", improper or not timely, will lead to highway congestion and even regional traffic paralysis. May cause casualties and property damage, bringing a wide range of social impact(*3*, *4*).

Tunnel section under normal circumstances, the use of static speed limit method can maintain the stability of the traffic flow, so that the driver to avoid changing the speed limit and frequent changes in the speed of the drawbacks, contribute to traffic safety. However, in the event of an accident or bad weather, traffic congestion in the tunnel section, if the static speed limit method is used, the vehicle at the upstream section of the accident is still running at a static speed limit, and the speed of the vehicle will be reduced after reaching the accident point.

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Due to vehicle brakes caused by the chance of collision accidents, but also makes the vehicle in the upper reaches of the accident point to form a large number of queuing phenomenon, aggravate the instability of traffic flow, triggering more secondary accidents(*5—7*).

Luo Luan high-speed tunnel is mainly concentrated in the Song County to Luanchuan section, the section of a total of 24 tunnels. According to the definition of the tunnel group(*8*), Luo Luan high-speed common tunnel group 4, were named as No. 1, No. 2, No. 3, No. 4 tunnel group. In order to study the convenience, this paper takes Luo Luan high-speed tunnel group as an example to study the variable speed limit effect of highway section of mountainous highway.

Luo Luan high-speed tunnel group set up in Table 1, the schematic diagram shown in Figure 1.

TABLE 1 Discussion on the Setting of Luoluan high - Speed Tunnel Group

Tunnel group	Name of the tunnel	Upward		Down	
		Starting and ending station	length（m）	Starting and ending station	length（m）
No.3 tunnel group	Long Bo 1 tunnel	K106+338.112~K106+446.112	108	K106+245.112~K106+438.112	193
	Long Bo 2 tunnel	K106+650.112~K106+901.112	251	K106+536.112~K106+886.112	350
	Long Bo 3 tunnel	K107+045.112~K107+194.112	149	K107+029.112~K107+191.112	162
	Long Bo 4 tunnel	K107+319.112~K107+842.112	523	K107+314.112~K107+824.112	510
	Shang Qiu Hua Yin tunnel	K108+308.112~K109+246.112	938	K108+294.112~K109+241.112	947

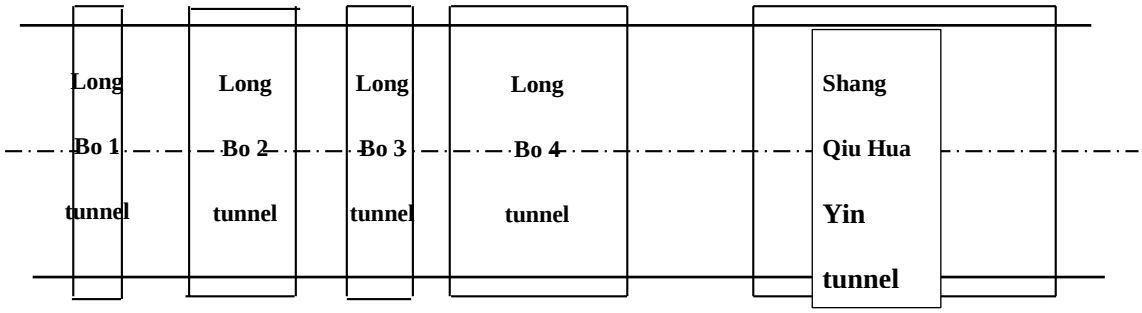

FIGURE 1 Analysis on Distribution of Luo Luan High - Speed Tunnel Group

2. SIMULATION EXPERIMENT

In order to construct the simulation experiment scenario, this paper makes the following assumptions and regulations:

1. The accident occurred at Luo Luan high-speed tunnel group III, the specific location for the Long Bo 4 tunnel upstream direction of the exit (station K107 +842);
2. After the accident occurred for 15 minutes, the 15 minutes of the accident point at the lane closed, 15 minutes after the road to resume smooth(*1*, *3*);
3. The variable speed limit section is implemented by setting the "deceleration zone" in the VISSIM simulation software. Turning off the lane is achieved by setting the speed of the "deceleration zone" to the minimum;
4. The start time of the accident is 0s and 900s for the simulation time.

2.1 Build Simulation Model

According to the design document of Luolong Expressway, the third tunnel group is divided into 6 sections according to the slope, and the length and slope of each section are shown in Table 2.

TABLE 2 Simulation of Road Section Settings

Section number	Starting and ending station	Section length（m）	slope（%）
1	K106——K106+200	200	-2.9
2	K106+200——K106+820	620	-2.7
3	K106+820——K107+100	280	-1.4105
4	K107+100——K108+320	1220	0.4
5	K108+320——K109+060	740	3.0
6	K109+060——K1K110	940	-1.8

In order to study the characteristics of variable speed limit, this paper divides the third tunnel group into seven speed limit sections (Fig. 2), Set the tunnel group static speed limit flag before entering the third tunnel group 200m (point A in the figure), speed limit of 70km / h;

After the exit of the third tunnel group 100m (H points in the figure) set to lift the speed limit signs, then the vehicle can be in accordance with the general road section 80km / h speed limit travel; The variable speed limit flag is set at the entrance of each tunnel in the tunnel group (B, C, D, E, G points in the figure); The accident occurred for the Long Bo 4 tunnel exit (Figure F point), after the accident, F point lane closed, the upstream vehicles will be queued here.

After the accident at point F, the variable speed limit flag for the upstream tunnel shows the speed limit. According to the characteristics of the accident affected by the near and far gradually weakened , the speed limit of the variable speed limit flag is gradually reduced from B to E. Therefore, the setting of the speed limit section in the simulation is shown in Table 3.

TABLE 3 The Division of Variable Rate Sections in Simulation Model

Speed section number	1	2	3	4	5	6
Starting and ending points	A——B	B——C	C——D	D——E	E——F	F——H
length（m）	200	312	395	274	723	1204

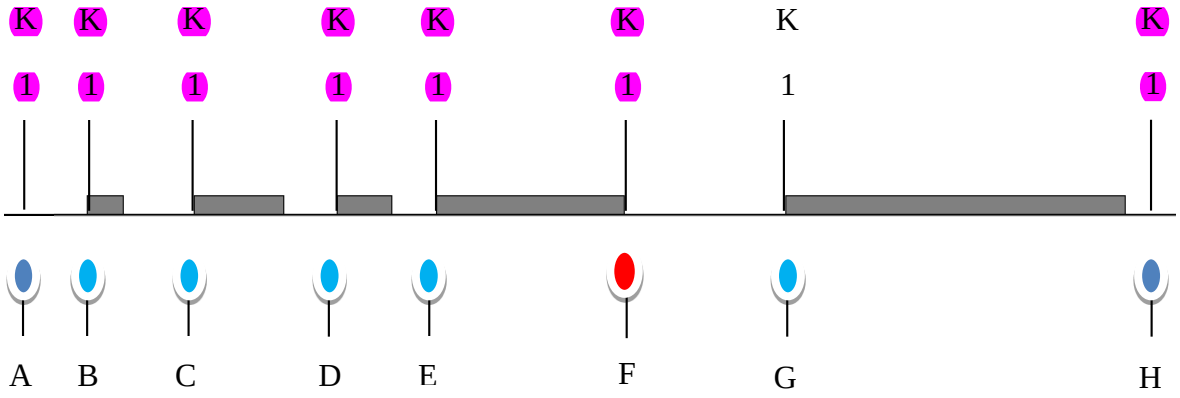

FIGURE 2 No.3 Tunnel Group Simulation Speed Limit Section of the Situation

2.2Simulation Parameter Settings

In this paper, the simulation section belongs to the tunnel group area, according to the third tunnel group average 85% speed to define the initial speed, the vehicle type is selected for small passenger cars and trucks, the proportions are set to 0.8 and 0.2 respectively. Set the speed limit is 900s, the maximum hourly flow of the peak period of the Luo Luan Expressway is taken as the input parameter of the traffic flow, and the maximum hourly flow rate is 1200pcu / h. In this paper, in order to study the traffic situation within the time of the accident, 900s as the vehicle input time interval, the simulation time is 3600s. According to " Analysis of Speed Limitation of Expressway Tunnel Based on VISSIM ", the driver's minimum front view distance is set to 50m, the headway is set to 2.5s and the minimum lateral spacing of the vehicle at 50 km / h is set to 1.2 m.

3. EFFECT EVALUATION

After the simulation is completed, the result of the queue length, delay time and travel time of the vehicle is output according to the setting of the output file, including the corresponding compiled file and database file. In addition, in order to analyze the effect of variable speed limit from the perspective of road, this paper also evaluates the simulation sections and obtains the corresponding evaluation results. Through the comparative analysis of these output results, the effect of variable speed limit can be evaluated.

3.1Queuing Length Simulation Results and Evaluation

TABLE 4 3600s in the Queue Length Comparison

Output the result	Average queuing length （m）	Maximum queuing length （m）	Number of vehicles parked （Times）
Variable speed limit	16	271	366
Static speed limit	65	509	1111

It can be seen from the table that the average queuing length, the maximum queuing length and the number of queuing vehicles in the variable speed limit are far less than the static rate limit during the whole simulation time. Therefore, the use of variable speed limit can reduce the queue congestion in the case of tunnel length, reduce the degree of congestion under the circumstances of the accident, so that traffic flow more stable.

In order to further study the specific time period in which the vehicle is queued, set the time interval in the queued configuration file to 100s, and the simulation result of the queue length is output every 100s, Statistical analysis of the data in the vehicle queuing database file, as shown in Figures 3 and 4, By queuing the results of the database file, it was found that the queuing of the vehicle occurred in the first 1100s of the simulation time, and the queuing length after the 1100s was 0, that is, there was no queuing phenomenon.

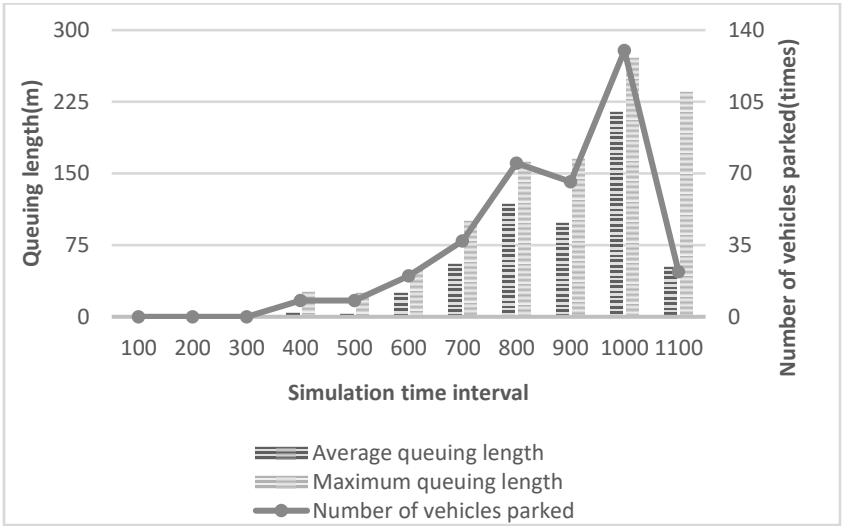

FIGURE 3 Variable Length Limit Every 100s Queuing Length

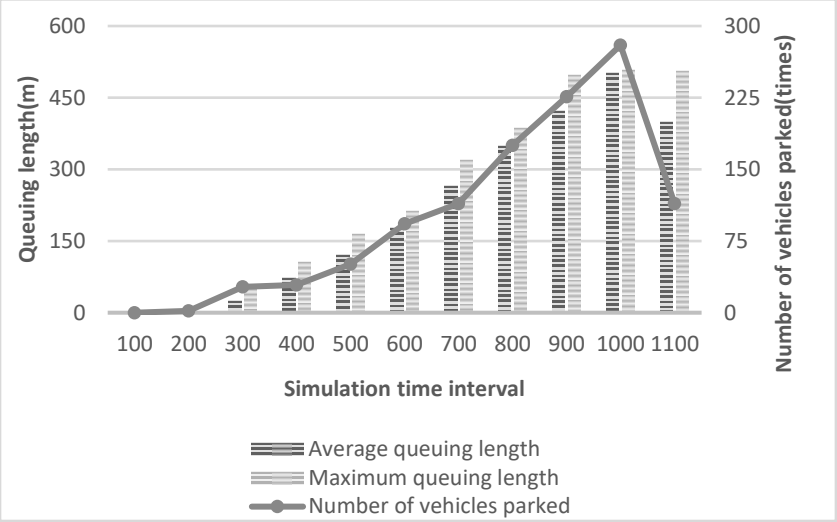

FIGURE 4 Static Rate Limit Every 100s Queuing Length

Compared with the results of variable speed limit and static speed limit, it can be seen that the variable length limit is less than the static speed limit in each 100s, and the variable speed limit queuing time is mainly concentrated in 800s - 1000s Range, the static speed limit is mainly concentrated in the range of 600s - 1100s. Thus, the queuing peak duration at variable speed limits is much less than the queuing peak duration at the static rate limit, which is only 40% of the latter. It can be seen that the use of variable speed limit can make the tunnel group accident conditions congestion time is shorter, Thereby reducing the possibility of traffic accidents caused by traffic congestion.

3.2Simulation Results and Evaluation of Travel Time

The travel time reflects the length of time the vehicle takes on the given road section, the shorter the travel time, indicating that the lower the time cost of the vehicle through the road, the higher the operating efficiency of the vehicle and the more smooth road. In VISSIM, you can set the start and end of the vehicle travel in the road network by using the "travel time" tool. You can also use the link assessment tool to determine the length of the travel time section in the "path" setting.

In this simulation, the travel length of the travel time is 3970.1m, and Table 5 shows the output result when the data output time interval is the whole simulation time (ie 3600s).

TABLE 5 The Simulation Interval is 3600s in the Case of Travel Time

Output the result		Average travel time per vehicle（s）	3600s Number of vehicles passing through the travel section（vehicle）
Variable speed limit	Car	248.5	882
	truck	256.9	213
Static speed limit	Car	276.7	882
	truck	291.3	213

As can be seen from Table 5, the variable speed limit and the static speed limit in the entire simulation time, variable speed limit and static speed limit the average travel time per vehicle (car and truck) is less than the value at the static speed limit if the number of vehicles passing on a given section is the same. Therefore, the variable speed limit can shorten the travel time of the vehicle under the congestion of the tunnel group, improve the operation efficiency of the vehicle and the traffic capacity of the tunnel group.

Fig. 5 and Fig. 6 show the change trend of the travel time obtained by the database file according to the travel evaluation data with the passage of the end of the section. It can be seen from the figure that the travel time of the vehicle at variable speed limit is higher at 253s - 1115s, and the average travel time of the vehicle becomes stable after 1115s. The travel time of the vehicle under static speed limit is higher at 242s - 1274s, and the average travel time of the vehicle becomes stable after 1274s. According to the output of the queue length, the higher travel time period is also the time period when the vehicle is queued, that is, the vehicle congestion occurs and the travel time of the vehicle is increased. Comparison of variable speed limit and static speed limit travel time of the peak duration can be seen, the variable speed limit value is less than the static speed limit value, that is variable speed limit of the congestion time is relatively short. In addition, the maximum travel time at variable speed limit is 409s, the maximum travel time of static speed limit is 583s, the former is 174s less than the latter, so the variable speed limit can reduce the congestion time under the tunnel fault, can make the road faster to restore the state.

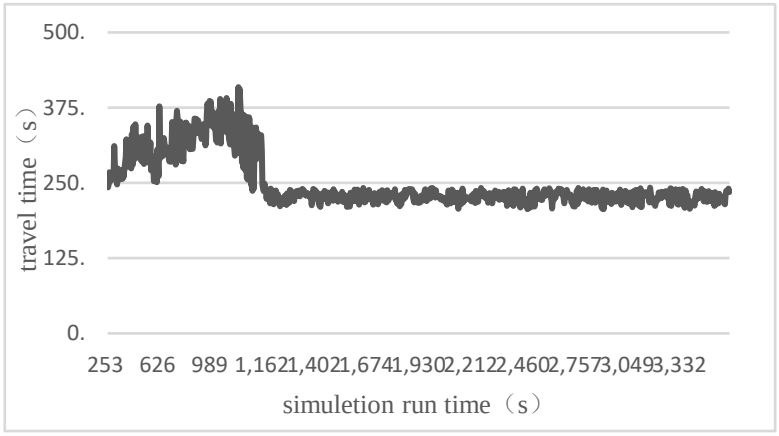

FIGURE 5 \Variable Travel Time Limit at Variable Speed Limit

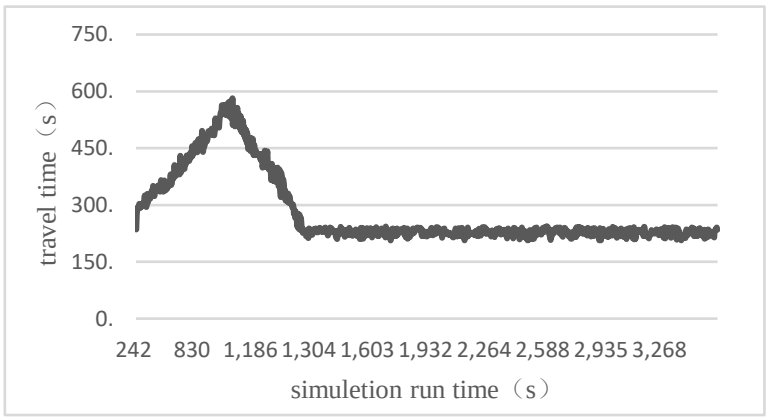

FIGURE 6 The Trend of Travel Time Change Under Static Speed Limit

3.3Delayed Time Results and Evaluation

The delay of the vehicle reflects the difference between the actual travel time of the vehicle and the travel time in the ideal state. The longer the delay time represents the less smooth the traffic on the road, the lower the operation efficiency of the vehicle, Comparison of variable speed limits and static delay rate delay time can be assessed at variable speed limit of the road speed and the stability of the traffic flow.

The results of the delay simulation output under variable speed limit and static speed limit are shown in Table 6.

TABLE 6 The Simulation Results are Simulated over the Entire Simulation Time

Output the result		Average delay time（s）	The average number of stops per car（Times）	Average parking time per car（s）
Variable speed limit	Car	17.6	0.37	0.7
	truck	21.5	0.37	0.5
Static speed limit	Car	41.6	2.18	5.5
	truck	52.5	2.49	6.9

It can be seen from the table, in the entire simulation time, the variable speed limit delay of the simulation results are smaller than the static speed limit, variable speed limit delay time is about 40% of the static rate limit. The average number of stops and average downtime at variable speed limits are about 16% and 10% respectively. The fewer the number of vehicles parking, indicating that the traffic flow more stable, the lower the degree of road congestion; the longer the average stop time, the longer the congestion time of the road, the greater the impact of the vehicle being congested. Therefore, the variable speed limit effect under the congestion condition of the tunnel group is obviously better than the static speed limit.

3.4Comparison of Road Segment Evaluation Results

The above three evaluation results are obtained from the perspective of the vehicle variable speed and static speed limit under the relevant parameters, VISSIM can also be assessed on the road section, get traffic on the road parameters. In order to further study the change of traffic flow parameters under variable speed limit and static speed limit, the traffic flow parameters such as density, vehicle speed, traffic volume and loss time ratio under variable speed limit are obtained by setting the section evaluation parameters during the road modeling process. Based on the statistical analysis of the output database file, (Figure 7-9, the dark curve represents the static speed limit; the light-colored curve represents the variable speed limit) shows the change of the traffic flow parameters with the variable speed limit and the fixed speed limit.

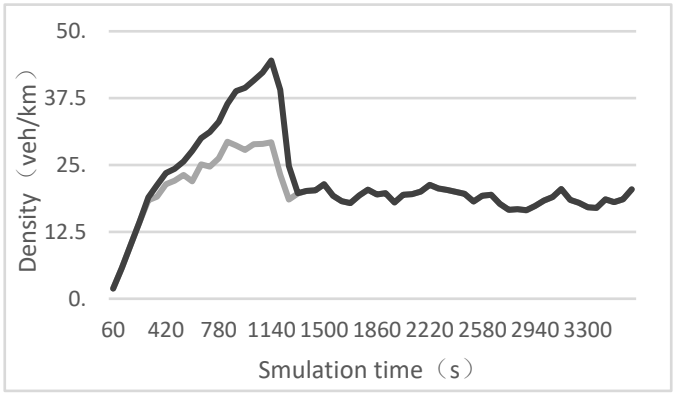

FIGURE 7 Comparison of Traffic Density Between Variable Speed Limit and Static Speed Limit

It can be seen from Fig. 7 that since the accident occurred within the first 900 s of the simulation time, the traffic density continued to increase during this period, reaching the maximum in 960s - 1140s, and after 1320s, the traffic density became stable , Kept in the 15-20veh / km range. Traffic flow density in the first 240s below the stability level, the reason is from the beginning of the simulation run to the first car away from the simulation section of about 240s of time, during this time on the road simulation of the vehicle from scratch, Only inflows do not flow out. The traffic density at any time is equal to the cumulative input traffic from the simulation start time to the time, as the simulation time goes on, the traffic density of the section increases rapidly. Since then, as time increases, the number of vehicles on the road segment increases, and because of the front section of the accident caused the vehicle line up and make the density increases.

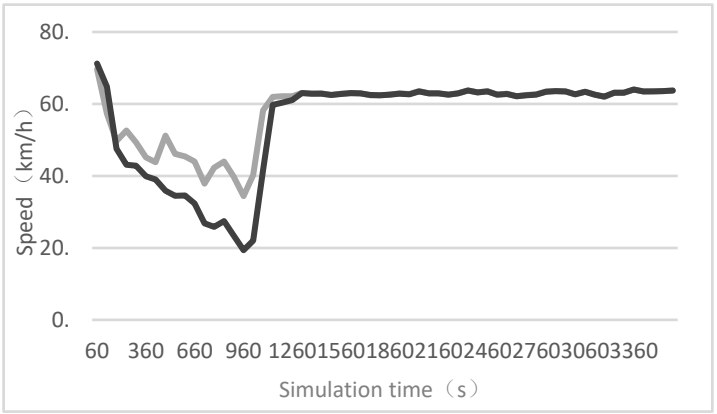

FIGURE 8 Comparison of Speed Between Variable Speed Limit and Static Speed Limit

It can be seen from Figure 8, the simulation time in the first 960s within the vehicle speed was declining trend, to about 900s to reach the lowest value. Because the accident occurred in the first 900s, the vehicles on the road were queued before the accident, with the passage of time the speed is getting lower and lower. After 900s, the accident processing is completed, the road section to restore the static speed limit, the rapid increase in traffic flow rate, 1320s after the vehicle's speed to restore stability, to maintain between 60-70km / h.

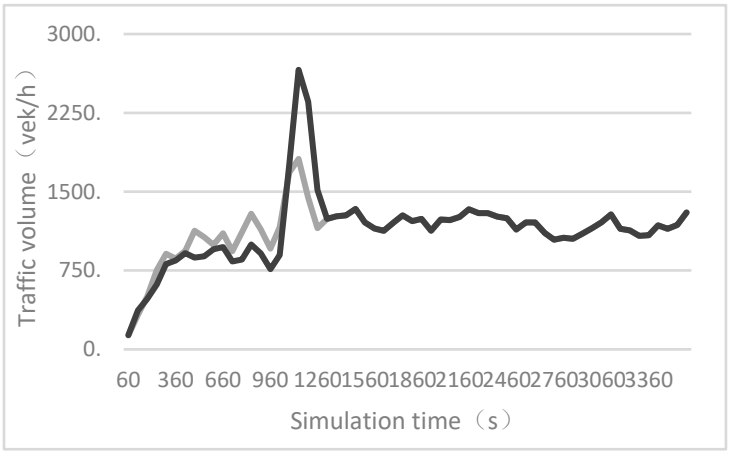

FIGURE 9 Comparison of Traffic Volume Between Variable Speed Limit and Static Speed Limit

It can be seen from Fig. 9 that in the first 960s of the simulation time, the traffic volume on the road section (calculated from the traffic flow within 60s) gradually increases, in which the growth rate of the first 240s is faster. From 960s to 1140s, the traffic volume increased sharply, reaching the maximum. Because this time, the accident has just been completed, variable speed limit to lift, a large number of vehicles queuing at the point of the accident can simultaneously move downstream at a higher speed, resulting in a rapid increase in traffic flow through the short period of time. From 1140s to 1320s, the traffic flow from the maximum quickly reduced to a stable level, because this time, queuing vehicles gradually leave the road, with the reduction of queuing vehicles, the unit time through the end of the traffic flow is also rapidly reduced. After 1320s, traffic flow is basically in a stable state, because at this time variable speed limit to lift, queuing vehicles have all out of the road.

4. CONCLUSION

Through the comparative analysis of the simulation results can be seen that the variable speed limit can indeed improve the traffic congestion in the tunnel group congestion situation, the specific conclusions are as follows:

1. When traffic accidents occur in the tunnel section, the traffic congestion on the road section is increased and the traffic density on the road section increases. The use of variable speed limit can slow down the increase in traffic density and reduce the increase in traffic density, and play a role in improving the stability of traffic flow.
2. The variable speed limit can reduce the travel time of the tunnel section, improve the operation efficiency of the vehicle, reduce the congestion time of the tunnel group, reduce the queue length of the vehicle and reduce the congestion degree of the tunnel group.
3. Variable speed limit can effectively reduce the driver's time cost, reduce the number of parking and parking time of vehicles to improve the stability of traffic flow in the tunnel section.
4. Variable speed limit can make the congestion state of the tunnel group section of the vehicle speed, traffic volume changes more gentle, the vehicle running more stable, the driver is quick to accelerate, the frequency of slowdown is lower, the driver's workload is

reduced, the speed difference is smaller, the probability of accident is reduced, and the traffic safety of the tunnel group is improved.

5. Variable speed limit to a certain extent, delayed the congestion of the tunnel group, but can not completely avoid the occurrence of congestion, to avoid a wide range of congestion, to improve the upstream road traffic safety.

References

1. Shaofei WANG, Zhi LIN, Jianzhong CHENG, "Probe into Traffic Safety Problems in Tunnels of Expressways in Mountainous Area". *Technology of Highway and Transport*, no.6,2009
2. Minli GE, Lu SUN, "Study on Montanic Highway Tunnel Traffic S afety" *Journal of Transportation Engineering and Information*, No.1,Vol. 11 Mar. 2013.
3. Shengrui ZHANG, Yun LI, Yougong ZHAO "Analysis method for traffic safety of mountainous freeway tunnel groups" *Journal of Traffic and Transportation Engineering*, Vol.11, No.6, Dec. 2011.
4. Gonghong HU, Yunfei FAN, Jianpin GAO "An Analysis on the Typical security factors in the Tunnels of Mountainous Expressways and Their Countermeasures" *Western China Communications Science & Technology*, 2007.
5. Guangzheng ZHOU, "Study On The Speed Limit of Highway Tunnels" *Chongqing: PhD's degree thesis of Chongqing Jiaotong University*, 2012.
6. Shunfeng HU, "Research on Highway Tunnel (Group) Traffic Safety Technology and Engineering Measures Considering the Dark Adaptation" *Xi' an: PhD's degree thesis of Chang' an University*, 2015.
7. Wenyong WANG, et al, "Study on Speed Limit of Vehicles on Freeway Tunnel Group" *Xi' an: PhD's degree thesis of Chang' an University, 2011*.
8. Zhongye ZHOU, Zhigao LIAO ,Benmin LIU, et al, "Analysis of Traffic Property and Safety in Freeway Tunnel Group " *Journal of Transport Information and Safety*, 2008.
9. Rui WU, Wendao ZHANG, Qi CHENG "Analysis of Highway Tunnel Speed Limit Based on Vissim" *Journal of Hubei University of Automotive Technology*, Vol. 29, No. 4, 2015.