# Effect analysis of speed guidance on traffic demand and driver compliance

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**Abstract**

Active traffic management is method of increasing capacity and smoothing traffic flows. As one of the most important methods, speed guidance control could be used to improve operational efficiency and reduce accident rates. This paper aims to consider a variety of factors to determine the best traffic management services. Driver obedience for the speed guidance value affected the effect directly. The effect might also lose even play a negative role when the traffic demand reached a certain level. Simulation was carried out depending on different traffic demand and driver compliance rate through abstract urban expressway model. Six kinds of traffic demand under different obedience level were analysed comparatively. Speed guidance control has the positive effect about safety and efficiency when the traffic demand is low or medium. When the traffic demand is high, the effect on safety and efficiency both are negative, and different driver compliance rate affected the effect level to some extent.

*Keywords:* Urban expressway, speed guidance, conflict, compliance rate, effect analysis

## 1 Introduction

As the backbone of the city road network, urban expressway shares large proportion of the traffic. In Beijing, major urban expressway accounts for only 8% of the total length, but carries nearly 50% of the traffic flow; only 5% bears more than 35% of the city traffic traveling in Shanghai [1]. Urban expressway plays a vital role in the urban road network, which gradually shifted from the large-scale infrastructure construction to refinement traffic management. With the traffic demand rapid growing, much more congestion and traffic accidents, integrated traffic management should be introduced in the background of coordination between road and vehicle. In recent years, with the development of Vehicles Infrastructure Integration system, taking active traffic management to expressway has become the research hotspots in this subject. The U.S. department of transportation five year its strategic research plan clearly pointed out that dynamic speed harmonization would be one of the main means to optimize traffic flow in urban transportation networks [2]. The ministry of science and technology of china has put intelligent traffic management system as one of the key research areas in the national science and technology plan. As an important part of the active traffic management, the speed guidance control has certain positive significance to improve the expressway capacity, reduce the accident risk and decrease even eliminates traffic congestion.

A traffic flow model of the expressway under the speed guidance condition was derived and an optimal coordination function for ramp metering and main road speed guidance to maximize the expressway service capacity and minimize the ramp queue delay was built [3-6]. Without entrance ramp limit, combining vehicles state and the road state, and the fuzzy control method for highway was given for highway speed limitation. Incorporation the characteristics of urban expressway with a macroscopic dynamic traffic flow model, a variable speed limit control approach was proposed based on the principle of fuzzy logic. The control for speed limit on expressway was a nonlinear and time variable system, intelligent control method of neural network and neural-fuzzy network were proposed to solve the problem. Speed limited value was determined by the binary tree analysis considering traffic volume, vehicle speed and occupies [7-9]. Shockwaves result in longer travel times and in sudden large variations in the speeds of the vehicles, which could lead to unsafe and dangerous situations, and variable speed limits could be used to eliminate or at least to reduce the effects of shock waves [10-14].

In fact, there have been several variable speed limits (VSL) applications in Germany, Netherlands, UK and other counties in Europe [15-17]. Some VSL experiment had been carried out and concluded that VSL experiment had a significant effect in reducing speed variation. These studies did not reveal the quantitative effect of VSL for the traffic safety [18-20]. Based on the accident data, Lee established a model, which was, used for comparative analysis the risk changes before and after the VSL controls. With the same model, Allaby analysed the road safety effects under different traffic demand by VSL controls. According to different traffic speed level,

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Abdel-Aty founded two kinds of dynamic accident prediction models, which used in the simulation analysis for different VSL control strategies. The effects of VSL on traffic flow were studied using fundamental traffic model and shockwave theory [21-27]. In addition, some new models were involved in VSL research [28, 29]. Nevertheless, most of them were designed to smooth traffic flow without considering fuel consumption. Studies have shown that VSL has good control effect on greenhouse gas emissions [30, 31]. VSL control method has essential uncertain characteristics about speed limits value for drivers; they generally choose the driving speed among a range. For example, if the value of VSL is 80km/h, then vehicle speed not exceeding 80km/h is legitimate, may be 30km/h, 50km/h or 60km/h. This will cause the control not precise enough. However, this paper focused on speed guidance control, which provides the driver with a clear speed value.

Although speed guidance control can improve road efficiency and reduce the rate of accident, obedience of the driver directly affects the effect. Simultaneously, when the road traffic demand reaches a certain level, the speed guidance control may lose effect even may play a negative role. Traffic demand and driver obedience were adopted as the sensitivity analysis variable. The result provides theoretical support for speed guidance control in active traffic management.

## 2 Macro dynamic traffic flow model

Control-oriented macro dynamic traffic flow model describes the relationship among traffic flow over space and time even traffic control variables. LW model was proposed by British scholar Lighthill and Whitham in 1955. Against the defects, Payne proposed dynamic relationship between speed and density. The model was further extended considering off-ramp, on-ramp and lane change factors by Papageorgiou. Scholars between domestic and foreign have also proposed various models which are mostly around dynamic relationship between speed and density. Model proposed by Payne and Papageorgiou are widely used in practice. Urban expressway was divided into several segments. Each segment contained up to one entrance and one exit. Speed guidance control was embedded as a new variable in urban expressway. Dynamic speed change was affected not only by regular traffic flow parameters but also interfered by speed guidance control variable. When speed guidance control introduced as a control variable, Payne model was extended. To make the calculated optimal speed guidance value more realistic and accurate, dynamic traffic flow model are described as equation (1) to equation (3):

$$q_i(k)=\rho_i(k)v_i(k)\lambda_i\,, \tag{1}$$

$$\rho_i(k+1)=\rho_i(k)+\frac{T}{L_i\lambda_i}(\rho_{i-1}(k)v_{i-1}(k)-\rho_i(k)v_i(k)+r_i(k)-s_i(k))\,, \tag{2}$$

$$v_i(k+1)=v_i(k)+\frac{T}{\tau}(u_i(k)-v_i(k))+\frac{T}{L_i}v_i(k)(v_{i-1}(k)-v_i(k))-\frac{1}{\tau}\left(\frac{vT}{L_i}\frac{\rho_{i+1}(k)-\rho_i(k)}{\rho_i(k)+\kappa}\right), \tag{3}$$

where is road segment index, is time interval index, is the time step used for data collection, is length of road segment. are the model parameters, is a time constant, is the anticipation constant and is model parameters which are equal at a segment. is the traffic density of road segment at time index, is the mean speed of road segment at time index, is the metering flow rate of road segment at time index, is the total off-ramp flow rate of road segment at time index, is the desired control speed of road segment at time index and is the number of lanes of road segments.

The paper determines the origins flow and speed parameters of upstream mainline by the ramp length of queue of upstream cell segment. The models are listed as equation (4) to equation (6):

$$w_0(k+1)=w_0(k)+T(d_0(k)-q_0(k))\,, \tag{4}$$

$$q_0(k)=\min\left[d_0(k)+w_0(k)/T,\ Q_0\frac{\rho_{\max}-\rho_{\mu,1}(k)}{\rho_{\max}-\rho_{crit,\mu}}\right], \tag{5}$$

$$v=\min\left[(1+\alpha)v_{crit,m}(k),\ v_{free}\exp[-\frac{1}{\alpha m}(\frac{\rho_{\mu,1}(k)}{\rho_{crit,u}})^{\alpha m}]\right], \tag{6}$$

where is the onramp flow capacity, is the maximum density of onramp, is the critical density of onramp at which the traffic flow becomes unstable, is the density of mainline which segment the onramp linked, is the critical speed of mainline, at which the traffic flow becomes unstable, is the speed of freely traffic flow, is the maximum number of vehicles stored in onramp and is the onramp demand flow.

Based on consideration of traffic safety, the speed change should be smooth temporally and spatially. Therefore, the control speed variation should be less than 10km/h over time and distance interval, the following constraints are adopted in equation (7):

$$\bar{V}_{\min}\le u_i(k)\le\bar{V}_{\max}\,, \tag{7}$$

where and are the minimum and maximum control speed for speed guidance control respectively, taken as 20 km/h and taken as 80 km/h.

The extended macroscopic dynamic traffic flow models of urban expressway under speed guidance control listed as formulas (1) to (7) which were the foundations of sensitivity simulation analysis.

## 3 Control strategy and simulation system

The Speed guidance value has great influence on the effect of traffic operation, domestic and international research results could be used as a sample. 85% speed value was usually used as the speed limit in some foreign country. The effects of safety and efficiency were determined by the speed dispersion of the vehicles on the road. When the roads are crowded, 85% speed as the speed limits seems not precise. To take full account of the parameter flexibility, dynamic control strategy of speed guidance value was shown in Figure 1.

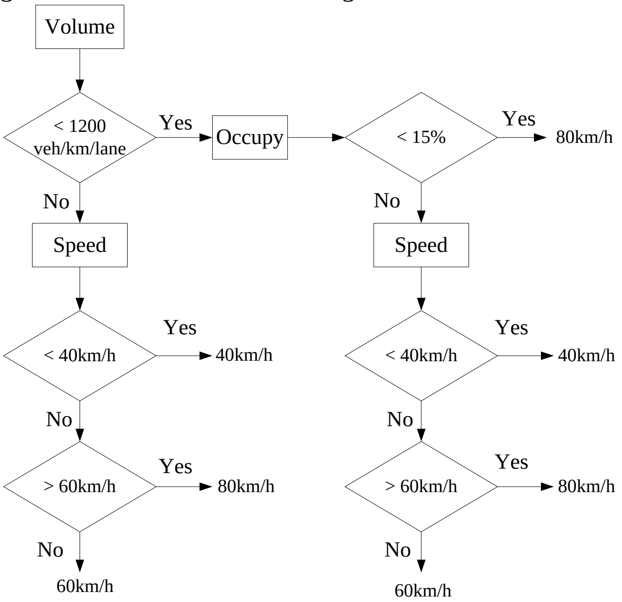


FIGURE 1 Strategy of speed guidance control

In the speed guidance control online simulation system, VISSIM software is used to simulate the real world traffic. The macro dynamic traffic flow model is established in MATLAB software. Data and control strategies were exchange through the API interface among VB.NET, VISSIM and MATLAB. According to the functional orientation, online simulation system was divided into four modules: simulation module, strategy module, interface module and database module. The structures of the simulation system as well as the relationship among the modules were shown in Figure 2.

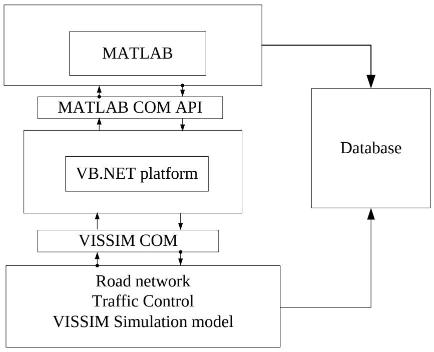


FIGURE 2 Framework of online simulation system

## 4 Simulation analysis and results

Road safety assessment can be divided into direct and indirect methods. Direct assessment method was based on accident statistics, which was widely used in road traffic management. Though the method was simple to operate, it also had some disadvantages, such as relatively small of the road traffic accidents data, relatively long of the statistical period, great randomness of the accident and other problems.

Traffic conflict technique is the representative method of the indirect traffic safety evaluation, which has obvious advantages, relatively large number of conflict, short period and strong regularity. It was extremely widely applied in the field of road traffic safety. However, traffic conflict observed manually always was arbitrary, taking a lot of manpower and resources.

Therefore, SSAM (Surrogate Safety Assessment Model) which was developed by the United States Federal Highway Administration was used to analyse micro-simulation model output trajectory file. SSAM employed the simulation method to analyse the security. Figure 3 showed the test expressway. The road section used in sensitivity simulation analysis of speed guidance control was shown in Figure 4. It was the inner ring expressway in Shanghai about 5.2 km long. The research road section contained bottleneck caused by reducing lane, which provided a direct target object to analyse the speed guidance control effect. The section was divided into eight parts and each one affected by speed guidance control. The cycle of speed guidance control changed was 1 minute.

FIGURE 3 Test expressway overview

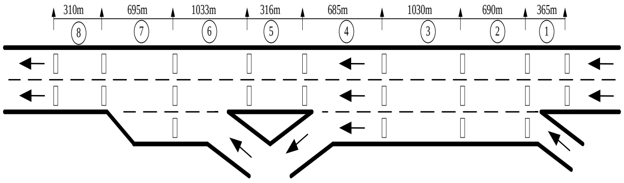


FIGURE 4 Simulation sections of expressway

The macroscopic traffic flow parameters characteristic is an important research content in traffic flow theory. As the backbone road network, traffic flow characteristic parameters have great value for the control and management of urban expressway. Parameters such as free-flow speed, capacity, blocking density, critical density and the critical speed described characteristic of traffic flow. Based on the real-time traffic date, basic parameters of the traffic flow were analysed and extracted, then the average length of the vehicle was statistical analysis to establish the relationship between occupy and density. Four parameter structure model proposed by Van Aerde in 1995 which implements conversion between macroscopic and microscopic traffic flow model has been widely applied. Data was collecting from Shanghai expressway traffic information collection system. Raw data collection interval period was 20s, and a complete data record includes acquisition time, flow, speed, occupancy, headway, data validation, etc. The error data was removed and repaired. Macroscopic dynamic traffic flow model parameters were shown in Table 1.

TABLE 1 Model parameters

| **Parameter** | $d_0(k)$ | $w_0(k)$ | $\rho_{\max}$ | $\rho_{crit,\mu}$ | $Q_0$ | $T$ | $v_{free}$ | $v_{crit,m}$ | $\alpha$ | $\alpha m$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **Value** | 2000 | 10 | 150 | 38 | 1800 | 10 | 78 | 50 | 0.05 | 1.87 |

Driver compliance rate and traffic demand were considered in sensitivity simulation analysis of urban expressway under speed guidance control. Driver compliance rate rose up from 0% to 100% step by 10% increments. 0% represented no speed guidance control and 100% represented the driver fully complied the speed guidance control.

Traffic demand of the mainline entrance rose up from 1000veh/h to 3500veh/h step by 500 veh/h increments. Traffic demand of the upstream entrance ramp rose up from 500veh/h to 1750veh/h step by 250 veh/h increments. Traffic demand of the downstream entrance ramp rose up from 1000veh/h to 3500veh/h step by 500 veh/h increments.

According to the traffic demand of ramp and entrance, modes of traffic demand was divided into six categories as shown in Table 2. Mode A, B, C and D represented that the traffic demand was in low level. Mode E and F corresponded to high traffic demand. Different random seed was selected and 6 times simulation had been carried out. Then the average result was utilized to analyse and evaluate the program.

TABLE 2 Traffic demand pattern

| **Traffic demand pattern** | **Mainline traffic demand** | **Upstream ramp traffic demand** | **Downstream ramp traffic demand** |
|---|---|---|---|
| A | 1000veh/h | 500veh/h | 1000veh/h |
| B | 1500veh/h | 750veh/h | 1500veh/h |
| C | 2000veh/h | 1000veh/h | 2000veh/h |
| D | 2500veh/h | 1250veh/h | 2500veh/h |
| E | 3000veh/h | 1500veh/h | 3000veh/h |
| F | 3500veh/h | 1750veh/h | 3500veh/h |

Each mode contained eleven different kinds of driver compliance rates; simulation analysis was conducted in VISSIM software. One km part of the expressway was selected as the travel time monitoring segment.

The number of conflicts and monitored link travel time under mode A traffic demand were showed in Figure 5. Conflicts tended to reduce when the driver compliance rate increased. Compared to uncontrolled situation, the conflicts decreased 36% when all the vehicles were under speed guidance control. Travel time decreased significantly at first and when 40% vehicles under control time reached the minimum. Monitored link travel time decreased 3.4% if all the vehicles were under speed guidance control. In the case of traffic patterns A, the results indicated that speed guidance control not only reduce the number of conflicts but also reduce travel time, which demonstrated that safety and efficiency both had been improved.

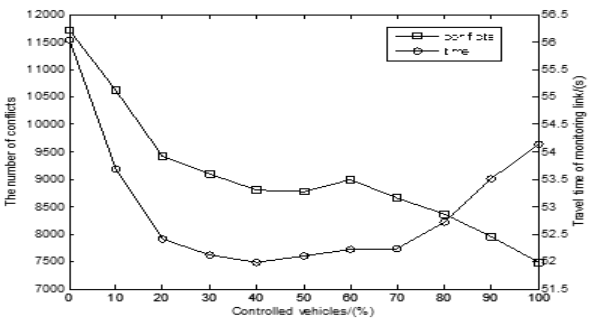


FIGURE 5 Conflicts and travel time under mode A

Figure 6 showed the number of conflicts and monitoring link travel time changes in the case of mode B under different driver compliance rate. Conflicts also tended to reduce when the driver compliance rate increased. Compared to uncontrolled situation, the conflicts decreased 52% when all the vehicles were under control, which was as same as the mode A. Monitored link travel time decreased 5% if all the vehicles were under speed guidance control. In the case of traffic patterns B, the results also indicated that speed guidance control not only reduce the number of conflicts but also reduce travel time, safety and efficiency both had been improved, the effect was same as the mode.

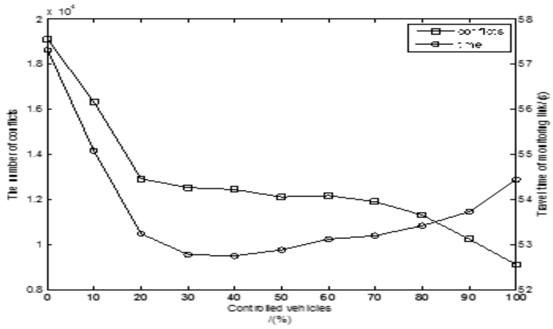

FIGURE 6 Conflicts and travel time under mode B

The number of conflicts and monitored link travel time under mode C were showed in Figure 7. Conflicts were not tended to reduce when the driver compliance rate increased. The number of conflicts slight rose when the driver's obedience was 50%. The travel time changes were different from mode A and B. With the increased of driver compliance rate, the travel time was in the course of a partial repetition. Because of the growing traffic flow, interactions between controlled vehicles and uncontrolled vehicles began to appear. Compared to uncontrolled situation, the conflicts decreased 64% when all the vehicles were under speed guidance control. Monitored link travel time decreased 10% if all the vehicles were under speed guidance control. In the case of traffic patterns C, the effect of reducing conflicts and travel time was more obvious.

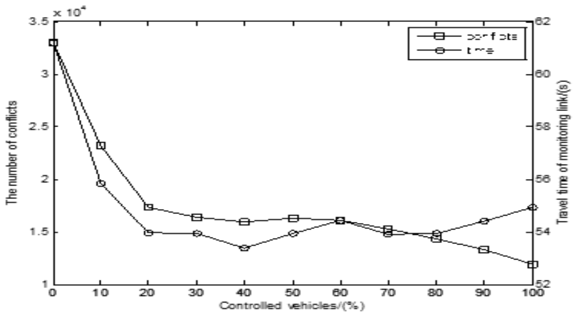

FIGURE 7 Conflicts and travel time under mode C

The number of conflicts and monitored link travel time under mode D were showed in Figure 8. Conflicts and time changed irregularly. Compared to uncontrolled situation, the conflicts decreased 74% when all the vehicles were under speed guidance control. Monitored link travel time decreased 33% when all the vehicles were under speed guidance control. In the case of traffic patterns D, safety and efficiency both also had been improved.

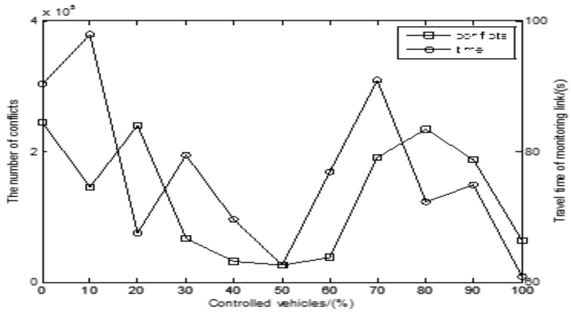

FIGURE 8 Conflicts and travel time under mode D

The number of conflicts and monitored link travel time under mode E were showed in Figure 9. Conflicts changed irregularly, but the travel time tended to rise when the driver compliance rate increased. Compared to uncontrolled situation, the conflicts increased 1.3% when all the vehicles were under control. Monitored link travel time increased 21% when the vehicles were under speed guidance control. Both conflicts and travel time were increased in traffic patterns E, which demonstrated that speed guidance control had negative impact on road safety and efficiency.

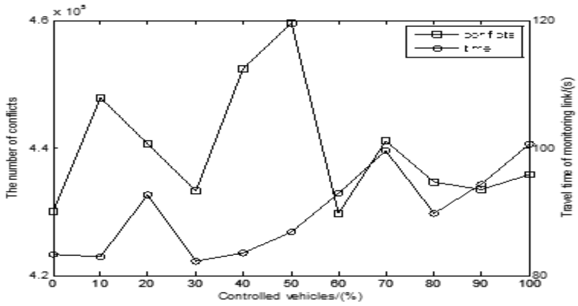

FIGURE 9 Conflicts and travel time under mode E

The number of conflicts and monitored link travel time under mode F were showed in Figure 10. Travel time changed irregularly, but the conflicts tended to gradually rise when the driver compliance rate increased. Compared to uncontrolled situation, the conflicts increased 3.4% when all the vehicles were under control. Monitored link travel time increased 11.4% when the vehicles were under control. Both conflicts and travel time were increased. Speed guidance control had negative impact on road safety and efficiency, which was the same as the mode E.

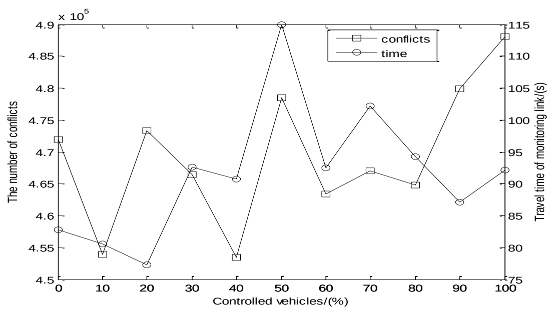

FIGURE 10 Conflicts and travel time under mode F

Comparative statistics analysis of speed guidance control effects were listed in Table 3. It can be seen that in traffic demand pattern A, B, C and D, the number of conflicts and travel time showed a downward trend. Especially in the case of traffic demand mode D both had the largest decline. In those four traffic demand modes, speed guidance control has positive effect in enhancing road traffic safety and improving operational efficiency. By contrast, conflicts and travel times were increased in mode E and F; speed guidance control had negative effects in such two kinds of mode. TRG files generated by simulation results were analysed through SSAM. Conflicts were contrastive processed and the results shown in Figure 11.

TABLE 3 Change of conflicts and travel time under speed guidance control

| Traffic demand pattern | Change of the conflicts /% | Change of travel time /% |
|---|---|---|
| A | -36.1061 | -3.40232 |
| B | -52.1696 | -5.00489 |
| C | -63.7791 | -10.2006 |
| D | -74.1142 | -32.6657 |
| E | 1.334282 | 20.65837 |
| F | 3.422591 | 11.35174 |

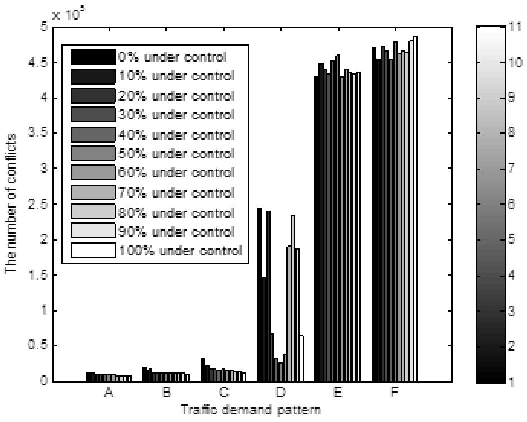


FIGURE 11 Conflicts under different traffic demand

The result of data analysis showed that travel time and the number of conflicts were reduced in low traffic demand when the expressway under speed guidance control. If the traffic demands in high level, both were increased immediately. The effect of speed guidance control were different, in some cases it might had a negative effect. When the speed guidance control applied in practice, detailed analysis about its boundary conditions should be considered to maximize the positive effect.

## 5 Conclusions

Simulation analysis platform of urban expressway was established by VB.NET. Data and control strategy were exchange between VISSIM and MATLAB. Simulation was carried out depending on different traffic demand and driver compliance rate through abstract urban expressway model. Six kinds of traffic demand under different obedience level were analysed comparatively. Speed guidance control has the positive effect about safety and efficiency when the traffic demand is low or medium. When the traffic demand is high, the effect on safety and efficiency both are negative. Different driver compliance rate affected the effect level to some extent. Concrete measures should be designed based on the specific circumstances when the speed guidance control involved in the management and control of urban expressway.

Nevertheless, there are remains rooms that needed future endeavours. More factors should be taken into account in the research. The length of the road section was decided considering the reference researches, which pay close attention to the physical properties of the expressway. Dividing the length of the road into different sections will inevitably lead to different results, and then the effect of speed guidance control was diversification. Optimal control model based on length of the road needs to establish in the future. Though efficiency and security had been taking into account in the research, environmental benefits were ignored. As a very important direction of future research, speed guidance control based on ecological driving is required to establish the models and strategies.

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