SENSITIVITY SIMULATION ANALYSIS OF URBAN EXPRESSWAY UNDER SPEED GUIDANCE CONTROL

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ABSTRACT

Urban expressway could improve operational efficiency and reduce accident rates under speed guidance control. 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 analyzed 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.

Keywords: *Urban Expressway; Speed Guidance; Conflict; Compliance Rate*

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 [1]; in Shanghai, only 5% bears more than 35% of the city traffic traveling. 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 active traffic management should be introduced in the background of coordination between road and vehicle. 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 [2]. Without entrance ramp limit, and combining vehicles state and the road state, the fuzzy control method for highway was given for highway speed limitation [3]. 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 [4]. 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 [5, 6]. Speed limited value was determined by the binary tree analysis considering traffic volume, vehicle speed and occupies [7].

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 [8]. The model was further extended considering off-ramp, on-ramp and lane change factors by Papageorgiou [9, 10]. 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 [11].

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 as follow.

$$q_i(k) = \rho_i(k)v_i(k)\lambda_i \qquad (1)$$

$$\rho_i(k+1) = \rho_i(k) + \frac{T}{L_i\lambda_i}[q_{i-1}(k) - q_i(k) + r_i(k) - s_i(k)] \qquad (2)$$

$$v_i(k+1) = v_i(k) + \frac{T}{\tau}[v(\rho_i(k)) - v_i(k)] + \frac{T}{L_i}v_i(k)[v_{i-1}(k) - v_i(k)] \qquad (3)$$
$$- \frac{\eta T}{\tau L_i}[\frac{\rho_{i+1}(k) - \rho_i(k)}{\rho_i(k) + \kappa}] + \frac{\gamma T}{\tau L_i}[\frac{v_{sg,i+1}(k) - v_{sg,i}(k)}{v_{sg,i}(k)}]$$

$$v(\rho_i(k)) = \min[v_f \exp[-\frac{1}{a}(\frac{\rho_i(k)}{\rho_{crit}})^a], v_{sg,i}(k)] \qquad (4)$$

Where $q_i(k)$ is the traffic volume, k indicates the time instant, $\rho_i(k)$ is the traffic density, $v_i(k)$ is the traffic speed, $r_i(k)$ is the on-ramp volume, $s_i(k)$ is the off-ramp volume, λ_i is the number of the lanes, L_i is the length of the segment, $v_{sg,i}(k)$ is the value of the speed guidance, T is the time step used for the simulation of traffic flow. τ , η ,a , κ and γ are model parameters, v_f is the average speed that drivers assume if traffic is freely flowing, ρ_{crit} is the density at which the traffic flow is maximal, ρ_{max} is the maximum density. $v(\rho_i(k))$ is the desired speed by the drivers.

$$q_0(k) = \min[q_{lim,1}(k), d_0(k) + \frac{w_0(k)}{T}] \qquad (5)$$

$$q_{lim,1}(k) = \begin{cases} q_{cap,1} & ; \text{if } v_{lim,1}(k) \geq v_0(\rho_{cirt}) \\ v_{lim,1}(k)\rho_{crit}[-a\ln(\frac{v_{lim,1}(k)}{v_f})]^{\frac{1}{a}} & ; \text{if } v_{lim,1}(k) < v_0(\rho_{cirt}) \end{cases} \qquad (6)$$

$$v_{lim,1}(k) = \min(v_1(k), v_{sg,1}(k)) \qquad (7)$$

Where $q_0(k)$ is the traffic volume of entrance, $d_0(k)$ is the traffic demand, $w_0(k)$ is the queue length. $q_{lim,1}(k)$ is the restricted flow of the first segment under speed guidance control, $v_{lim,1}(k)$ is the restricted speed value. $q_{cap,1}$ is the capacity of the first segment.

If the road segment contains the ramp, the flow is

$$q = \min[Q_i \frac{\rho_{max} - \rho_i(k)}{\rho_{max} - \rho_{crit}}, d_i(k) + \frac{w_i(k)}{T}] \qquad (8)$$

Where $d_i(k)$ is the on-ramp traffic demand, $w_i(k)$ is the queue length of the on-ramp, Q_i is the capacity of the on-ramp.

Origins and on-ramp are modeled with a simple queue model. The length of the queue equals the previous queue length plus the demand, minus the outflow.

$$w_i(k+1) = w_i(k) + T[d_i(k) - q_i(k)] \qquad (9)$$

The extended macroscopic dynamic traffic flow models of urban expressway under speed guidance control listed as formulas 1 to 9 which were the foundation of sensitivity simulation analysis.

3. CONTROL STRATEGY AND SIMULATION SYSTEM FRAMEWORK

3.1 Dynamic Control Strategy of Speed Guidance Control

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.
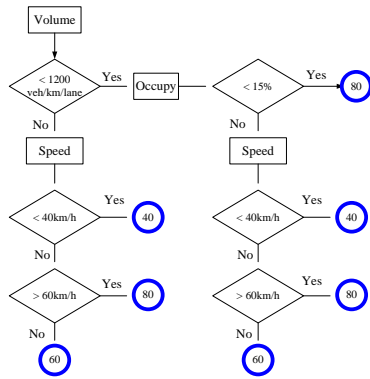
Figure 1: Strategy Of Speed Guidance Control

3.2 Framework of Online Simulation System

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.
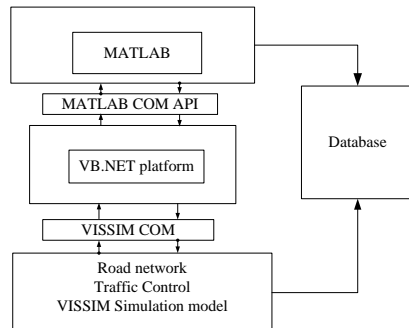

Figure 2: Framework Of Online Simulation System

4. NUMERICAL ANALYSIS

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 analyze micro-simulation model output trajectory file. SSAM employed the simulation method to analyze the security.

The road section used in sensitivity simulation analysis of speed guidance control was shown in Figure 3. It was the inner ring expressway in Shanghai about 5.2km long.
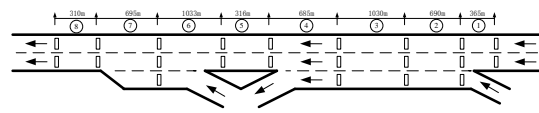

Figure 3: Simulation Sections Of Expressway

The research road section contained bottleneck caused by reducing lane which provided a direct target object to analyze 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. Macroscopic dynamic traffic flow model parameters were shown in Table 1.

Table 1: Model Parameters

Parameter	Value
T $/(s)$	10
τ $/(s)$	18
v_f $/(km\cdot h^{-1})$	78
γ $/(km^2\cdot h^{-1})$	10
ρ_{crit} $/(veh\cdot km^{-1})$	38
ρ_{max} $/(veh\cdot km^{-1})$	150

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, model of traffic demand was divided into six categories as shown in Table 2. Model A, B, C and D represented that the traffic demand was in low level. Models 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 analyze 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. 1 km part of the expressway was selected as the travel time monitoring segment. Statistics of travel time under different traffic demand patterns were shown in Table 3.

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	-63.7891	-10.2006
D	-74.1142	-32.6657
E	1.334282	20.65837
F	3.422591	11.35174

On the other hand, TRG files generated by VISSIM simulation results were analyzed through SSAM. Conflicts were contrastive processed and the results shown in Figure 4 and Figure 5.
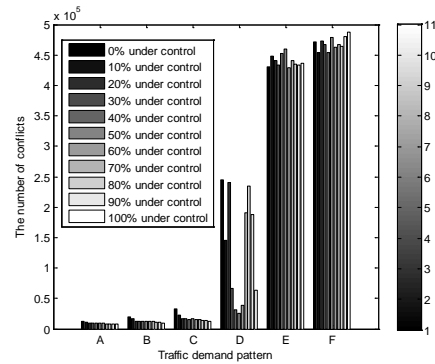

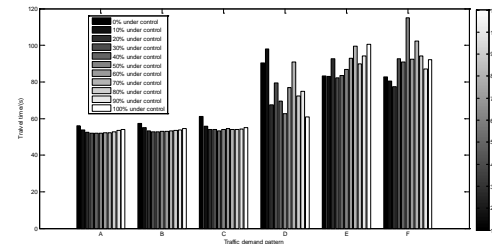*Figure 4: Conflicts Under Different Traffic Demand*

Figure 5: Travel Time Under Different Traffic Demand Mode

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. CONCLUSION

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 analyzed 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.

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