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Research Article

Research on Joint Control of On-Ramp Metering and Mainline Speed Guidance in the Urban Expressway Based on MPC and Connected Vehicles

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The traffic operational efficiency of the urban expressway system will affect one of the entire cities. Moreover, the idea that traffic control can improve the traffic operational efficiency of the urban expressway system has been fully confirmed. At present, the main control methods include on-ramp metering and speed guidance control. However, there is a gap in using these two control methods together, such as unclear application conditions and unsystematic methods. In this paper, on-ramp metering and speed guidance control are combined effectively. Based on the research of METANET macroscopic traffic flow model and model predictive control (MPC), a novel joint control method based on MPC and connected vehicles (CVs) for on-ramp metering and speed guidance control of the urban expressway is proposed. Finally, the simulation results show that the proposed control method can effectively improve the traffic efficiency and traffic safety.

1. Introduction

The urban expressway system is a corridor for urban mass transit and rapid traffic, and its smoothness directly affects the traffic efficiency of the entire city. At present, many large and medium-sized cities and towns are facing serious traffic congestion problems. How to ease traffic congestion and to prevent the traffic accident of urban expressways through intelligent operation management measures has become the focus of relevant management departments [1]. Relevant theoretical research and practice prove that the combination of these two methods of ramp control and dynamic speed guidance can more effectively alleviate the frequent congestion and accident problems of the urban expressway bottleneck.

In this study, the MPC idea is applied to the joint control of the ramp and the mainline of the urban expressway. The classical METANET model is optimized and reconstructed, and the optimized model is used as the MPC prediction model to realize the urban expressway entrances. The on-ramp metering and the mainline speed guide jointly control to improve traffic efficiency and traffic safety.

2. Literature Review

Most of the research on the coordinated control of the on-ramp and the mainline speed guidance is based on the METANET model of the expressway macro traffic flow model. However, the METANT model was put forward and used since the 1990s [2]. Van et al. [3] improved the second-order METANET model through the fundamental diagram of traffic flow to make it more suitable for the urban expressway under the coordinated control of ramp and variable speed limit, and the system was simulated by a virtual road segment. Elefteriadou et al. [4] proposed a data-driven collaborative control method. By introducing the bottleneck failure theory into the expressway system, the bottleneck failure probability based on a large number of data predictions is used as a criterion for judging the implementation control. The goal is to maintain the bottleneck failure probability below the set threshold.

Liang [5] evaluated the expressway system under system control from the two dimensions of traffic efficiency and the environment through the METANET macroscopic traffic flow model and the comprehensive modal emission model (CMEM) vehicle emission model and optimized the parameters in the model. Moreover, fuel consumption and/or emission have increasing attention in traffic control [6]. Li [7] used the neural network technology to design the freeway speed guidance control algorithm and compared the effects of independent ramp metering and ramp and mainline coordination control. The results show that coordinated control is better than the independent ramp metering in traffic efficiency.

In the study of joint control of ramp and mainline speed guidance based on MPC strategy, the prediction model is dominated by the METANET macro traffic flow model [8], but the ramp and mainline speed guidance control will affect the model to a certain extent, and the model needs to be made some detailed improvements. However, MPC approach was widely used to ramp metering and speed guidance [9–13]. Moreover, dynamic speed limit control was jointly applied with other models, such as a traffic state prediction model [14–16]. From the literature review, it was found that the operational efficiency or capacity was used as the main optimization objective while traffic safety was rarely considered. Besides, there was a new trend that the connected vehicles and/or V2X (vehicle to vehicle, vehicle to infrastructure, and others) were considered increasingly which greatly influenced the operation environment [17, 18].

This study will optimize the METANET macro traffic flow model, improve the adaptability of the model under the joint control of the ramp and the mainline speed guidance, and finally propose an MPC scheme based on this. More importantly, traffic safety will be also considered together with the connected vehicles which were analyzed scarcely.

3. METANET Model Modification

3.1. Basic METANET Model Analysis. The essence of the METANET model is the speed dynamics equation [2]. The core idea is that when the current traffic conditions change, the driver needs a certain time to adjust the driving speed to the equilibrium speed, that is, the change of the vehicle speed is always behind the downstream $x + \Delta x$ for a time interval τ [19]. It can be expressed as follows:

$$v(x, t + \tau) = v[\rho(x + \Delta x, t)]. \tag{1}$$

The relationship between headway distance and density is $\Delta x = 1000/\rho$; after performing Taylor expansion, constant transformation, etc., the standard form of the METANET model is finally obtained, as shown in the following equation:

$$\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial x} = \frac{v\cdot\rho(x,t) - v(x,t)}{\tau} - \frac{\gamma}{\tau\rho}\frac{\partial\rho}{\partial x}. \tag{2}$$

After the discretization of the model, we can obtain the following equations:

$$\frac{\partial v}{\partial t} = \frac{1}{T}\left[v_i(n+1) - v_i(n)\right], \tag{3}$$

$$\frac{\partial v}{\partial x} = \frac{1}{L_i}\left[v_i(n) - v_{i-1}(n)\right], \tag{4}$$

$$\frac{\partial\rho}{\partial x} = \frac{1}{L_i}\left[\rho_{i+1}(n) - \rho_i(n)\right]. \tag{5}$$

On this basis, after introducing the relevant sensitivity coefficients, several sets of difference equations as shown in equations (6)–(9) can be obtained, which is the common type of the current METANET model. Equation (6) is the flow-density-speed parameter relationship equation, equation (7) is the dynamic density equation, equation (8) is the dynamic speed equation, and equation (9) is the steady-state speed equation:

$$q_i(k) = \rho_i(k)v_i(k)\lambda_i, \tag{6}$$

$$\rho_i(k+1) = \rho_i(k) + \frac{T}{L_i\lambda_i}\left[q_{i-1}(k) - q_i(k) + r_i(k) - s_i(k)\right], \tag{7}$$

$$\begin{aligned} v_i(k+1) = {} & v_i(k) + \frac{T}{\tau}\left\{V\left[\rho_i(k)\right] - v_i(k)\right\} \\ & + \frac{T}{L_i}v_i(k)\left[v_{i-1}(k) - v_i(k)\right] - \frac{\eta T}{\tau L_i} \\ & \cdot \frac{\rho_{i+1}(k) - \rho_i(k)}{\rho_i(k) + k} + \frac{T}{\tau L_i}\cdot\frac{v_{i+1}(k) - v_i(k)}{v_i(k)}, \end{aligned} \tag{8}$$

$$V\left[\rho_i(k)\right] = v_f\cdot e^{\left[-(1/a)\left(\left(\rho_i(k)\right)/\rho_{\mathrm{cr}}\right)^a\right]}, \tag{9}$$

where $\rho_i(k)$ is the average density of the road segment i at time k, veh/km or veh/(km·lane); $v_i(k)$ is the average speed of the road segment i at time k, km/h; $q_i(k)$ is the volume of the road segment i at time k, veh/h. $r_i(k)$ is the on-ramp volume connecting the road segment i at time k, veh/h; $s_i(k)$ is the off-ramp volume connecting the road segment i at time k, veh/h; v_f is the free-flow speed, km/h; ρ_{cr} is the critical density, veh/km; L_i is the length of the section i, km; T_i is the sampling cycle, h; λ_i is the number of lanes of the section i; τ is the time lag coefficient; η is the expected coefficient; a is the model parameter.

Since the METANET model is a set of difference equations obtained after discretization in space and time, the solution of the model can be continuously promoted by iteration. As shown in Figure 1, during the k^{th} period in the spatial dimension, the traffic flow parameters in the segment $i+1$ can be derived from the segment i. In the section i on the time dimension, the traffic flow parameters of the $k+1^{\mathrm{th}}$ cycle can be derived from the k^{th} cycle and so on [20].

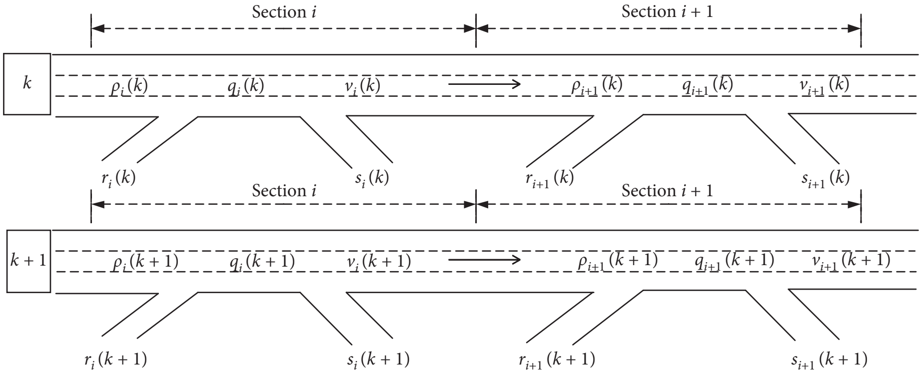

FIGURE 1: Schematic diagram of the METANET model.

3.2. METANET Model Optimization under Joint Control. The basic METANET macro traffic flow model is mainly proposed for the uncontrolled urban expressway system. If the joint control of the on-ramp and the mainline speed guidance were implemented for the urban expressway system, the METANET model needs to be further optimized and improved to meet the implementation control.

The main improvements focus on three aspects: the flow equation for the initial section, the flow equation for the on-ramp, and the sensitivity factor of speed guidance.

3.2.1. Initial Section Flow Equation. The basic METANET model applies to urban expressway sections without speed guidance control, and the traffic flow conditions are generally homogeneous. After the implementation of the speed guidance control to some sections of the urban expressway, the traffic flow conditions of the entire urban expressway will no longer be the state of the previous homogeneous distribution. In other words, the traffic flow parameters of the speed guidance control section will no longer be the traffic flow parameters of the previous section of the section or the previous period without the speed guidance control is derived. Therefore, it is necessary to add the traffic flow equation of the initial section of the urban expressway speed guidance control section and to derive the traffic flow parameters of the speed guidance control section by the traffic flow parameters of the initial section.

First, after implementing the speed guidance control, the speed situation has changed and the actual driving speed in the road section, $v_1^{\mathrm{REAL}}(k)$, is the minimum of the speed value and the speed limit value was calculated based on the previous road segment, as shown in equation (10). where ω indicates the CVs ratio in the heterogeneous flow and also the percent of vehicles following the control. $\omega \in [0,1]$, where $\omega = 0$ indicates that there is no speed guidance control and $\omega = 1$ shows that each vehicle strictly adheres to speed guidance control:

$$v_1^{\mathrm{REAL}}(k) = \min\left\{v_1(k), \omega v_1^{VSL}(k)\right\}. \tag{10}$$

After the determination of the actual driving speed, the traffic flow volume of the initial section for the speed guidance can be determined, as shown in equations (10)–(12), where, $d_0(k)$ and $w_0(k)$ are the traffic demand and the number of queued vehicles of the on-ramp, respectively. It should be noted that if the initial section of the speed guidance control includes an on-ramp, the volume of the initial section is in the form shown in equations (11) and (12); otherwise, $q_1(k) = q_1^{\mathrm{REAL}}(k)$.

$$q_1(k) = \min\left[q_1^{\mathrm{REAL}}(k), d_0(k) + \frac{w_0(k)}{T}\right], \tag{11}$$

$$q_1^{\mathrm{REAL}}(k) = \begin{cases} q_1^{\mathrm{cap}}, & v_1^{\mathrm{REAL}}(k) \geq V(\rho_{\mathrm{cr}}), \\ v_1^{\mathrm{REAL}}(k) \cdot \rho_{\mathrm{cr}}\left[-a \ln \frac{v_1^{\mathrm{REAL}}(k)}{v_f}\right]^{1/a}, & v_1^{\mathrm{REAL}}(k) < V(\rho_{\mathrm{cr}}), \end{cases} \tag{12}$$

where $q_1^{\mathrm{REAL}}(k)$ indicates the traffic flow volume at actual speed; q_1^{cap} is the expressway segment capacity; and $V(\rho_{\mathrm{cr}})$ represents the speed value (critical speed) corresponding to the critical density.

3.2.2. On-Ramp Flow Equation. The volume equation for the on-ramp is shown in equations (13) and (14), where $q_i(\rho_{\mathrm{jam}} - \rho_i(k))/(\rho_{\mathrm{jam}} - \rho_{\mathrm{cr}})$ indicates the merging volume to mainline and $d_i(k) + w_i(k)/T$ indicates the on-ramp demand. Meanwhile, the final merging volume will also be subject to the on-ramp metering rate, $r_i(k)$. In equation (14), $w_i(k)$ and $d_i(k+1)$ represent the number of queued vehicles and on-ramp traffic demand, respectively:

$$q_i^{\mathrm{RAMP}}(k) = r_i(k) \cdot \min\left\{q_i \frac{\rho_{\mathrm{jam}} - \rho_i(k)}{\rho_{\mathrm{jam}} - \rho_{\mathrm{cr}}}, d_i(k) + \frac{w_i(k)}{T}\right\}, \tag{13}$$

$$w_i(k+1) = w_i(k) + T\left[d_i(k+1) - q_i(k)\right]. \tag{14}$$

3.2.3. Speed Guidance Sensitivity Factor. The most intuitive effect of speed guidance control is the effect on dynamic speed for the vehicles, which can be reflected in the speed-density sensitivity parameter, η. In the process of METANET traffic flow equation from the continuous equation through Taylor expansion and discretization to difference equation, η is essentially derived from the partial derivative of the speed-density function to the density. It can be corrected according to equation (15), where $\rho_{\mathrm{cr}}^{\mathrm{VSL}}$ is the critical density and can be obtained from the volume-density fundamental diagram:

$$\eta = \frac{\partial V\left[\rho_i(k)\right]}{\partial \rho_i(k)} = -v_f^{\mathrm{VSL}} \cdot \frac{\left[\rho_i(k)\right]^{a-1}}{\left(\rho_{\mathrm{cr}}^{\mathrm{VSL}}\right)^a} \cdot e^{(-1/a)\left[\rho_i(k)\right]^a/\left(\rho_{\mathrm{cr}}^{\mathrm{VSL}}\right)^a}. \tag{15}$$

4. MPC Control Scheme

4.1. Basic Idea. MPC is a control structure based on a predictive model. In this research, the improved METANET macroscopic traffic flow model for urban expressway is used as the predictive model. Then, a genetic algorithm is used to solve the model to obtain the speed guidance control value and the on-ramp metering rate, and the rolling optimization is performed in a fixed period.

4.2. Joint Control Model. Based on the improved METANET model, the joint control model embeds the control methods of on-ramp metering and speed guidance into the traffic flow model to describe the traffic flow conditions under the joint control mode

Then, by solving the multiobjective function, the optimal on-ramp metering and speed guidance strategies are obtained. In the modified METANET model, the on-ramp metering rates and expected speed values are embedded in a set of closed expressions, so the optimal metering rates and speed guide values can be jointly solved. The joint control model mainly consists of three parts: dynamic traffic flow model, objective function, and constraints.

4.2.1. Dynamic Traffic Flow Model. The dynamic traffic flow model consists of three components: the speed guidance initial section model, the speed guidance road segment model, and the on-ramp traffic volume model.

4.2.2. Objective Function. The selection of the objective function follows two main principles: the minimum total travel time (TTT, including the mainline and the on-ramp vehicles) and the least number of serious conflicts (SCs). The former focuses on urban expressway traffic efficiency and the latter on traffic safety. TTT can be calculated from the detector data, while the SCs cannot. In this study, an SC prediction model is introduced by the relationship between traffic flow parameters and the SCs, and the minimum predicted the value of the SC number is one of the objective functions.

Due to the complexity and randomness of traffic accidents or traffic conflicts, microscopic simulation cannot be directly used to evaluate traffic safety. However, the operational risk prediction model [21] can be constructed from measurable variables related to traffic safety.

This study intends to screen out the most representative indicators by the factor analysis method and uses these indicators as the independent variables of the accident risk index model to construct a conflict risk prediction (CRP) model. Through the regression analysis (RA) between the number of SCs and the selected variables, the model is initially constructed and the model is adapted to be the objective function of the MPC control model by the corresponding transformation.

The first step in the study is to select traffic flow parameters that may affect traffic safety and can be detected by road detectors. The selected parameters are as follows: urban expressway mainline traffic q_m, ramp traffic q_r, ramp vehicle average speed v_r, mainline average speed v_m, mainline time speed difference (SVT), mainline space speed difference (SVD), and mainline occupancy o_m; the values of these parameters can be obtained through the detector. The section of simulated data collection is the section of Beihuan avenue (Beihuan Nanshan interchange-Shenyun interchange) in Shenzhen with the most interlacing complex conflicts (Beihuan Majialong flyover-Beihuan Nanhai interchange). And, the speed is obtained by the average speed of the location; through the investigation, a total of 30 sets of data were obtained.

Factor analysis is a data extraction and simplification technique by analyzing the relationship between variable data, to avoid the interference of information overlap on modeling and select several independent variables with high common factor loading (i.e., high information content) as the input parameters of the model.

So far, four input parameters of the conflict risk prediction model were determined by factor analysis with SPSS software: SVD, SVT, mainline occupancy, mainline, and ramp speed difference.

Based on determining the input parameters, combined with the number of serious traffic conflicts ($\mathrm{TTC} \leq 5\,\mathrm{s}$ or $\mathrm{PET} \leq 1.5\,\mathrm{s}$) analyzed by the surrogate safety assessment model (SSAM), the conflict risk prediction model is constructed through regression analysis. The results of multiple linear regressions are shown in Table 1.

In summary, the linear regression model is shown in the following equation:

$$\begin{aligned}\mathrm{PSC}_i = {} & 591.634 - 29.744 O_i + 1.625 \Delta_i + 1.638 \mathrm{SVT}_i \\ & + 0.877 \mathrm{SVD}_i.\end{aligned} \tag{16}$$

According to the conversion relationship between the occupancy and the density, the parameters such as speed difference are further specified, and the number of predicted serious conflicts can also be expressed as follows:

$$\begin{aligned}\mathrm{PSC}_i = {} & 591.634 - 14.872 \rho_i + 1.625\left(v_i - v_{r_i}\right) \\ & + 1.638\left(v_i(k+1) - v_i(k)\right) + 0.877\left(v_i(k) - v_{i-1}(k)\right).\end{aligned} \tag{17}$$

Consider the total travel time and the number of serious conflicts. The objective function is as shown in the following equation:

Table 1: Coefficient[a] table.

Model		Unnormalized coefficient		Standardization coefficient	t	Significant	Collinear statistics	
		B	Standard error	Beta			Tolerance	VIF
1	(Constant)	591.634	142.612		4.149	0.000		
	Occupancy	−29.744	7.537	−0.805	−3.946	0.001	0.091	3.033
	Mainline and ramp speed difference	1.625	2.186	0.152	1.743	0.043	0.091	2.043
	SVT	1.638	2.932	0.036	5.559	0.000	0.908	1.102
	SVD	0.877	1.168	0.046	3.740	0.003	0.960	1.042

[a] Dependent variable: number of serious conflicts.

$$\begin{aligned}\min J(k) = {} & T \sum_{i=k}^{k+N_p-1}\left[\sum_{m,i}\rho_{m,i}(k)L_m\lambda_m + \sum_i L_i^q(k)\right] \\ & + \sum_i\left[591.634 - 14.872\rho_i + 1.625\left(v_i - v_{r_i}\right) + 1.638\left(\left|v_i(k+1) - v_i(k)\right|\right) + 0.877\left(\left|v_i(k) - v_{i-1}(k)\right|\right)\right],\end{aligned} \tag{18}$$

where $L_i^q(k)$ indicates the length of the queue for the ramp.

4.2.3. Constraints. Based on the basic principle of traffic flow theory and the actual traffic conditions of the urban expressway bottleneck, the following constraints should be considered in the joint control model: the upstream traffic of the mainline is lower than the actual bottleneck capacity; the variation of the velocity guidance value in the adjacent interval of the same time and at the adjacent time of the same interval should be less than 10 km/h; the queue length of the ramp is less than the effective length of the ramp; the fluctuation of the merge rate is less than 15%, as shown in equations (19)–(23) [22–24]:

$$\lambda_i\rho_{i-1}(k)v_{i-1}(k) \le q_i^{\text{cap}}, \tag{19}$$

$$\left\|v_{i-1}(k) - v_i(k)\right\| \le 10, \tag{20}$$

$$\left\|v_i(k+1) - v_i(k)\right\| \le 10, \tag{21}$$

$$w_i(k) < L_{\text{ramp}}, \tag{22}$$

$$\frac{\left\|r_i(k+1) - r_i(k)\right\|}{r_i(k)} \le 15\%, \tag{23}$$

where q_i^{cap} indicates road capacity, veh/h; $w_i(k)$ indicates the length of the queue; and L_{ramp} indicates the length of the ramp. Other parameters are as described above.

4.3. Joint Control Model Solving. The essence of solving the joint control model is to solve a multiobjective optimization problem. The stochastic algorithm represented by the genetic algorithm has good applicability in solving a multiobjective optimization problem. Here, the most widely used NSGA-II algorithm is selected as the model solving algorithm. The algorithm is called the nondominated sorting genetic algorithm with elite strategy.

Nondominated sorting of randomly generated population n and then obtaining the first generation of progeny population are through three basic operations of genetic algorithm (mutation, selection, crossover). The child and parent populations produced in the previous step are combined to form a new population, and the nondominated sorting is also performed; on this basis, the crowding degree was calculated for each individual. The results of nondominated sorting and congestion calculation jointly select new individuals to form a new parent population.

Then, a new generation population is generated, and the above steps are repeated until the end condition of the algorithm is satisfied, and the Pareto optimal solution is output. Pareto optimal solution refers to the relatively ideal state in the process of resource allocation, that is, changing the allocation scheme under this state will certainly make the individual and the overall interests suffer losses.

5. Simulation Analysis

5.1. Simulation Platform Architecture. Through the establishment of the simulation platform, the control system is simulated and verified. The simulation platform is composed of three components and four modules, which are traffic simulation software VISSIM, mathematical calculation software MATLAB, and database ACCESS. VISSIM is used for traffic flow simulation. The construction of the METANET traffic flow model and the solution of the objective function are realized in MATLAB. Data exchange and control command sending and receiving are realized through the VB language and API interface of VISSIM and MATLAB.

The traffic operation is simulated through VISSIM, and then real-time traffic flow data are transmitted to the strategy implementation module through the interface module. The strategy implementation module uses MATLAB to calculate the optimal control parameter combination, and then the control parameters are fed back to the simulation module through the interface module. The simulation

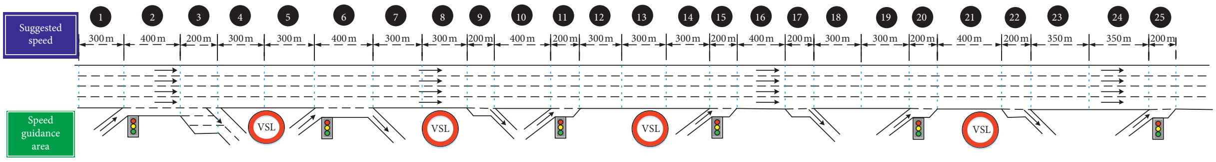

Figure 2: Simulation stage division diagram.

module implements corresponding traffic management control commands in VISSIM according to the control parameters received. Here, the ACCESS module is not only a storage unit but also the bridge and link of data exchange between the traffic operation in the VISSIM module and the control strategies in the MATLAB module.

5.2. Model Parameter Calibration. Based on the actual traffic survey, the simulation model was established. The actual survey section was about 7.3 km from Shenzhen Beihuan Road (Nanshan Interchange-Shenyun Interchange). According to the principle of the consistent number of segments, the whole road segment is divided into 25 stages, as shown in Figure 2. There are detectors at each stage: queue detector and flow detector at the entrance ramp, flow detector at the exit ramp, and a total of 42 detectors at the whole road section.

According to the research and analysis of existing literature and combined with the least square quantitative calibration and the nonlinear fitting function in MATLAB-lsqnonlin, the parameter calibration values obtained by estimating the above parameters are shown in Table 2 [25].

Table 2: Calibration of model parameters.

Parameter	Calibration value
τ	20
γ	8.5
a	0.5
K	13
v_f	58.2
ρ_{cr}	33.2
K_R	70
α_i	0.85^i
o_{cr}	28
o_{obj}	30
q_i^{cap}	3500
L_{ramp}	100

5.3. Analysis of Simulation Results. According to the research results in Sections 3 and 4, speed guidance and control can exert the maximum positive effect in the two dimensions of traffic safety and efficiency only under the condition of medium traffic demand. Therefore, the traffic volume input of the joint control is 2000 veh/h for the mainline and 1000 veh/h for the on-ramp. Compare the traffic condition of joint control and no control. Considering the warm-up time of VISSIM and some irregular and unexplained congestion caused by software bugs in the later part of the simulation, simulation data of 1800~5400 s for one hour were selected as the basis for analysis.

Figures 3 and 4 show the specific distribution of vehicle speed in each section from 1800 s to 2100 s (5 min) under uncontrolled and control of combined ramp and mainline speed guidance. The red dot in the figure indicates the specific vehicle speed measured by a segment speed detector. The color squares are the speed-density calculated according to the vehicle speed distribution of each vehicle (the ratio of a certain speed to all speeds). Comparing the two figures, it can be seen that the vehicle speed distribution under the uncontrolled situation is relatively discrete. To make a more intuitive comparison, the ordinate ranges of the two figures are determined to be the same. In fact, the overall distribution of vehicle speed without control is within the range of 25~68 km/h, and some data points have exceeded the axis. Compared with the joint control of the ramp and the speed guidance, the speed distribution is more concentrated, mainly distributed in the interval of 31~55 km/h.

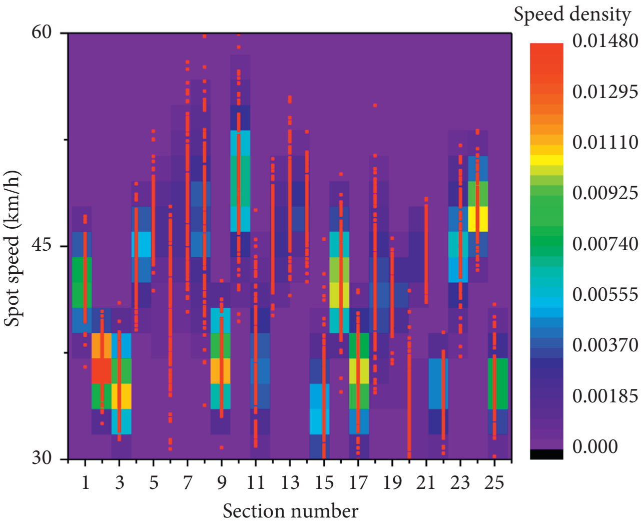

Figure 3: Distribution of vehicle speed in each segment within 5 min without control.

By studying the speed distribution of each segment, the speed distribution of segments 2, 3, 9, 11, 15, 17, 22, and 25 is in the lower interval without control, by comparing the segment numbers in Figure 4, it can be seen that these segments are all located in the mainline and merge or diverging sections of the on-ramp or off-ramp, indicating that the merging and diverging have a significant impact on the efficiency of the urban expressway system. Compared with the speed distribution diagram under the joint control, it can be seen that the speed distribution interval of vehicles under the corresponding segment increased significantly, and the speed difference from the basic segment is further reduced. It shows that the joint control of the ramp and the mainline

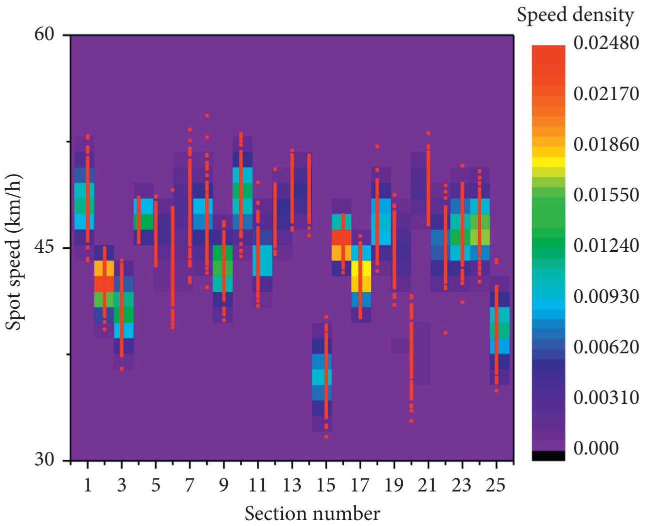

Figure 4: Distribution of vehicle speed in each segment within 5 minutes under joint control.

speed can effectively improve the traffic efficiency during the urban expressway merging and diverging, ensure the traffic flow running at a relatively stable speed, and maintain a relatively uniform. While improving the overall traffic efficiency of the expressway, the reduction of the speed difference and the speed homogenization effect greatly reduce the risk of rear-end collision and the lateral collision caused by frequent lane change to some extent, which also has a positive effect on the improvement of traffic safety of the expressway system.

6. Conclusion

In this paper, the METANET macroscopic traffic flow model is improved by combining the characteristics of joint control. The serious traffic conflict prediction model based on urban expressways detector data is established by factor analysis and multiple linear regressions. The model is used as a part of the objective function in the joint control model. Based on the improved METANET model, the joint control model is established with the traffic efficiency and traffic safety level as the objective functions. The traffic efficiency is based on the TTS, the traffic safety level is based on the number of serious conflicts, and the number of serious conflicts is obtained through the prediction model. The control model is solved by the genetic algorithm NSGA-II. The simulation results show that the control scheme proposed in this paper can effectively improve the efficiency and safety of urban expressway traffic.

However, there are some other unsolved problems that we want to discuss for the future studies: (1) in the part of speed guidance sensitivity analysis, this paper takes the specific traffic demand as the basis of analyzing the adaptability of speed guidance control. In future research, the traffic demand can be fuzzified, so that the research results have more reference value in practical application. It can also be used to analyze the adaptability and sensitivity of the combined control of on-ramp metering and mainline speed guidance; and (2) based on the METANET model, the study of multiramp dynamic selection control can be more inclined to the microlevel, with the actual waiting time of each vehicle as the index of on-ramp metering classification. Furthermore, the application conditions of the algorithm in urban expressway type, on-ramp number, and traffic demand are proposed.

Data Availability

The basic data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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