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Effects of on-ramp on the fuel consumption of the vehicles on the main road under car-following model

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HIGHLIGHTS

- We calibrate the optimal speed of car-following model.
- We extended the car-following model [23].
- We study the fuel consumption of each vehicle on the main road.

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ABSTRACT

In this paper, we use the car-following model accounting for real-time road condition to explore the impacts of on-ramp on the vehicle's fuel consumption on the main road under uniform flow. Numerical results illustrate that on-ramp can enhance each vehicle's fuel consumption on the main road and that the increments are related to the traffic state of the main road and the inflow of the on-ramp.

1. Introduction

Recently, traffic problems (e.g., congestion, safety, fuel consumption, exhaust emissions, etc.) have turned more and more serious and attracted researchers to develop various traffic flow models to explore the complex traffic phenomena from different perspective [1,2]. Roughly speaking, the existing traffic flow models can be divided into micro models [3–25] and macro models [26–44], where the micro models focus on investigating the micro traffic phenomena (e.g., the car-following behavior, lane-changing, overtaking, etc.) while the macro models focus on investigating the macro properties of traffic flow (e.g., the relationships among density, speed and flow).

However, the above traffic flow models cannot be applied to directly study the vehicle's fuel consumption since they do not consider this factor. The data of the International Energy Agency (IEA) show that the average growth of the vehicle's fuel consumption is 1.5% from 2006 to 2030 and higher than that of the global energy consumption [45]. To investigate the vehicle's fuel consumption, Ahn et al. [46,47] carried out some tests and found that each vehicle's fuel consumption is relevant to its instantaneous speed and acceleration, thus they developed a VT-Micro model based on the test data. Rakha et al. [48] incorporated the VT-Micro model into the simulation tool INTEGRATION and studied the effects of traffic light on

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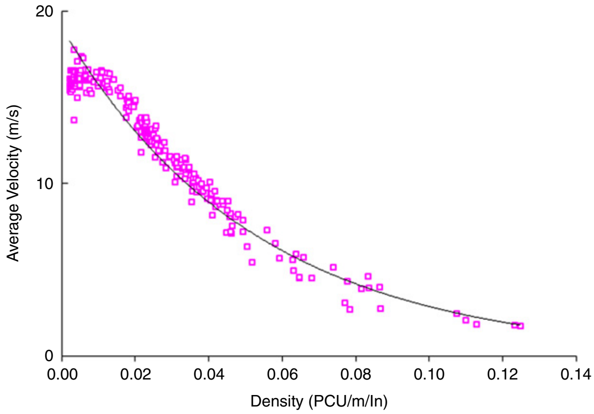

Fig. 1. The empirical data of the Beitaipingzhuang of the Third Ring Road in Beijing in June, 2006.

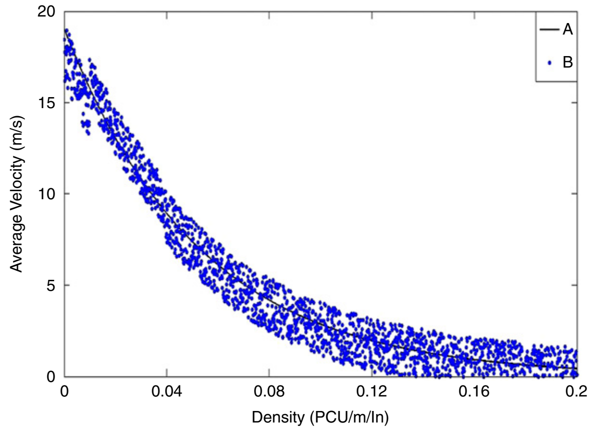

Fig. 2. The speed–density relationship on Beitaipingzhuang segment of the Third Ring Road in Beijing, where A is the curve obtained by Eq. (2) and B is the scattered data obtained by Eq. (1).

the vehicle's fuel consumption. Wu et al. [49] studied each vehicle's fuel consumption in the mixed traffic system consisting of human drivers and autonomous vehicles. Tang et al. [50] used car-following model to study the vehicle's fuel consumption. The above studies illustrate that exploring driving behavior can help driver to reduce the vehicle's fuel consumption, but they do not further explore the effects of ramp on fuel consumption of vehicles. In this paper, we use the car-following model [23] to explore the impacts of on-ramp on the fuel consumption of each vehicle on the main road.

2. Model description

We study the impacts of on-ramp on the vehicle's fuel consumption on the main road of urban traffic system in this paper, so we should apply the empirical data collected on the Beitaipingzhuang segment of the Third Ring road in Beijing in June, 2006 (see Fig. 1). Applying the data of Fig. 1, the equilibrium speed can be defined as follows:

$$v_e(\rho) = \bar{v}_e(\rho) + \xi(\rho), \tag{1}$$

where $\bar{v}_e$ is the average speed, ξ is the deviation resulted by real-time road condition, ρ is the density. Here, $\bar{v}_e(\rho)$, $\xi(\rho)$ can be calibrated as follows:

$$\bar{v}_e(\rho) = 19.037\mathrm{e}^{-18.94\rho} \tag{2}$$

$$\xi(\rho) = \begin{cases} \alpha & \alpha \in [-2.84898 \quad 0.50643], \ 0 \le \rho < 0.0099 \\ \beta & \beta \in [-0.85745 \quad 1.76852], \ 0.0099 \le \rho \le 0.0396 \\ \gamma & \gamma \in [-1.70269 \quad 1.22813], \ \rho > 0.0396 \end{cases} \tag{3}$$

where $R^2 = 0.9553$ shows that Eq. (2) can fit the empirical data very well, α, β, γ are three random digits. Using Eqs. (2) and (3), we can obtain the velocity–density relationship on the Beitaipingzhuang segment (see Fig. 2). From this figure, we find that the shape is similar to the empirical data.