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RESEARCH PAPER

A Traffic Kinetic Model Considering Desired Speed

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Abstract: In this paper, the desired speed variable is introduced into the ‘table of games’, and a new ‘table of games’ and corresponding traffic kinetic model are then formulated. The hybrid programming technique of VBA and MATLAB is used to develop the computational engine for the proposed model. The study focuses on the effect of desired speed on the speed-density curve. With one desired speed, the relationship between average speed and density is investigated under different road conditions and desired speeds. With multiple desired speeds, an investigation is carried out on the effect of the coefficient of variation on average speed, and the effect of percentage of low desired speed vehicles on average speed. An important factor influencing average speed is the variation of the desired speed. When density is low, traffic flow is in an individual flow pattern, and the average speed of the traffic flow is determined by the variation of the desired speed. When density is high, traffic flow is in a collective flow pattern, and the average speed is determined by density.

Key Words: traffic engineering; kinetic model; table of games; desired speed; discrete kinetic theory

1 Introduction

Various traffic flow models have been developed at macroscopic, mesoscopic, and microscopic levels. With regard to mesoscopic models, the main concern is the velocity distribution evolution. The pioneered mesoscopic model is the Prigogine-Herman model[1], which is similar in spirit to the gas kinetic theory, and results in Boltzmann-type equations. The Prigogine-Herman model is an integro-differential equation, known for its difficulty to solve. Lu *et al*.[2] integrated the cell transmission model and Prigogine-Herman model and formulated a hybrid model of velocity distribution which transforms the integro-differential equation into an algebra equation. In recent years, a method named discrete mathematical kinetic theory has been applied to traffic flow modeling. This approach, on one hand, simplifies the computation by converting Boltzmann’s integro-differential equation to a set of partial differential equations, and on the other hand, relaxes the continuum hypothesis and includes the granular nature of vehicular traffic. Further details on the methods of discrete mathematical kinetic theory are referred to in Refs. [3]–[5]. The typical characteristic of this approach is discrete velocity. There exist three methods of discrete velocity: first, there is the method adopting a fixed velocity grid[6]. Second, the one employing an adaptive velocity grid[7]. Third, the one considering the coupling of a fixed velocity grid and an adaptive velocity grid[8]. For the third method, the number of velocity classes is constant. When the density is lower than the critical density, the velocity is discrete with a fixed grid, and when the density is higher than the critical density, the velocity is discrete with an adaptive grid. Bonzani and Mussone[9] dealt with the identification of the parameters of the Delitala-Tosin model using experimental data obtained on the highway at Padova-Venezia. Vehicular traffic flow is composed of combinations of driver-vehicle units. Driver-vehicle units can modify their dynamics according to specific strategies and their ability, which are named active particles. They are different from the classical particles in Newtonian dynamics. Gramani *et al*.[10,11] modeled a driver-vehicle unit as an active particle. In particular, they introduced the generalized velocity distribution function into an activity variable describing the driving skills to model individual behaviors.

According to their individual character, driving technical proficiency, gender, age, and so on, the drivers can be divided into different groups. Drivers are varied for different desired

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speeds, and are divided into three types: adaptive, conservative, and adventurous, according to the space headway relative to the leading vehicle in the driving process. The adaptive type keeps a space headway approximately equal to the safety space headway, the conservative type keeps a space headway larger than the safety space headway, while the adventurous type maintains a space headway less than the safety space headway. With the same road condition and traffic environment, adventurous drivers tend to have a relatively higher desired speed, conservative drivers maintain a relatively lower desired speed, and adaptive drivers are between the two.

In actual traffic flow observations, even if traffic density remains unchanged, the flow rate and average velocity will be different because of different degrees of interaction among vehicles. Drivers have different desired speeds, and a desired speed difference leads to overtaking and lane-changing as a major factor. Therefore, desired speed should be introduced into traffic kinetic models, so that the model can take into account the impact of driving behavior on traffic flow performance. It is worth mentioning that, Paveri-Fontan[12] also introduced desired speed to improve the Prigogine-Herman model. The existing literatures, with the discrete mathematical kinetic theory, only take density into consideration. This paper ventures to introduce the desired speed to build a new model while studying the effect of the desired speed on average speed of traffic flow.

2 New table of games and traffic kinetic model

The discrete mathematical kinetic theory uses the table of games and interaction rate to describe vehicle interactions. For heterogeneous traffic flow, the evolution equation of velocity distribution is the hyperbolic partial differential equations. The mathematical structure of this approach is shown in Eq. (1), and the details of this equation can be found in Ref. [7].

$$\frac{\partial f_i}{\partial t}+\frac{\partial (v_i f_i)}{\partial x}=J(f) \qquad (1)$$

$$J(f)=\sum_{h=1}^{2n-1}\sum_{k=1}^{2n-1}\eta_{hk}A_{hk}^{i}f_h f_k-f_i\sum_{k=1}^{2n-1}\eta_{ik}f_k$$

where f_i is the ith class vehicle speed distribution, f_h is the hth class vehicle speed distribution, f_k is the kth class vehicle speed distribution, V_i is the average speed of the ith speed class, t represents time, x represents position, $J(f)$ indicates the speed distribution evolution equation, h, k represents the speed class, η_{hk} represents the number of interactions between speed class h and k, η_{ik} represents the number of interactions between speed class i and k, A_{hk}^{i} represents the probability that the hth speed class reaches the ith speed class after interaction with the kth speed class.

In $\eta=1/(1-u)$, u is defined as the ratio between the number of vehicles and the maximum number of vehicles at the jam density. Due to the nature of the table of games A_{hk}^{i},

$$\sum_{i=1}^{n}A_{hk}^{i}=1,\ h,k=1,2,\cdots,n$$

where the number of vehicles is conservative. There are three models for the table of games A_{hk}^{i} in the existing literature: (1) Delitala-Tosin[6] used a fixed grid for discrete speed, and introduced density ρ and road condition α into the table of games. The model requires that two interaction speed classes be the adjacent speed class, but the speed class can only be converted into an adjacent speed class after an interaction. (2) Coscia *et al*.[7] used the adaptive grid for discrete speed and the table of games is developed based on an adaptive grid. This model assumes that the transforming probability between different speed classes is constant and only adjacent speed classes can interact. Additionally, the speed class can only be converted to the adjacent speed class; (3) Bianca and Coscia[8] used coupling of fixed velocity grid and adaptive velocity grid for discrete speed, and the table of games is the same as that of the Delitala-Tosin model, but different in that interaction and conversion are not limited to adjacent speed class.

Our research introduces the desired speed ω to the Delitala-Tosin model and improves the table of games. The new table of games provides a mathematical interpretation of vehicle interactions which are the probabilities that a candidate vehicle with speed V_h reaches speed V_i, after an interaction with the field vehicle with speed V_k.

(i) Interaction with a faster vehicle, i.e., $V_h<V_k$,

$$A_{hk}^{i}(u)=\begin{cases}1-\dfrac{|\omega-v_h|}{\omega}\alpha(1-u), i=h\\ \dfrac{|\omega-v_h|}{\omega}\alpha(1-u), i=h+1\end{cases} \qquad (2)$$

(ii) Interaction with a slower vehicle, i.e., $V_h>V_k$,

$$A_{hk}^{i}(u)=\begin{cases}1-\alpha(1-u), i=k & \text{(a)}\\ \dfrac{|\omega-v_h|}{\omega}\alpha(1-u), i=h+1 & \text{(b)}\\ \dfrac{v_h}{\omega}\alpha(1-u), i=h & \text{(c)}\end{cases} \qquad (3)$$

where the sum of (b) and (c) is the passing probability.

(iii) Interaction with an equally fast vehicle, $V_h=V_k$,

$$A_{hh}^{i}(u)=\begin{cases}\dfrac{|\omega-v_h|}{\omega}\alpha u, i=h-1\\ 1-\dfrac{|\omega-v_h|}{\omega}\alpha, i=h\\ \dfrac{|\omega-v_h|}{\omega}\alpha(1-u), i=h+1\end{cases} \qquad (4)$$

$$A_{11}^{i}(u)=\begin{cases}1-\dfrac{|\omega-v_h|}{\omega}\alpha(1-u), i=1\\ \dfrac{|\omega-v_h|}{\omega}\alpha(1-u), i=2\end{cases} \qquad (5)$$

$$A_{nn}^{i}(u)=\begin{cases}\dfrac{|\omega-v_h|}{\omega}\alpha u, i=n-1\\ 1-\dfrac{|\omega-v_h|}{\omega}\alpha u, i=n\end{cases} \qquad (6)$$

where ω is the desired speed, v is the current speed, α is a phenomenological parameter with $\alpha\in[0,1]$ showing the road condition. A higher value of α indicates a better road condition. u is the normalized number density in $u\in[0,1)$.