 CMES, vol.86, no.6, pp.533-549, 2012

The Cellular Automaton Model of Microscopic Traffic Simulation Incorporating Feedback Control of Various Kinds of Drivers

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Abstract: The cellular automaton (CA) model for traffic flow describes the restrictive vehicle movements using the distance headway (gap) between two adjacent vehicles. However, the autonomous and synergistic behaviors also exist in the vehicle movements. This paper makes an attempt to propose a microscopic traffic simulation model such that the feedback control behavior during the driving process is incorporated into the CA model. The acceleration, speed holding and deceleration are manipulated by the difference between the gap and the braking reference distance the driver perceives, which is generally observed in the realistic traffic. The braking reference distance is related to the current speed and braking performance of vehicle grasped by the driver. Consequently, the proposed CA model with feedback control (CA-FC) can assign the vehicle with rationale acceleration and deceleration rates which aim at maintaining the moderate safe-driving distance to the preceding adjacent vehicle and thereby accomplishing the speed tracking with regard to that vehicle. Besides, the variety and randomness of driving behaviors are kept through the adjustable parameters for the conservative, prudent and aggressive drivers. The comparative study of CA-CF model with the typical CA and car following (CF) models is undertaken using the go-and-stop cases without and with signal control. The simulation results demonstrate that the proposed CA-FC model can replicate the restrictive, autonomous and synergistic behaviors of vehicle movements. The consistency is revealed with the macroscopic property of traffic flow such as the relationship between any two of density, flow and speed.

Keywords: cellular automata, feedback control, traffic flow, microscopic modeling, safe driving.

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1 Introduction

Traffic flow modeling can be roughly categorized into two types, i.e. macroscopic and microscopic approaches [Tyagi, Darbha, and Rajagopal (2008)]. Macroscopic traffic flow models deal with the aggregate behaviors of a collection of vehicles on a link of road network mainly based on the hydrodynamic theory of traffic flow and the kinetic statistical theory of gases. Microscopic traffic flow models tackle the interactive behaviors among vehicles through the description of the rules of acceleration and deceleration. If the flow performance of a link is calculated utilizing the macroscopic model, but the vehicle movements are individually recorded, in this case, the traffic flow model is especially differentiated as mesoscopic one [Celikoglu and Dell'Orco (2007)]. Macroscopic and microscopic traffic flow models describe the essential properties and phenomena of realistic traffic from different levels, such as the relationship between density and flow [Nagel and Schreckenberg (1992); Chowdhury, Santen, and Schadschneider (2000); Maerivoet and Moor (2005)], traffic shock and expansion stability [Vikram, Mittal, and Chakroborty (2011)], speed following [Bando, et al. (1995); Helbing and Tilch (1998)], etc. The intrinsic consistency between microscopic and macroscopic traffic flow models can be attained if the appropriate parameters are configured for the microscopic ones [Daganzo (2006)]. Macroscopic and microscopic traffic flow models have been applied to traffic planning, dynamic traffic assignment [Peeta and Mahmassani (1995); Ran and Boyce (1996)] and signal control [Galán Moreno, et al. (2009)] to improve the performance of road network.

Car-following (CF) model is one kind of microscopic description of traffic flow. Various versions of CF models have been proposed, which essentially represent the driver behavior as the response to the certain aspects of current traffic conditions that the vehicle confronts. The optimal velocity model (OVM) [Bando, et al. (1995)] was proposed where the acceleration of the car is proportional to the difference between the optimal speed and its current one. The generalized force model (GFM) [Helbing and Tilch (1998)], calibrated from OVM with empirical data, was presented to overcome the disadvantages of too high acceleration and unrealistic deceleration that OVM encounters, where the acceleration of the vehicle was modeled as the function of the speed of the vehicle, the speed difference between it and its lead one, and the distance headway between them. The full velocity difference model (FVDM) [Jiang, Wu, and Zhu (2001)] was developed to supplement the effect of positive speed difference on the vehicle dynamics which was overlooked in the GFM. The CF models have attained further advancement at the description of vehicle dynamics such as the multiple velocity difference model (MVDM) put forward to overcome the frequent acceleration and deceleration [Wang, Gao, and Zhao (2006)].

Another kind of typical microscopic traffic-flow model is the cellular automaton (CA). In the CA model, the complex physical and biological movements are described as the synchronous state transitions of cells on the one or multiple-dimensional grid in the discrete time and space. The one-dimensional probabilistic traffic-flow model [Nagel and Schreckenberg (1992)], called NaSch model, was proposed to reconstruct the realistic traffic through describing the hopping of particles (vehicles) on the grid. All vehicles attempt to accelerate towards their maximum speeds unless their respective front empty cells are insufficient to support the accelerative hopping in one time step such that the deceleration has to happen. The speed is randomly slowed down, which is similar to the spontaneous or compulsory speed fluctuation during the driving process. The NaSch model can reproduce the observed phenomena of real traffic such as the spatio-temporal evolution of traffic jams, and reveal the macroscopic properties of traffic flow such as the relationship between density and flow. It can depict the essential aspect of realistic traffic, while the improved CA models have been presented through modifying the rules of the NaSch model so as to capture more dynamics of vehicle movements. The speed of the front car was taken into account in the deceleration rule of NaSch model to avoid collision [Lárraga, del Río, and Alvarez-lcaza (2005)]. The safe lane-changing rules were introduced into the NaSch model in order to describe the mixed traffic flow behavior with motorcycles [Meng, et al. (2007)]. The gap was altered into depending on the speed of vehicle to achieve more stable traffic flow [Lo and Hsu (2010)]. The randomization probability was revised to be related to the corresponding gap, which makes the model more consistent with the real traffic [Li, Wang, and Liu (2011)]. In order to estimate the traffic delay occurred in the work zone on the road, the randomization probability was formulated as the function of the transition and activity length of working zone and the traffic flow across it [Meng and Weng (2011)].

In the Nasch model, the vehicles are modeled as particles having unrealistic acceleration and deceleration rates, because they accelerate independent of their velocity and decelerate abruptly from the extreme case of maximum speed to a stop [Nagel (1998); Bham and Benekohal (2004)]. Besides, the speed following and the safe headway maintenance are not involved in the CA model. Although the CF model describes the speed following phenomenon, there exist the deficiency at modeling the variety and randomness of driving behaviors, for example, various kinds of safe-driving distance maintenance. This paper attempts to model the vehicle movements under the CA framework incorporating the feedback control in various types of driving behaviors. The idea originates the observation of realistic traffic that the driver maneuvers the vehicle according to the difference between the gap and braking reference distance [Zhou and Mi (2012)] that may differs for various types of drivers. The braking reference distance is related to the estimates of current speed and braking performance of the vehicle. The behavior of feedback adjustment, i.e. reasonable acceleration or deceleration, will happen until the proper safe-driving distance is maintained if the speed of the vehicle can catch up with that of its preceding adjacent one.

The paper is organized as follows. Section 2 summarizes the typical CA and CF models of microscopic traffic simulation which will be compared with the proposed CA model with feedback control (CA-FC). Section 3 in detail develops the CA-CF model considering various types of driving behaviors. The simulation results of comparative study are demonstrated and elucidated in section 4. Finally, the conclusions are drawn in section 5.

2 Typical microscopic traffic simulation models

2.1 CA model

The NaSch model [Nagel and Schreckenberg (1992)] describes the microscopic traffic behaviors using a set of update rules. The road is decomposed into a series of cells. Define $v_n \in \{0, ..., v_{\max}\}$ is the speed of vehicle n, gap_n is the number of empty cells in front of vehicle n, and x_n is the cell position the vehicle locates at. The update rules of speed and position of the vehicle are sketched as:

1. Acceleration: $v_n \to \min(v_n + 1,\ v_{\max})$.
2. Deceleration to avoid accidents: $v_n \to \min(v_n,\ gap_n)$.
3. Randomisation with a certain probability p: $v_n \to \max(v_n - 1,\ 0)$.
4. Vehicle movement: $x_n \to x_n + v_n$.

2.2 CF model

One of the typical CF models was the GFM [Helbing and Tilch (1998)], which formulates the speed update rate as:

$$\frac{dv_j(t)}{dt} = a\left[V\left(\Delta x_j(t)\right) - v_j(t)\right] + \lambda\Theta\left(-\Delta v_j(t)\right)\left(\Delta v_j(t)\right) \tag{1}$$

where $v_j(t)$ is the speed of car j at time t, $\Delta x_j(t)$ is the headway or the difference of the positions of car j+1 and j, $V(\cdot)$ is the optimal velocity function, $\Theta(\cdot)$ is the Heaviside function, $\Delta v_j(t)$ is the difference of the speeds of car j+1 and j, a is the sensitivity of a driver, and λ is the sensitivity coefficient different from a. The GFM utilizes the following calibrated optimal velocity function:

$$V\left(\Delta x_j(t)\right) = V_1 + V_2 \tanh\left[C_1\left(\Delta x_j(t) - l_c\right) - C_2\right] \tag{2}$$

where l_c is the length of a car. The typical values of parameters in Eq. 1 and Eq. 2 are adopted as $a = 0.85s^{-1}$, $V_1 = 6.75m/s$, $V_2 = 7.91m/s$, $C_1 = 0.13m^{-1}$, $C_2 = 1.57$, and $l_c = 5m$.

3 Proposed model

3.1 Notation

(1) Time-independent variables

$v^{\max}$: the expected maximum running speed of the vehicle which is determined by the road condition, the driving ability of the driver, the speed limitation of the vehicle.

$a^{\min}$: the minimum acceleration that the driver can adopt.

$a^{\max}$: the maximum acceleration that the driver can adopt. It is related to the maximum acceleration ability of a vehicle.

$b^{\min}$: the minimum deceleration that the driver can adopt, into which the deceleration caused by the friction between wheels and road surface should be incorporated

$b^{\max}$: the maximum deceleration that the driver can adopt. It is related to the maximum braking ability of a vehicle.

(2) Time-dependent variables

v :the current speed of the vehicle at current time.

a : the acceleration that the driver is adopting which is related to the current speed and target one (usually determined by the speed of the preceding adjacent vehicle) of the vehicle, and the driving habit of the driver such as the expected acceleration time towards the target speed.

b : the deceleration that the driver is adopting which is related to the current and target speeds of the vehicle, and the driving habit of the driver such as the expected deceleration time towards the target speed.

d_t : the current distance of the vehicle to the preceding adjacent one. For simulation convenience, d_t is configured as $d_t = d_h - l_v - SM$ where d_h is the distance headway between two adjacent vehicles, l_v is the length of the vehicle, and SM is the safety margin for the stopping of the vehicle.

$d_b^{\min}$: the minimum braking reference distance of the vehicle to the preceding adjacent one when the driver adopts $b^{\max}$. The theoretical value is $d_b^{\min} = v_b^2/(2b_{\max}) + v_b$ with $v_b = \max(v - b_{\max},\ 0)$. Different drivers have their own sensory estimates about $d_b^{\min}$.

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v_a with $v_a = \min(v + a_{\max}, v_{\max})$. Different drivers have their own sensory estimates about $d_b^{\max}$.

d_b : the braking reference distance which is related to the current speed and the deceleration the driver perceptually holds and intends to take. The theoretical value is $d_b = v^2/(2b) + v$. When the speed of the vehicle follows that of the preceding adjacent one, d_b approaches the steady-state safe-driving maintenance distance.

The above variables are with regard to a specific vehicle n. The vehicle number n is omitted for simplicity. For the time-dependent variables, the current time k is also omitted for simplicity.

3.2 Modeling aspects of microscopic traffic simulation

Modeling road traffic should describe the following aspects:

(1) When will the driver accelerate or decelerate

Based on the braking reference distance determined by the current speed and the braking ability of the vehicle, the driver speculates the occasion to accelerate or decelerate. There exist the inexperienced and experienced drivers with conservative, prudent and aggressive driving behaviors. Different types of drivers have their corresponding estimates about the braking reference distance. The appropriateness of those estimates determines the driving safety.

(2) What is the rate of acceleration or deceleration

The rate of acceleration or deceleration is determined by the driving habit of driver such as the expected time of acceleration or deceleration and by the capability of acceleration or deceleration of vehicle. Different types of drivers will adopt their respective acceleration or deceleration rates according to the traffic conditions.

(3) What are the expected speed and safe following distance of vehicle

It can be observed that the driver endeavors to approach his own $v^{\max}$ at the shortest time. If $v^{\max}$ of the current vehicle is greater or equal to that of the front adjacent one, the expected speed of the considered vehicle is restricted by that of the front adjacent one, and the following distance is determined by the braking reference distance of the vehicle. Or, the expected speed of the vehicle is $v^{\max}$, and the following distance will become greater and greater if the front adjacent vehicle does not decelerate.

3.3 Three scenarios of driving process

The purpose of this section is to develop the three scenarios of driving process, i.e. the best-effort or relaxed acceleration phase (S_a) if $d_t \geq d_b^{\max}$, the restrictive acceleration or deceleration (S_b) if $d_b^{\min} < d_t < d_b^{\max}$, and the best-effort deceleration

(S_c) if $d_t \leq d_b^{\min}$. The three scenarios of driving process are described as follows.

(1) speed update

S_a : if $d_t \geq d_b^{\max}$, $v \to \min(v + a_{\max}, v_{\max},\ d_t)$

S_b : elseif $d_b^{\min} < d_t < d_b^{\max}$

begin

$p = (d_t - d_b^{\min})/(d_b^{\max} - d_b^{\min})$

if $p > p_m$, $v \to \min(v + a, v_{\max},\ d_t)$

else $v \to \min(\max(v - b,\ 0),\ d_t)$

end

S_c : else $v \to \min(\max(v - b_{\max},\ 0),\ d_t)$

(2) position update

$x \to x + v$

Remark 1: It can be observed that the driver compares d_t with the perceptually held braking reference distance to determine the acceleration or deceleration behavior. In S_b, the more d_t approaches $d_b^{\max}$, the greater tendency to accelerate the driver will hold. And on the contrary, the more d_t approaches $d_b^{\min}$, the greater tendency to decelerate the driver will possess. p_m is the marginal value between acceleration and deceleration. The following section will further discuss the boundary between acceleration and deceleration from the angle of braking reference distance d_b.

3.4 Modeling speed following and safe-driving distance maintenance

In this section, we model the restrictive acceleration or deceleration phase (S_b) as a feedback adjustment process for speed following and moderate safe-driving distance maintenance. The update rules of speed and position are described as follows.

(1) speed update

S_a : if $d_t \geq d_b^{\max}$, $v \to \min(v + a_{\max},\ v_{\max},\ d_t)$

S_b : elseif $d_b^{\min} < d_t < d_b^{\max}$

begin

if $d_t > d_b$, $v \to \min(v + a,\ v_{\max},\ d_t)$

elseif $d_t = d_b$, $v \to v$

else $v \to \min(\max(v - b,\ 0),\ d_t)$

end

S_c : else $v \to \min(\max(\ v - b_{\max},\ 0),\ d_t)$

(2) position update

$x \rightarrow x + v$

Remark 2: Three kinds of braking reference distances do objectively exist. $d_b^{\max}$ reflects the distance limitation for free acceleration. d_b between $d_b^{\min}$ and $d_b^{\max}$ controls the vehicle to iteratively follow the front adjacent one until the steady-state following distance d_b is achieved when the speed of the vehicle can follow that of the preceding adjacent one. If the front adjacent vehicle decelerates, d_t will decrease, which in turn entails the hind one to decelerate so that an appropriate following distance d_b is kept. $d_b^{\min}$ is the marginal distance when emergent braking happens.

Remark 3: The acceleration a and deceleration b are related to $|d_t - d_b|$. The bigger $|d_t - d_b|$ is, and the bigger a or b is, which can be approximately formulated as $a = (1 - e^{-|d_t - d_b|})a_h$ or $b = (1 - e^{-|d_t - d_b|})b_h$, respectively. Similar to the CF model, the habitual acceleration a_h and deceleration b_h are temporarily chosen according to the difference of speeds between two adjacent vehicles. In this way, the adjustment process of speed following and moderate safe-driving distance maintenance can be both achieved with the diversity of driving behaviors.

3.5 Analysis of driver types

The proposed model in the last subsection is a framework for the microscopic traffic simulation. The configuration of parameters depends on the driver types, reflecting the following empirical observations:

1. Each driver has his own maximum driving speed, his acceleration and deceleration habit corresponding to the current speed and the target one
2. Each driver has the basic understanding about the braking capability of his car, and thus has his estimate about the braking reference distance corresponding to the current speed and the braking capability in the current traffic condition.

Tab. 1 lists the description of three kinds of driving behaviors for inexperienced and experienced drivers. For the conservative driver, the small acceleration a is usually adopted to make the vehicle arrive at small $v^{\max}$. Because the small deceleration b is adopted, it leads to the big braking reference distances $d_b^{\max}$, d_b and $d_b^{\min}$. For the prudent driver, he can accelerate to the moderate $v^{\max}$ at an appropriate acceleration a. He can proficiently manipulate the braking process, thus the smooth speed decrease can be observed. For the aggressive driver, $v^{\max}$ and a have approached the limitation of his vehicle. He often adopts the smallest braking reference distance, and thus the maximum braking level will be generally employed.

Table 1: Driving behaviors of different types of drivers

driver type	$v^{\max}$	a	b	$d_b^{\max}$	d_b	$d_b^{\min}$
conservative	small	small	small	big	big	big
prudent	moderate	moderate	moderate	moderate	moderate	moderate
aggressive	big	big	big	small	small	small

4 Simulation results

4.1 Microscopic traffic dynamics

4.1.1 Case I

In order to conveniently demonstrate the go-and-stop waves and speed following, we design the first case study assuming that all drivers are prudent with the same maximum driving speed. The vehicles run on the road with a length of $2km$, which are produced to yield to Poisson distribution $P(0.5)$ with certain initial speeds. The vehicles are loaded onto the road satisfying $d_t \geq d_b^{\min}$. We let the first vehicle stop for $360s$ when it arrives at the positions of $0.5km$, $1.0km$, $1.5km$ and $2km$ to reveal the phenomena of stopping and going, queuing, and its back propagation to the upstream. Fig. 1 demonstrates the space-time diagram of vehicle movements in case I using the typical CA and CF models discussed in Section 2 (so do the following simulation cases) and the proposed CA-FC model. Fig. 1 (c) and (d) are for the experienced drivers with comparatively accurate estimates of braking reference distances and for the inexperienced drivers with approximate estimates of braking reference distances. Fig. 1 (c) shows the homogeneous flow characteristics as those in Fig. 1 (a) and (b) resulting from the homogeneity of speeds. However, Fig. 1 (d) shows the smooth transition process of flow because of speed adjustment with speed variety incurred. Fig. 2 represents the time-speed diagrams using the three models in case I. The CA model is not based on speed following, and Fig. 2 (a) is its time-speed plot. For the CF model, the speed following in Fig. 2 (b) is very homogeneous. Fig. 2 (c) and (d) show the speed following with feedback adjustment using the CA-FC model for the experienced and inexperienced drivers, respectively. All vehicles can approach the same maximum speed through respective adjustment processes. The hinder vehicles (produced later) can follow their front adjacent ones (produced earlier) to keep appropriate safe-driving distances even though their initial speeds may vary. When the front vehicle decelerates, the hinder one will also decelerate utilizing respective deceleration rate. For the experienced drivers, the deceleration processes in Fig. 2 (c) are smooth because the braking reference distances have been appropriately evaluated. However, for the inexperienced ones, the occasional accelerations will happen during the deceleration processes because of the inappropriate estimates of braking reference distances with improper braking rates incurred, which can be often observed in the realistic traffic. The CA-FC model has the characteristics of both CA and CF models. It is gap-based but has the diversities of speed tracking.

4.1.2 Case II

The second case study is undertaken under the condition with traffic signal control and various driver types. At the positions of 0.5*km*, 1*km*, 1.5*km* and 2*km* on the road, we configure the traffic lights. The traffic lights are red from $2n\times 60s$ to $(2n+1)\times 60s$ and green from $(2n+1)\times 60s$ to $(2n+2)\times 60s$ (n=0, 1, 2, ...). Because the CA model is gap-based, it is easy to be adapted to describe the vehicle movements under traffic signal control through setting the distance of the headmost vehicle to the traffic light as gap. The CF model is revised to be applied to this case through actively decreasing the speed of the headmost vehicle meeting the red light at an appropriate place. Fig. 3 (a), (b) and (c) depict the stop-and-go waves in case II using the CA, modified CF and CA-FC models, respectively. Fig. 4 (a) and (b) together show the tracking performance of the first four vehicles utilizing the CA-FC model. From 0 to 60*s*, these four vehicles all stop close to the position of 0.5*km*. From 60*s* to 120*s*, they all run at their maximum or tracking speeds. From 120*s* to 180*s*, the first two vehicles stop close to the position of *2km*, but the second two vehicles stop close to the position of 1.5*km*. From 180*s* to 240*s*, the first two vehicles successively pass through the end, and afterwards, the second two vehicles also alternately override the end. Although different types of drivers exist, the favorable speed-tracking performance can be observed. Fig. 4 (c), (d) and (e) represent the speed-tracking performance from the fifteenth to twenty-fourth vehicles using the CA, modified CF and CA-FC models, respectively, which further testifies the favorable performances at speed-tracking and hence moderate safe-driving distance maintenance using the CA-FC model. It should be noted that under the signal control condition as depicted in Fig. 3, when the front vehicle decelerates or accelerates, it does not necessarily mean that the hinder adjacent one also has the same driving tendency in Fig. 4, because at certain time, the two adjacent vehicles do not necessarily run on the same road section (separated by traffic lights) and confront the same traffic light.

4.2 Macroscopic traffic patterns

Various microscopic traffic models will lead to the distinctions of macroscopic traffic patterns. In test case III, we make vehicles run on a road with a length of 0.5*km*. In order to demonstrate the jam, free and synchronized flows, we design the vehicles to run with the maximum speeds from 1 to 70*km*/*h*. When the maximum

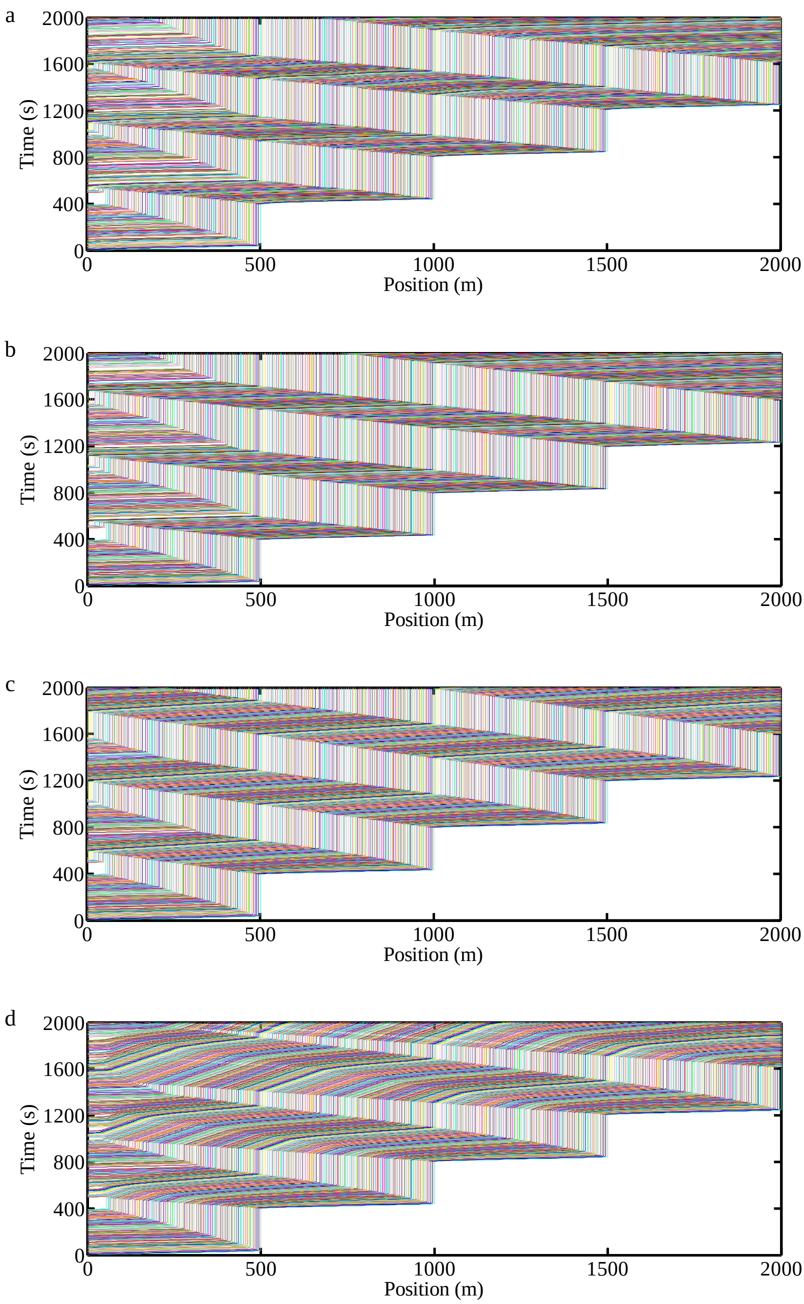

Figure 1: Space-time diagrams of test case I: to stop for 360s at specified points. (a) and (b) are for CA and CF models, respectively. (c) and (d) are for experienced and inexperienced drivers using CA-FC model, respectively.

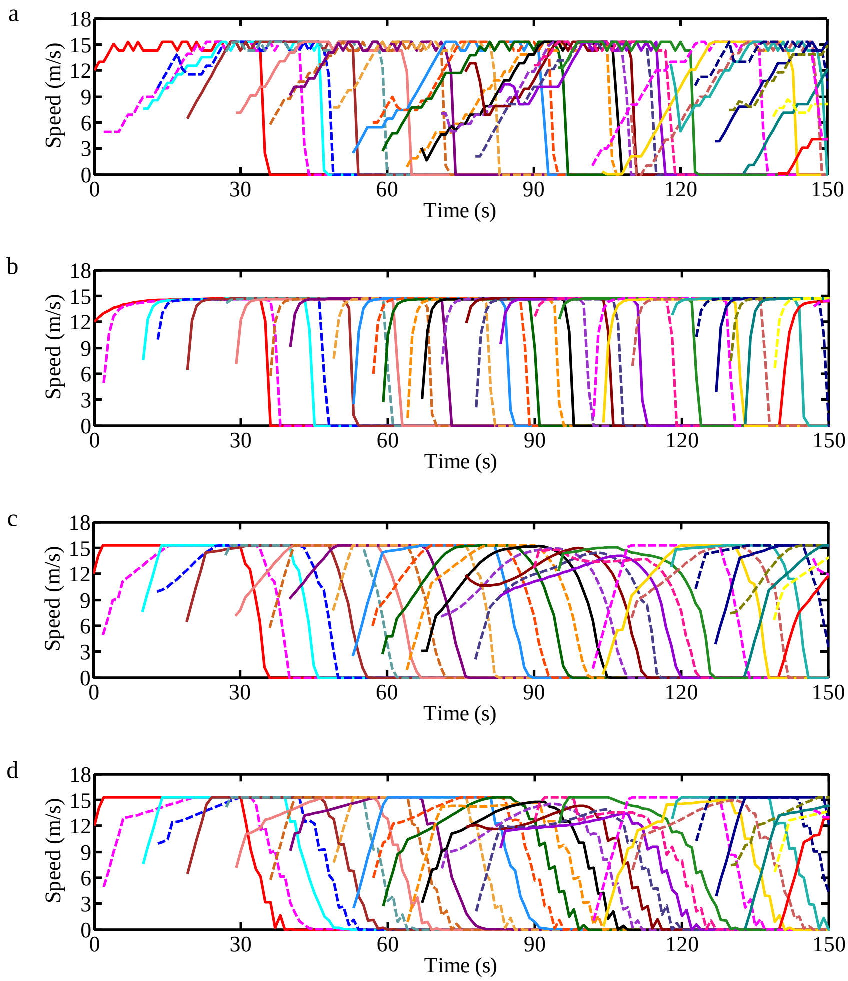

Figure 2: Time-speed diagrams of test case I: to stop for 360s at specified points. (a) and (b) are for CA and CF models, respectively. (c) and (d) are for experienced and inexperienced drivers using CA-FC model, respectively.

speed is low and the density of vehicles on the road is high, the jam flow can be observed. When the maximum speed is high and the density is low, the free flow can be observed. The vehicles are produced yielding to the Poisson distribution $P(\lambda)$ where λ is set as $-\log(0.1k)$ with k=9, 8, ..., 2, ε. ε is a small positive number so that λ approaches the maximum double floating number. In this way, different input flows can be produced to bright about various traffic densities combined with various maximum speeds. But as aforementioned, the vehicles are loaded onto the

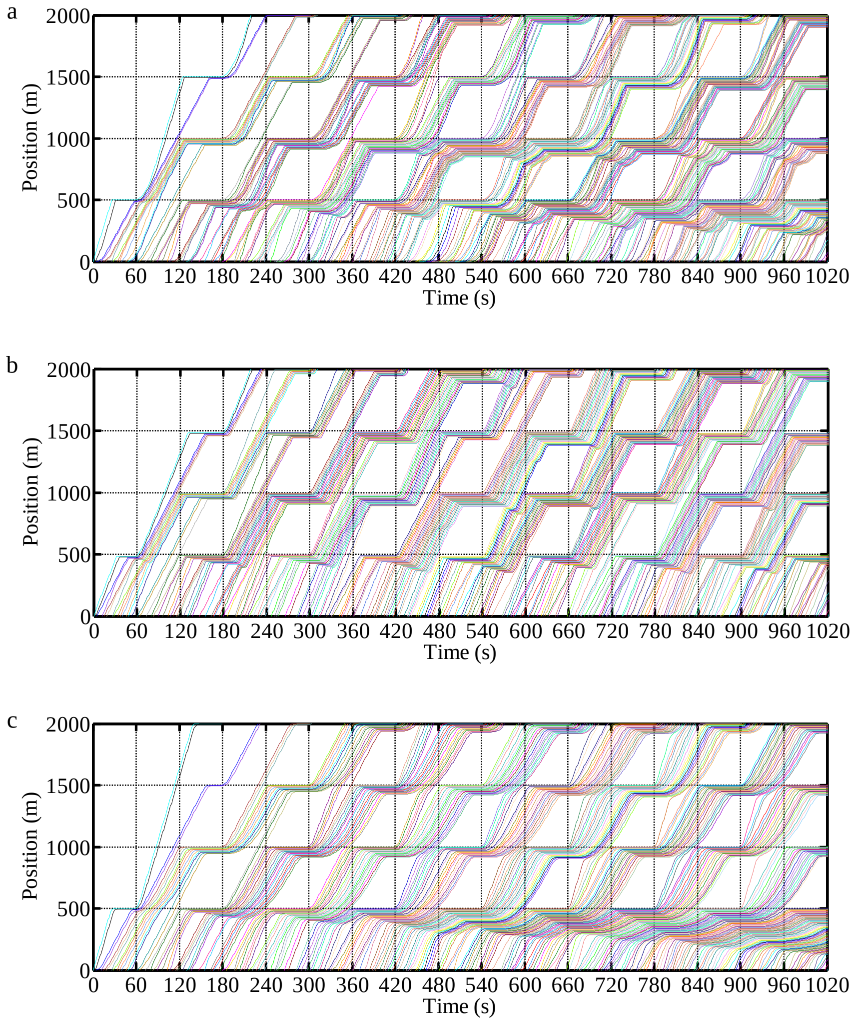

Figure 3: Time-space diagrams of test case II: to run with traffic signal control. (a), (b) and (c) are for CA, CF and CA-FC models, respectively

road satisfying $d_t \geq d_b^{\min}$. Fig. 5 demonstrates the macroscopic features using the CA, CF and CA-FC models. For the purpose of traffic signal control, we utilize the period $60s$ to make the statistics of flow, density and speed. Many statistic points can be attained as shown in Fig. 5. If the longer statistic period is utilized, the plots in Fig. 5 will become thinner. The macroscopic patterns for the CA-FC model (Fig. 5 (c)) are more similar to those for the stochastic CA model (Fig. 5 (a)), compared with those for the CF model (Fig. 5 (b)) which homogeneously describes the

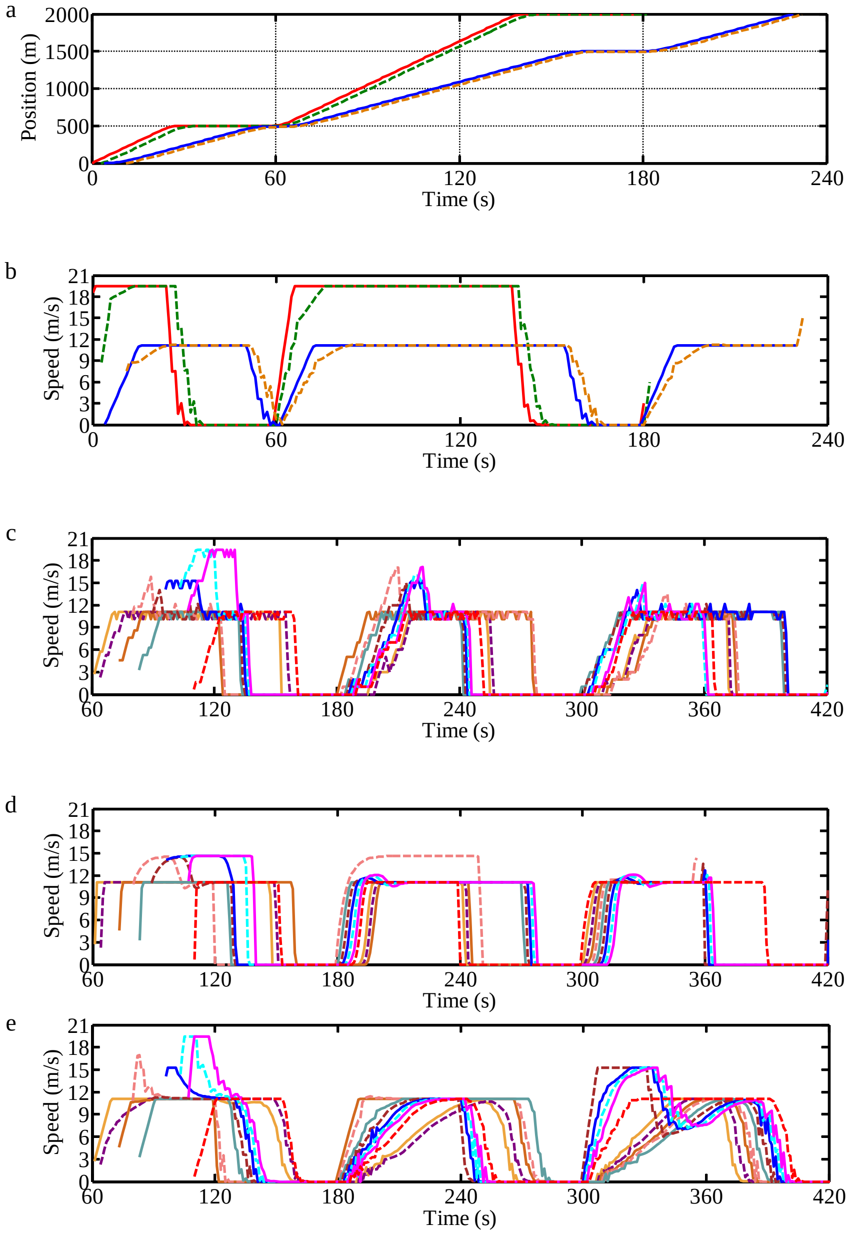

Figure 4: Time-space and time-speed diagrams of test case II: to run with traffic signal control. (a) and (b) are time-space and time-speed plots of the first – fourth vehicles for CA model, respectively. (c), (d) and (e) are time-speed plots of the fifteenth – twenty-fourth vehicles for CA, CF and CA-FC models, respectively

microscopic traffic behaviors. The contours in Fig. 5 (c) are roughly tantamount to the curves depicted according to the Greenshields formulae, which is due to the comprehensive representation of microscopic traffic behaviors utilizing the CA-FC model.

5 Conclusions

We have proposed one kind of microscopic traffic simulation model which introduces the feedback control behavior into the CA model so that the phenomena of speed tracking and accordingly safe-driving distance maintenance of all kinds of drivers can be revealed. The acceleration and deceleration rates are related to the difference between the gap in front of the vehicle and its braking reference distance, which is analogous to the error feedback adjustment of control system as well as

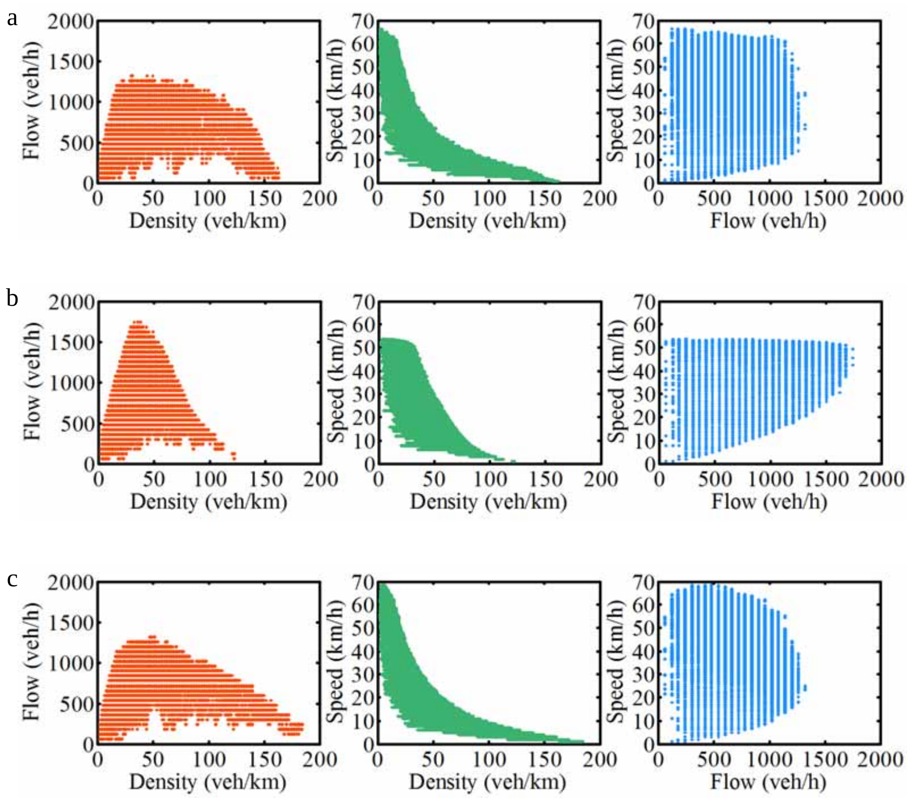

Figure 5: Macroscopic features of traffic flow. (a), (b) and (c) are for CA, CF and CA-FC models, respectively

human brain. The braking reference distance is involved with the current speed and braking performance of the vehicle perceived by the driver. Through feedback adjustment, the transient-state braking reference distance can be iteratively convergent to the steady-state one when the speed follows the preceding one. The proposed CA-FC model provides adjustable parameters for choosing such as acceleration and deceleration habits of conservative, prudent and aggressive drivers so that the variety of driving behaviors can be achieved. The simulation results demonstrate the favorable performances of speed following and moderate safe-driving distance maintenance even if there exist all types of drivers. The comprehensive microscopic traffic simulation model provides a supportive tool for the stochastic optimization of real-time traffic assignment and signal control where the distribution characteristics of vehicles on the link are entailed to be predicted.

Acknowledgement: This work is supported by the National Natural Science Foundation of China (Grant No. 61074138) and the Fundamental Research Funds for the Central Universities of China (Grant No. 2009JBM006).

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