SCIENCE CHINA
Information Sciences

• **RESEARCH PAPERS** •

November 2010 Vol. 53 No. 11: 2265–2271
doi: 10.1007/s11432-010-4070-1

Advanced information feedback strategy in intelligent two-route traffic flow systems

DONG ChuanFei[1,2]*, MA Xu[1,3] & WANG BingHong[1,4]

[1] *Department of Modern Physics and Nonlinear Science Center, University of Science and Technology of China (USTC), Hefei 230026, China;*
[2] *School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA 30332, USA;*
[3] *Department of Physics, Syracuse University, Syracuse, NY 13244, USA;*
[4] *The Research Center for Complex System Science, University of Shanghai for Science and Technology and Shanghai Academy of System Science, Shanghai 200093, China*

Received September 28, 2009; accepted July 1, 2010; published online September 14, 2010

Abstract The optimal information feedback has a significant effect on many socioeconomic systems like stock market and traffic systems aiming to make full use of resources. In this paper, we study dynamics of traffic flow with real-time information. The influence of a feedback strategy named vehicle number feedback strategy (VNFS) is introduced, in which we only calculate the vehicle number of first 500 route sites from the entrance. Moreover, the two-route traffic system has only one entrance and one exit, which is different from those in the previous work. Our model incorporates the effects of adaptability into the cellular automaton models of traffic flow, and simulation results by adopting this optimal information feedback strategy have demonstrated higher efficiency in controlling spatial distribution of traffic patterns than the other three information feedback strategies, i.e., TTFS, MVFS and CCFS.

Keywords vehicle number feedback strategy, two-route selecting traffic flow, intelligent vehicle, cellular automaton model

Citation Dong C F, Ma X, Wang B H. Advanced information feedback strategy in intelligent two-route traffic flow systems. Sci China Inf Sci, 2010, 53: 2265–2271, doi: 10.1007/s11432-010-4070-1

1 Introduction

Vehicular traffic flow and related problems have triggered great interest of a community of physicists in recent years because of its various complex behaviors [1–4]. A lot of theories have been proposed such as car-following theory [5], kinetic theory [6–10] and particle-hopping theory [11–13]. These theories have the advantages of alleviating the traffic congestion and enhancing the capacity of existing infrastructure. Although dynamics of traffic flow with real-time traffic information have been extensively investigated [14–19], finding a more efficient feedback strategy is an overall task. Recently, some real-time feedback strategies have been proposed, such as travel time feedback strategy (TTFS) [14, 20], mean velocity feedback strategy (MVFS) [14, 21] and congestion coefficient feedback strategy (CCFS) [14, 22]. It has been proved that TTFS is the worst one because this strategy brings a lag effect, making it impossible

*Corresponding author (email: dcfy@gatech.edu, dcfy@mail.ustc.edu.cn; bhwang@ustc.edu.cn, bhwangustc@gmail.com)

to provide the road users with the real situation of each route [21]; CCFS is more efficient than MVFS because the random brake mechanism of the Nagel-Schreckenberg (NS) model [12] brings about fragile stability of velocity [22]. However, CCFS is still not the best one due to the fact that its feedback is still based on road condition of the whole route, and thus it is unable to reflect the real situation near the entrance of the route. In order to provide road users with better guidance, a strategy named vehicle number feedback strategy (VNFS) is presented, which only calculates the vehicle number of first 500 route sites. We report the simulation results of adopting four different feedback strategies in a two-route scenario with a single route following the NS mechanism.

The remainder of this paper is arranged as follows. In section 2, the NS model and a two-route scenario are briefly introduced, together with four feedback strategies of TTFS, MVFS, CCFS and VNFS, all depicted in detail. In section 3, some simulation results will be presented and discussed based on the comparison of all these feedback strategies. In the last section, we will make some conclusions.

2 The model and feedback strategies

2.1 NS mechanism

The Nagel-Schreckenberg (NS) model is so far the most popular and simplest cellular automaton model in analyzing the traffic flow [1–3, 12, 23–26], where the one-dimension CA with periodic boundary conditions is used to investigate highway and urban traffic. This model can reproduce the basic features of real traffic like stop-and-go wave, phantom jams, and the phase transition on a fundamental diagram. In this section, the NS mechanism will be briefly introduced as a basis of analysis.

The road is subdivided into cells with a length of Δx=7.5 m. We set the length of the route to be $L = 2000$ cells (corresponding to 15 km). Let N be the total number of vehicles on a single route of length L. Then the vehicle density is $\rho = N/L$. A time step corresponds to Δt =1 s, the typical time a driver needs to react. Let $g_n(t)$ be the number of empty sites in front of the nth vehicle at time t, and let $v_n(t)$ denote the speed of the nth vehicle, i.e., the number of sites that the nth vehicle moves during the time step t. In the NS model, the maximum speed is fixed at $v_{\max} = M$. In the present paper, we set M= 3 cells/time step (corresponding to 81 km/h) for simplicity.

The NS mechanism can be decomposed into the following four rules (parallel dynamics):

- Rule 1. Acceleration: $v_i \leftarrow \min(v_i + 1, M)$.
- Rule 2. Deceleration: $v'_i \leftarrow \min(v_i, g_i)$.
- Rule 3. Random brake: with a certain brake probability p do $v''_i \leftarrow \max(v'_i - 1, 0)$.
- Rule 4. Movement: $x_i \leftarrow x_i + v''_i$.

The fundamental diagram characterizes the basic properties of the NS model which has two regimes called "free-flow" phase and "jammed" phase. The critical density, basically depending on the random brake probability p, divides the fundamental diagram to these two phases.

2.2 Two-route scenario

Wahle et al. [20] first investigated the two-route model in which road users choose one of the two routes according to the real-time information feedback. In a two-route scenario, it is supposed that there are two routes A and B of the same length L. At each time step, a new vehicle is generated at the entrance of two routes and it will choose one route. If a vehicle enters one of two routes, the motion of it will follow the dynamics of NS model. If a new vehicle is unable to enter the desired route, it will be deleted. A vehicle will also be removed after it reaches the end point.

Additionally, two types of vehicles are introduced: dynamic and static vehicles. If a driver is a so-called dynamic one, he will make a choice on the basis of the information feedback [20], while a static one just enters a route at random ignoring any advice. The density of dynamic and static travelers are $S_{\rm dyn}$ and $1 - S_{\rm dyn}$, respectively.

The simulations are performed by the following steps: first, the routes and board are set to be empty; second, after the vehicles enter the routes, according to four different feedback strategies, information will be generated, transmitted, and displayed on the board at each time step; finally, the dynamic road users will choose the route with better condition according to the dynamic information at the entrance of two routes.

2.3 Related definitions

The road conditions can be characterized by fluxes of two routes, and flux is defined as follows:

$$F = V_{\text{mean}}\rho = V_{\text{mean}}\frac{N}{L}, \tag{2.1}$$

where V_{mean} represents the mean velocity of all the vehicles on one of the roads, N denotes the vehicle number on each road, and L is the length of two routes. Then we describe four different feedback strategies one by one.

• TTFS: At the beginning, both routes are empty and the information of travel time on the board is set to be the same. Each driver will record the time when he enters one of the routes. Once a vehicle leaves the two-route system, it will transmit its travel time on the board and at that time a new dynamic driver will choose the road with shorter time.

• MVFS: Every time step, each vehicle on the routes transmits its velocity to the traffic control center which will deal with the information and display the mean velocity of vehicles on each route on the board. Road users at the entrance will choose one road with larger mean velocity.

• CCFS: Every time step, each vehicle transmits its signal to satellite, then the navigation system (GPS) will handle that information and calculate the position of each vehicle which will be transmitted to the traffic control center. The work of the traffic control center is to compute the congestion coefficient of each road and display it on the board. Road users at the entrance will choose one road with smaller congestion coefficient.

The congestion coefficient is defined as

$$C = \sum_{q=1}^{m} n_q^w. \tag{2.2}$$

Here, n_q stands for vehicle number of the qth congestion cluster in which cars are close to each other without a gap between any two of them. Each cluster is evaluated by a weight w, where $w = 2$ [22].

• VNFS: We install pressure transducers at the entrance and the 500th route site of each route, respectively. The pressure transducer can calculate the number of the vehicles on each lane. Every time step, when a vehicle enters the route, the number of the vehicles shown on the board will increase by one by using pressure transducers. When it passes the 500th route site, the number will decrease by one in the same way. Thus, the number shown on the board is the total vehicle number of the first 500 route sites on each route. Road users at the entrance will choose one lane with smaller vehicle number.

In contrast with the former work [20–22], another important difference in this paper is that we set the two-route system to have only one entrance and one exit as shown in Figure 1 while the previous two-route system has one entrance and two exits. In reality, there are different paths for drivers to choose from one place to another place. In this paper, we focus on a two-route system. Therefore, different drivers departing from the same place could choose two different paths to get to the same destination which corresponds to the “one entrance and one exit” system. Hence, the road condition in this paper is closer to the reality. The rules at the exit of the two-route system are as follows:

(a) At the end of two routes, the car nearer to the exit goes first.

(b) If the cars at the end of two routes have the same distance to the exit, faster a car drives, first it goes out.

(c) If the cars at the end of two routes have the same speed and distance to the exit, the car in the route which owns more cars drives out first.

(d) If the rules (a), (b) and (c) are satisfied at the same time, then the cars go out randomly.

In the following section, performance by using four different feedback strategies will be shown and discussed in more details.

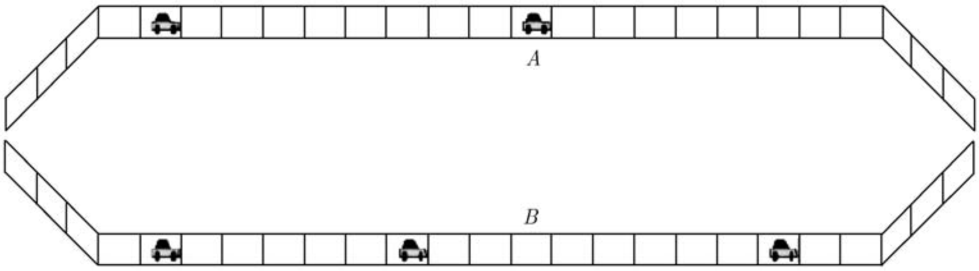

Figure 1 The one entrance and one exit two-route traffic system.

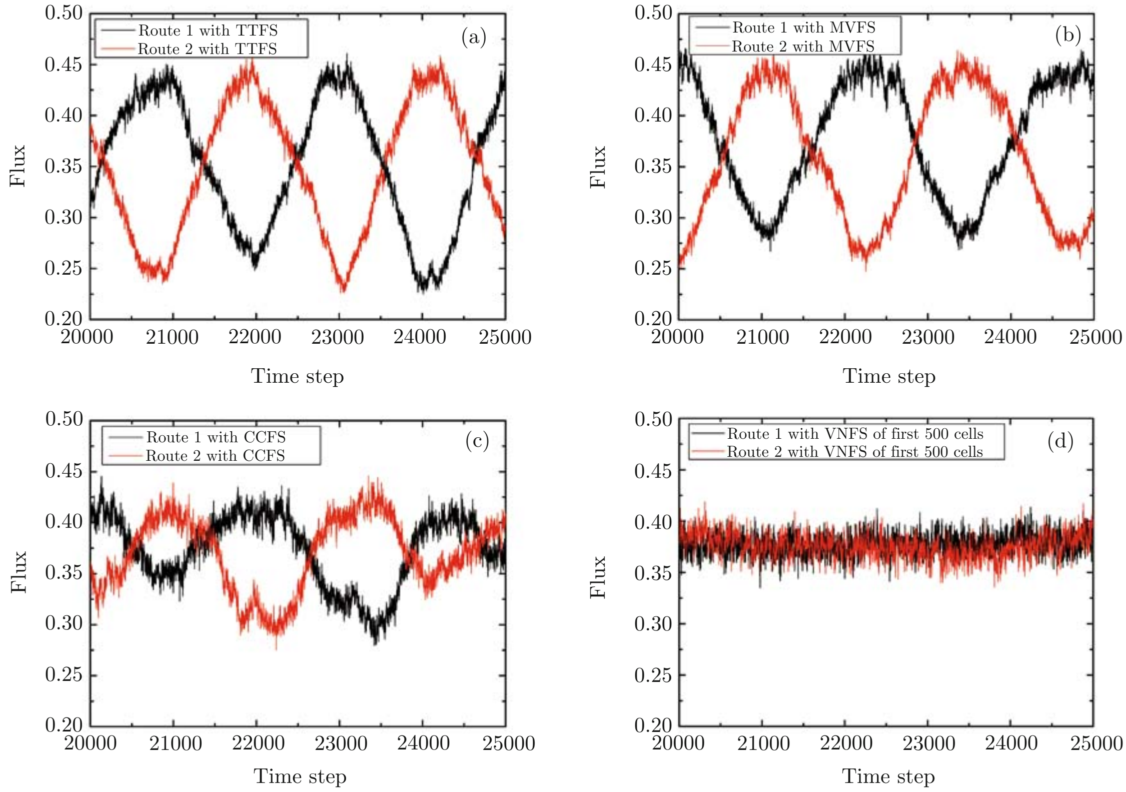

Figure 2 (a) Flux of each route with travel time feedback strategy; (b) flux of each route with mean velocity feedback strategy; (c) flux of each route with congestion coefficient feedback strategy; (d) flux of each route with vehicle number feedback strategy. The parameters are L=2000, p=0.25, and $S_{\rm dyn}$=0.5.

3 Simulation results

All simulation results shown here are obtained by 25000 iterations excluding the initial 5000 time steps. In contrast with VNFS, the fluxes of two routes adopting CCFS, MVFS and TTFS show larger oscillation (see Figure 2) due to the information lag effect. This lag effect can be understood from the fact that the other three strategies cannot reflect the road condition near the entrance while the new feedback strategy only calculates the vehicle number of the first 500 route sites. It is equivalent to setting the exit of the system at the 500th route site, which can more accurately reflect the road situation near the entrance. To some extent, it is equivalent to predicting the future road condition. Compared with CCFS, the performance adopting VNFS is remarkably improved, not only on the value but also the stability of the flux. Hence, with respect to the flux of the two-route system, VNFS is the best one.

In Figure 3, vehicle number versus time step shows almost the same tendency as Figure 2, and the routes' accommodating capacity is greatly enhanced with an increase in vehicle number from 290 to 800, so perhaps the high flux of two routes with VNFS are mainly due to the increase of vehicle number. Why

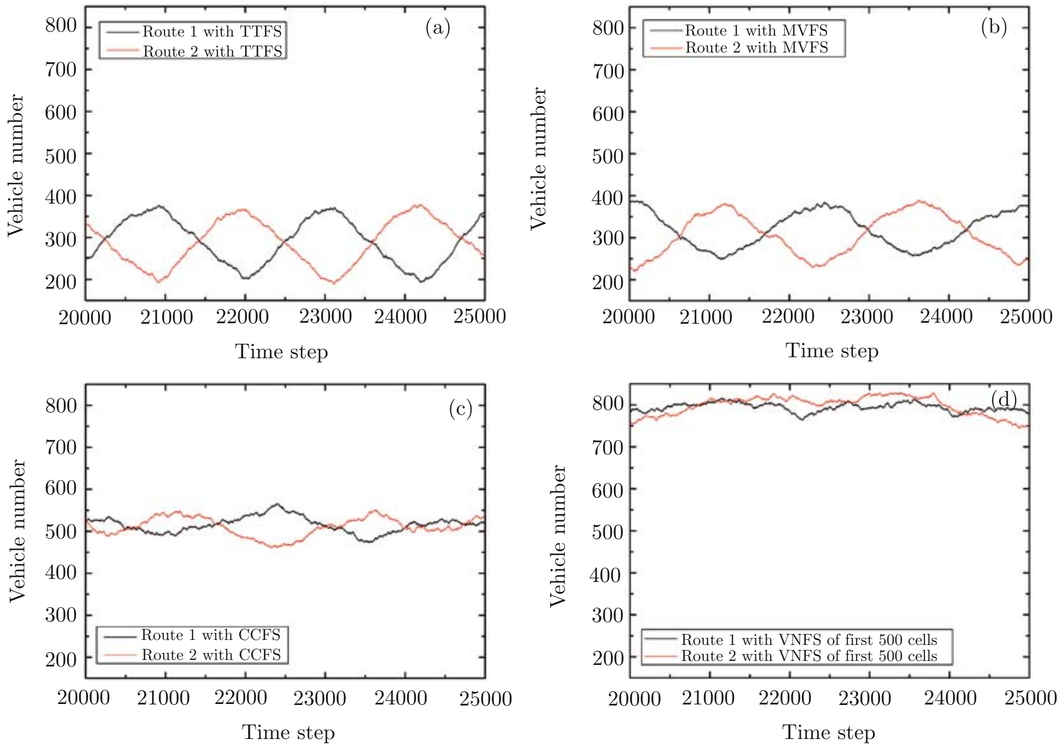

Figure 3 (a) Vehicle number of each route with travel time feedback strategy; (b) vehicle number of each route with mean velocity feedback strategy; (c) vehicle number of each route with congestion coefficient feedback strategy; (d) vehicle number of each route with vehicle number feedback strategy. The parameters are set the same as in Figure 2.

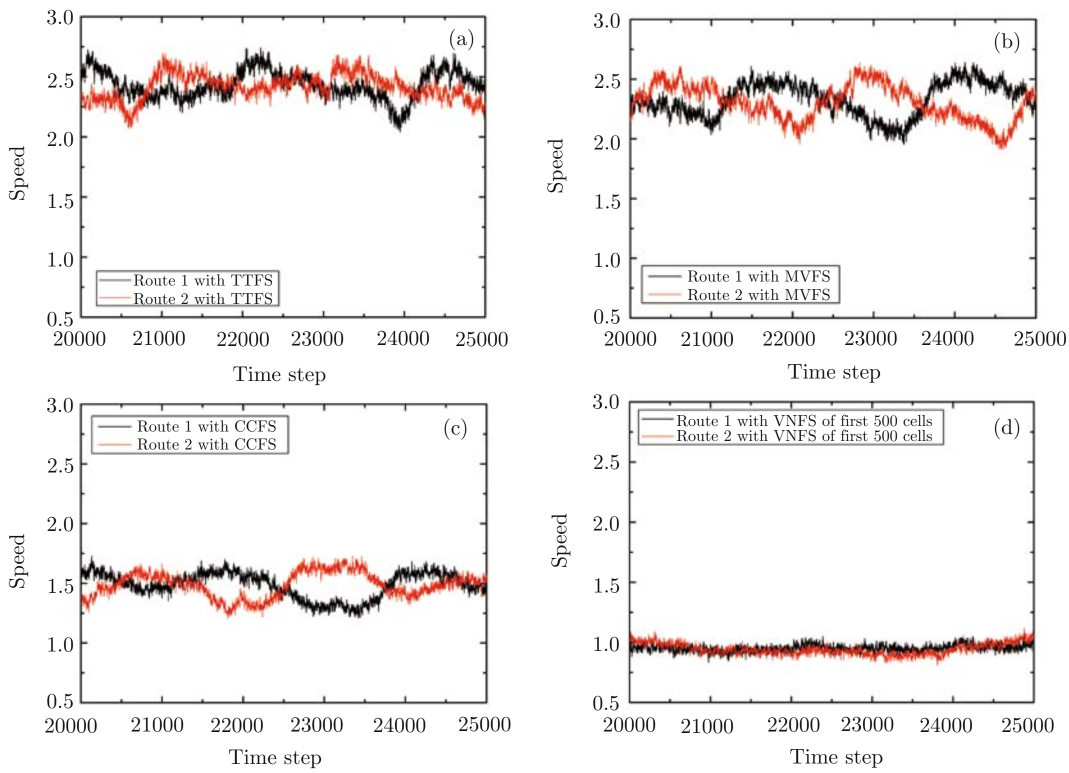

Figure 4 (a) Average speed of each route with travel time feedback strategy; (b) average speed of each route with mean velocity feedback strategy; (c) average speed of each route with congestion coefficient feedback strategy; (d) average speed of each route with vehicle number feedback strategy. The parameters are set the same as in Figure 2.

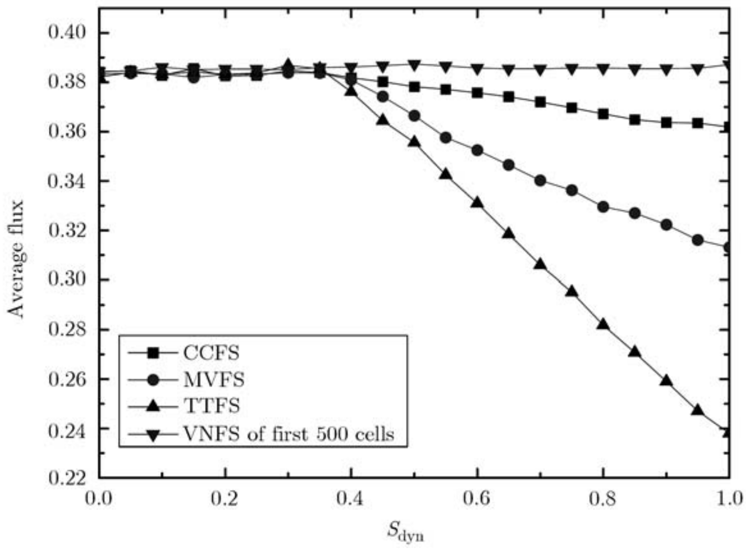

Figure 5 Average flux by performing different strategies vs. $S_{\rm dyn}$; L is fixed at 2000, and p is fixed at 0.25.

the vehicle number in Figure 3 using other three strategies is larger than the figures shown in the former work [22] lies in the fact that the road structure is different from that of the previous work. The two-route system in this paper only has one exit, and therefore, only one car can go out at each time step, thus leading to an increase in vehicle number on each route.

In Figure 4, speed versus time step shows that although the speed is stablest by using the new strategy, it is the lowest among the four different strategies. The reason is that the routes' accommodating capacity is best by using the new feedback strategy. As mentioned above, the road has only one exit and only one car can go out at each time step. Thus, the more cars the lane owns, the lower speeds the vehicles have. Fortunately, flux consists of two parts: mean velocity and vehicle density. Hence, as long as the vehicle number (because the vehicle density is $\rho = N/L$, and the length L is fixed at 2000 such that $\rho \propto$ vehicle number (N)) is large enough, the flux can also be the largest.

Figure 5 shows that the average flux fluctuates feebly with a persisting increase of dynamic travelers by using four different strategies. As to the routes' processing capacity, the new strategy is proved to be the best one because the flux is always the largest at each $S_{\rm dyn}$ value and keeps the two routes' fluxes in balance. The fact that the value of average flux in Figure 5 adopting other three strategies is smaller than the results shown in former work [22] may also result from the different structures of the traffic system which has only one exit as explained above.

4 Conclusions

We obtain the simulation results of applying four different feedback strategies, i.e., TTFS, MVFS, CCFS and VNFS in a two-route scenario all with respect to flux, number of vehicles, speed, average flux versus $S_{\rm dyn}$. The results indicate that VNFS has more advantages than the other three feedback strategies in a two-route system which has only one entrance and one exit. In contrast with three previous feedback strategies, VNFS can significantly improve the road conditions, including increasing vehicle number and flux, reducing oscillation, and average flux being stable with the increase of $S_{\rm dyn}$.

Due to the rapid development of modern scientific technology, it is easy to realize VNFS in reality, if only some pressure transducers are installed at the entrance and the 500th route site of each route, respectively. Furthermore, so doing will cost less than CCFS because pressure transducers are always cheaper than GPS. Also, we only need to install four pressure transducers in a two-route system, instead of installing a navigation system (GPS) in each vehicle as CCFS [22]. Taking into account the reasonable cost and more accurate description of road condition, we think this new feedback strategy will be applicable.

Acknowledgements

This work was supported by the National Basic Research Program of China (Grant No. 2006CB705500), the National Natural Science Foundation of China (Grant Nos. 10975126, 10635040), and the Specialized Research Fund for the Doctoral Program of Higher Education of China (Grant No. 20093402110032).

References

1 Chowdhury D, Santen L, Schadschneider A. Statistical physics of vehicular traffic and some related systems. Phys Rep, 2000, 329: 199–329
2 Helbing D. Traffic and related self-driven many-particle systems. Rev Mod Phys, 2001, 73: 1067–1141
3 Nagatani T. The physics of traffic jams. Rep Prog Phys, 2002, 65: 1331–1386
4 Long J C, Gao Z Y, Ren H L, et al. Urban traffic congestion propagation and bottleneck identification. Sci China Ser F-Inf Sci, 2008, 51: 948–964
5 Rothery R W. Traffic flow theory. In: Gartner N, Messner C J, Rathi A J, eds. Transportation Research Board Special Report, Vol. 165. Washington, DC: Transportation Research Board, 1992. Chap. 4
6 Paveri-Fontana S L. Boltzmann-like treatments for traffic flow–critical review of basic model and an alternative proposal for dilute traffic analysis. Transp Res, 1975, 9: 225–235
7 Lehmann H. Distribution function properties and the fundamental diagram in kinetic traffic flow theory. Phys Rev E, 1996, 54: 6058–6064
8 Wagner C, Hoffmann C, Sollacher R, et al. Second-order continuum traffic flow model. Phys Rev E, 1996, 54: 5073–5085
9 Helbing D. Gas-kinetic derivation of Navier-Stokes-like traffic equations. Phys Rev E, 1996, 53: 2366–2381
10 Helbing D, Treiber M. Gas-kinetic-based traffic model explaining observed hysteretic phase transition. Phys Rev Lett, 1998, 81: 3042–3045
11 Dong L F, Shu Y T, Chen H M, et al. Packet delay analysis on IEEE 802.11 DCF under finite load traffic in multi-hop ad hoc networks. Sci China Ser F-Inf Sci, 2008, 51: 408–416
12 Nagel K, Schreckenberg M. A cellular automaton model for freeway traffic. J Phys I, 1992, 2: 2221–2229
13 Biham O, Middleton A A, Levine D. Self-organization and a dynamic transition in traffic-flow models. Phys Rev A, 1992, 46: R6124–R6127
14 Yokoya Y. Dynamics of traffic flow with real-time traffic information. Phys Rev E, 2004, 69: 016121
15 Friesz T L, Luque J, Tobin R L, et al. Dynamic network traffic assignment considered as a continuous-time optimal-control problem. Oper Res, 1989, 37: 893–901
16 Ben-Akiva M, De Palma A, Kaysi I. Dynamic network models and driver information-systems. Transp Res Part A, 1991, 25: 251–266
17 Dong C F, Ma X, Wang B H. Weighted congestion coefficient feedback in intelligent transportation systems. Phys Lett A, 2010, 374: 1326–1331
18 Arnott R, de Palma A, Lindsey R. Does providing information to drivers reduce traffic congestion. Transp Res Part A, 1991, 25: 309–318
19 Kachroo P, Özbay K. Real time dynamic traffic routing-based on fuzzy feedback control methodology. Transp Res Rec, 1996, 1556: 137–146
20 Wahle J, Bazzan A L C, Klügl F, et al. Decision dynamics in a traffic scenario. Phys A, 2000, 287: 669–681
21 Lee K, Hui P M, Wang B H, et al. Effects of announcing global information in a two-route traffic flow model. J Phys Soc Jpn, 2001, 70: 3507–3510
22 Wang W X, Wang B H, Zheng W C, et al. Advanced information feedback in intelligent traffic systems. Phys Rev E, 2005, 72: 066702
23 Wang B H, Mao D, Hui P M. The two-way decision traffic flow model: mean field theory. In: Proceedings of the Second International Symposium on Complexity Science, Shanghai, 2002. 204
24 Wang B H, Wang L, Xu B M, et al. The gradual accelerating traffic flow gellular automaton model in which only high speed car can be delayed. Acta Phys Sin, 2000, 49: 1926–1932
25 Fu C J, Wang B H, Ying C Y, et al. Intelligent decision-making in a two-route traffic flow model. Acta Phys Sin, 2006, 55: 4032–4038
26 Peng L J, Kang R. One-dimensional cellular automaton model of traffic flow considering drivers' features. Acta Phys Sin, 2009, 58: 830–835