Advanced information feedback in intelligent traffic systems

Wen-Xu Wang,* Bing-Hong Wang, Wen-Chen Zheng, Chuan-Yang Yin, and Tao Zhou
Department of Modern Physics and Nonlinear Science Center, University of Science and Technology of China, Hefei Anhui, 230026, People's Republic of China

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The optimal information feedback is very important to many socioeconomic systems like stock market and traffic systems aiming to make full use of resources. As to traffic flow, a reasonable real-time information feedback can improve the urban traffic condition by providing route guidance. In this paper, the influence of a feedback strategy named congestion coefficient feedback strategy is introduced, based on a two-route scenario in which dynamic information can be generated and displayed on the board to guide road users to make a choice. Simulation results adopting this optimal information feedback strategy have demonstrated high efficiency in controlling spatial distribution of traffic patterns compared with the other two information feedback strategies, i.e., travel time and mean velocity.

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I. INTRODUCTION

Traffic flow, a kind of multibody system consisting of interacting vehicles, shows various complex behaviors. Therefore, in the past few decades, problems of traffic systems have triggered great interest of a community of physicists [1–3] and many theories such as kinetic theory [4–10], car-following theory [11], and particle-hopping theory [12,13] have been introduced with the aim of alleviating the traffic congestion and enhance the capacity of the 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 put forward, such as travel time feedback strategy (TTFS) [14,20] and mean velocity feedback strategy (MVFS) [14,21]. It has been proved that MVFS is more efficient than that of TTFS which brings a lag effect to make it impossible to provide the road users with the real situation of each route [21]. However, MVFS is still not the best one due to the fact that the random brake mechanism of the Nagel-Schreckenberg (NS) model [22] brings fragile stability of velocity and some other reasons which will be discussed delicately in this paper. In order to provide road users with better guidance, a strategy named congestion coefficient feedback strategy (CCFS) is presented. We report the simulation results adopting three different feedback strategies in a two-route scenario with each single route following the NS the mechanism.

The outline of this paper is as follows: in the next section the NS model and two-route scenario are briefly introduced, together with three feedback strategies of TTFS, MVFS, and CCFS all depicted in more detail. In Sec. III some simulation results will be presented and discussed based on the comparison of three different feedback strategies. The last section will make some conclusions.

*Electronic address: bhwang@ustc.edu.cn

II. THE MODEL AND FEEDBACK STRATEGIES

A. NS mechanism

The Nagel-Schreckenberg (NS) model is so far the most popular and simplest cellular automaton model in analyzing the traffic flow [1–3,22,23], 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 base of analysis.

The road is subdivided into cells with a length of $\Delta x = 7.5$ m. Let N be the total number of vehicles on a single route of length L, then the vehicle density is $\rho = N/L$. $g_n(t)$ is defined to be the number of empty sites in front of the nth vehicle at time t, and $v_n(t)$ to be 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 to be $v_{max} = M$. In the present paper, we set $M = 3$ for simplicity.

The NS mechanism can be decomposed to 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 $v_i'' \leftarrow \max(v_i' - 1, 0)$; and

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.

B. 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 the two-route scenario, it is supposed that there are two routes A and B of the same length L. At every time step, a new vehicle is generated at the entrance of two routes and will choose one route. If a vehicle enters one of two routes, the motion of it will follow the dynamics of the NS model. As a remark, if a new vehicle is not able to enter the desired route, it will be deleted. The vehicle will 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_{dyn} and $1-S_{dyn}$, respectively.

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

C. Related definitions

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

$$F = V_{mean}\rho = V_{mean}\frac{N}{L}, \qquad (1)$$

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 three different feedback strategies, respectively.

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. Then drivers can choose one road guided by the information on the board. The congestion coefficient is defined as

$$C = \sum_{i=1}^{m} n_i^w. \qquad (2)$$

Here, n_i stands for vehicle number of the ith congestion cluster in which cars are close to each other without a gap between any two of them. Every cluster is evaluated a weight w, here $w=2$, see Fig. 1 ($w=1$ shows no point for it just indicates the vehicle number and one can check out that $w>2$ leads to the similar results with $w=2$). The reason for adding weight to each cluster can be explained by the fact that travel time of the last vehicle of the cluster from the entrance to the destination is obviously affected by the size of cluster. Imagine that with the increasing of cluster size, travel time of the last vehicle will be more and more longer and the correlation between cluster size and travel time of the last vehicle is nonlinear. For simplicity, an exponent w is added to the size of each cluster to be consistent with the nonlinear relationship. In the following section, performance by using three different feedback strategies will be shown and discussed in more detail.

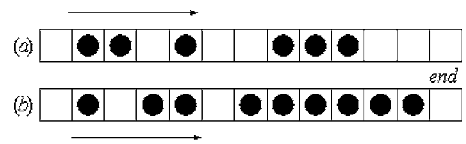

FIG. 1. Illustration of two routes with different congestion coefficient C. Each route has three clusters. According to Eq. (2), $C_a=14$, $C_b=41$. Apparently, condition of route a is better than that of route b, which can be accurately reflected by C.

III. SIMULATION RESULTS

All simulation results shown here are obtained by 30 000 iterations excluding the initial 5000 time steps. In contrast with MVFT and CCFT, the flux of two routes adopting TTFS shows oscillation obviously due to the information lag effect. This lag effect can be understood as that the travel time reported by a driver at the end of two routes only represents the road condition in front of him, and perhaps the vehicles behind him have got into the jammed state. Unfortunately, this information will induce more vehicles to choose his route until a vehicle from the jammed cluster leaves the system. This effect apparently does harm to the system. Compared to MVFS, the performance adopting CCFS is remarkably improved, not only on the value but also the stability of the flux. Therefore as to the flux of the two-route system, CCFS is the best one (see Fig. 2). In Fig. 3, vehicle number versus time step shows almost the same tendency as Fig. 2, the routes' accommodating capacity is greatly enhanced with an increase in vehicle number from 270 to 330, so perhaps the high flux of two routes with CCFS are mainly due to the increase of vehicle number.

The lag effect by TTFS also leads to severe amplitude oscillation in figures of travel time (Fig. 4) and vehicle speed (Fig. 5), but the performance adopting CCFS does not show much difference compared with mean velocity feedback strategy, but even behaves slightly bad in stability than MVFS. There are two reasons to explain why MVFS is not the optimal strategy. We have mentioned that the NS model has a random brake scenario which causes the fragile stability of velocity, so MVFS cannot completely reflect the real condition of routes. The other reason is that flux consists of two parts, mean velocity and vehicle density, but MVFS only grasps one part and lacks the other part of flux. Maybe someone will ask why we do not use the flux feedback strategy? Although adopting flux feedback strategy can indeed make full use of existing infrastructure of two routes, the cost of

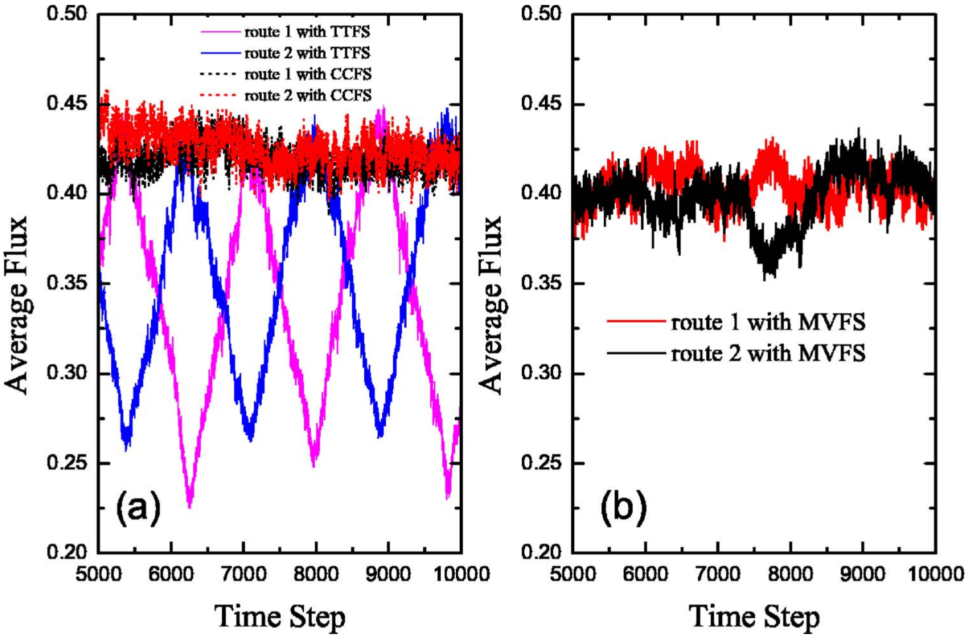

FIG. 2. (Color online) (a) Flux of each route with travel time and congestion coefficient feedback strategies. (b) Flux of each route with mean velocity feedback strategy. The parameters are $L=2000$, $p=0.25$, and $s_{dyn}=0.5$.

this strategy makes it not worthwhile to do it. As to CCFS, it avoids the shortcoming of insufficient information of road condition and large amount of expense and only needs the information of each vehicle's position. So CCFS is the most appropriate strategy at present.

Figure 6 shows that the average flux fluctuates feebly with a persisting increase of dynamic travelers by using the new strategy. As to the routes' processing capacity, the new strategy is proved to be the most proper one because the flux is always the largest at each S_{dyn} value and keeps the two routes' flux in balance. In this case the average flux of the two routes almost shows no change. So this will avoid any influence on using road conditions due to variation of unpredictable proportion of S_{dyn}.

In succession, we will discuss how the length of routes affects the average flux of two routes adopting three different strategies. One can see from Fig. 7 that in the range of the length less than 1000 cells, the average flux adopting MVFS and TTFS decreases severely with increasing L. This property indicates that compared to the other two strategies, average flux with C feedback almost does not depend on the changing of route length, and C feedback is the optimal strategy among them from this aspect.

Generally speaking, the road users who do not follow the information feedback may not choose route A or B completely at random, they may have their own preference to one of the routes, or perhaps some of them like to follow suit or not follow suit, so the real road users without information feedback are not the same as the static users in the model. However, if all road users choose routes completely at random, the routes can be utilized approximately in balance, which is why the average flux of the two routes adopting

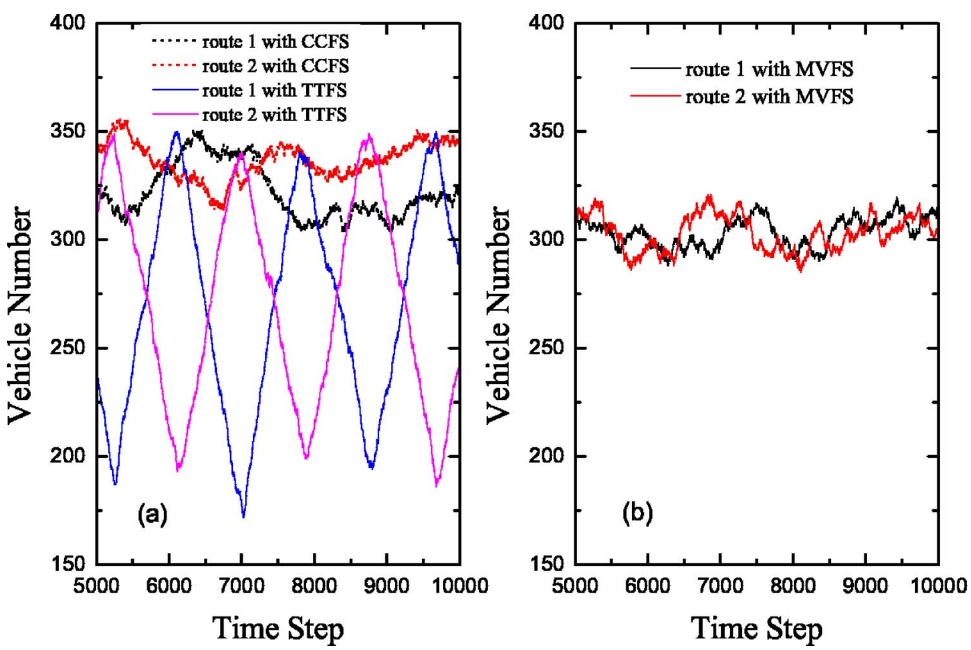

FIG. 3. (Color online) (a) Vehicle number of each route with travel time and congestion coefficient feedback strategies. (b) Vehicle number of each route with mean velocity feedback strategy. The parameters are set the same as in Fig. 2.

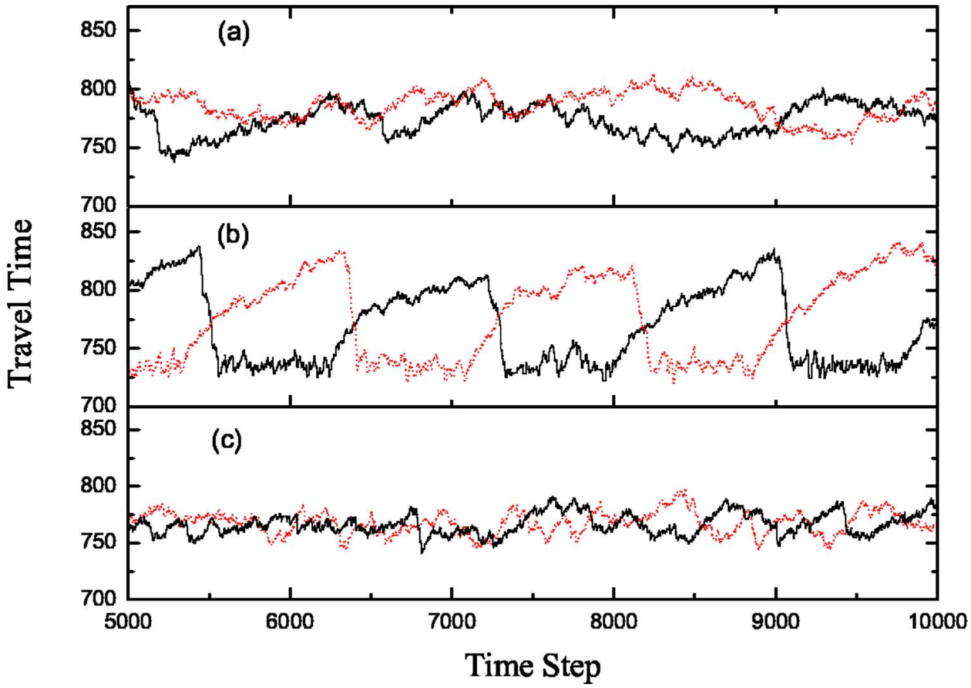

FIG. 4. (Color online) Travel time of each route adopting (a) congestion coefficient feedback strategy, (b) travel time feedback strategy, and (c) mean velocity feedback strategy. The dark line and red dotted line represent route 1 and route 2, respectively. The parameters are set the same as in Fig. 2.

three kinds of information feedback cannot overweight the flux of two routes chosen completely at random. However, our feedback strategy can make the roads be fully used as that selected completely at random, meanwhile it makes existing infrastructure used more efficiently than that without information feedback.

Furthermore, we investigate how the traffic properties adopting CCFS are influenced by the information feedback delay. From the perspective of technology, to realize CCFS the delay of information feedback should be considered. In Fig. 8, we depict the average flux of two routes as a function of feedback period. We find that the average flux decreases slightly when the period is short. While for the very long period, the average flux reaches a lower limit the same as in the case of adopting TTFS. Due to the feedback delay, the information displayed on the board cannot reflect the real-time route condition, which leads to the overbalance in the utilization of the two routes during the feedback period. Therefore one route gets more crowded than the other one and the velocity on this congested route decreases, thus the average flux will decrease. Figure 9 shows the vehicle number of two routes affected by the feedback period. It is found

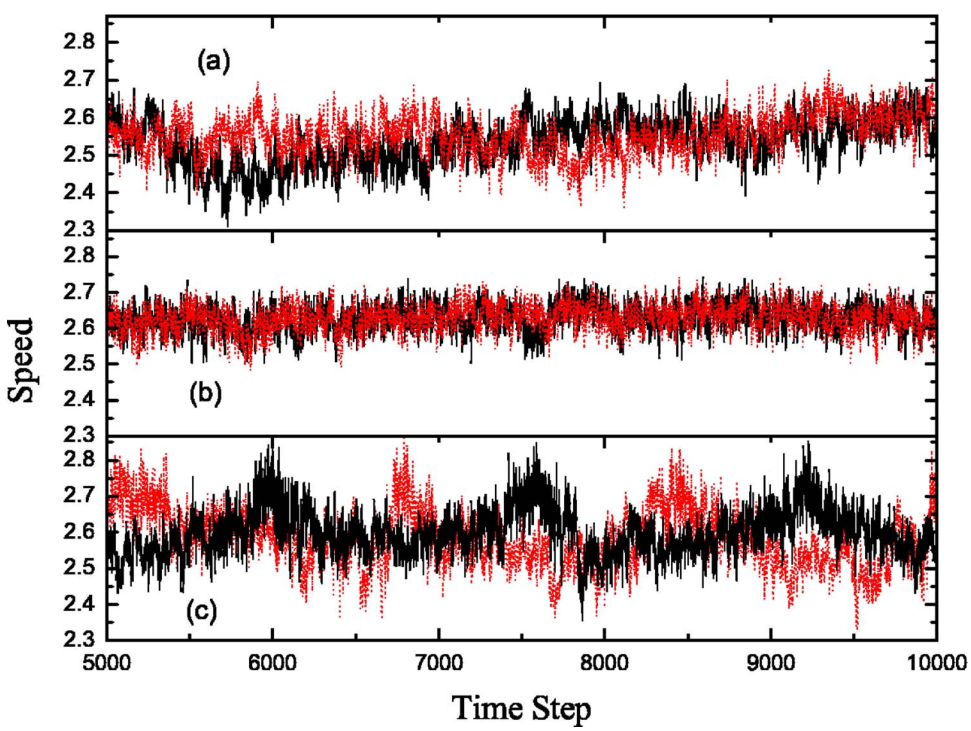

FIG. 5. (Color online) Average speed of each route by using (a) congestion coefficient feedback strategy, (b) mean velocity feedback strategy, and (c) travel time feedback strategy. The dark line and red dotted line represent route 1 and route 2, respectively. The parameters are set the same as in Fig. 2.

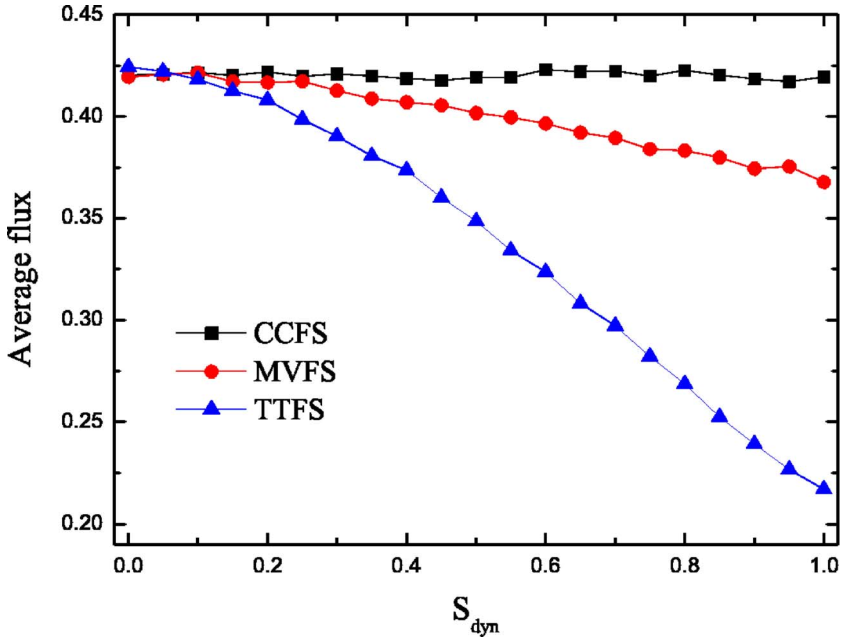

FIG. 6. (Color online) Average flux by performing different strategy vs S_{dyn}; L is fixed to be 2000.

that the vehicle number of two route reduces with increasing feedback period. For a short period, vehicle number does not exhibit considerable change compared to the case of no feedback delay, which indicates that the two-route system still performs satisfyingly in the case of short information feedback delay. While for long feedback delay, for example, when $period=1000$, the oscillation of the two-route vehicle number emerges and the system behaves in an undesirable way. As to the TTFS, the oscillation behaviors are also found, which are caused by the lag effect. Therefore we can conclude that the large delay of real-time information will lead to the oscillation of two-route utilization.

IV. CONCLUSION

We obtain the simulation results of applying three different feedback strategies, i.e., TTFS, MVFS, and CCFS on a two-route scenario all with respect to travel time, speed, number of cars, average flux, average flux versus S_{dyn}, and length. The results indicates that the CCFS strategy has more advantages than the two former ones. The highlight of this paper is that it brings forward a new and better quantity namely congestion coefficient to radically describe road conditions. In contrast with the two old strategies, the CCFS strategy can bring a significant improvement to the road conditions, including increasing vehicle number and flux, reducing oscillation, and that average flux does not reduce with increase of S_{dyn} and route lengths. The numerical simulations demonstrate that the congestion coefficient is meaningful and a basic quantity for describing the road condition.

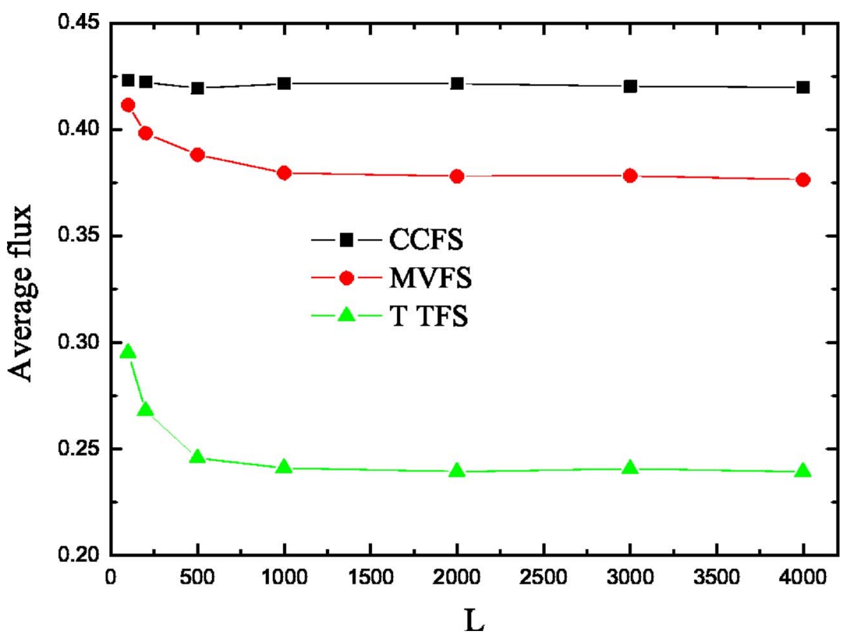

FIG. 7. (Color online) Average flux vs route length L by using three different strategies. The parameter is $S_{dyn}=0.9$.

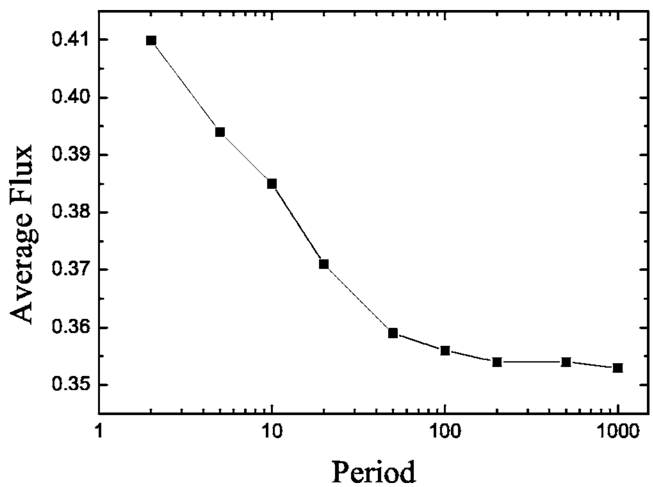

FIG. 8. Average flux vs information feedback period by adopting CCFS. The parameters are $L=2000$, $p=0.25$, and $s_{dyn}=0.5$.

Due to the rapid development of modern scientific technology, it is not difficult to realize CCFS. If only a navigation system (GPS) is installed in each vehicle, thus the position information of vehicles will be known, then the CCFS strategy can come true and also it will cost no more than MVFS. Taking into account the reasonable cost and more accurate description of road conditions, we think that this strategy shall be applicable.

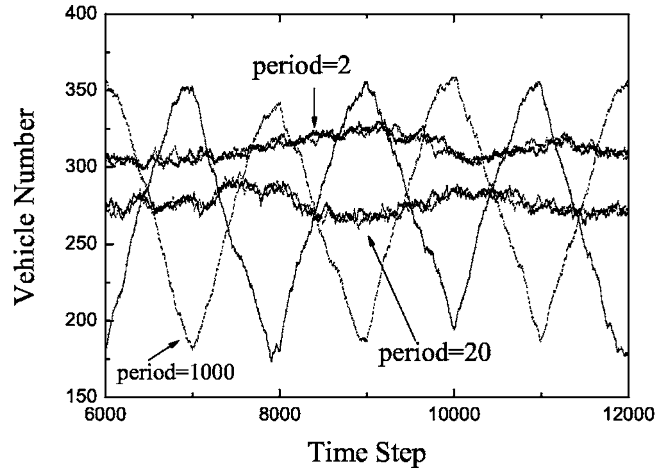

FIG. 9. Vehicle number of two routes as a function of time step by adopting CCFS for a different information feedback period. The parameters are the same as Fig. 8.

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