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Prediction feedback in intelligent traffic systems☆

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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 studied dynamics of traffic flow with real-time information provided and the influence of a feedback strategy named prediction 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. Our model incorporates the effects of adaptability into the cellular automaton models of traffic flow and simulation results adopting this optimal information feedback strategy have demonstrated high efficiency in controlling spatial distribution of traffic patterns compared with the other three information feedback strategies, i.e., vehicle number and flux.

1. Introduction

Vehicular traffic flow and related problems have triggered great interests of a community of physicists in recent years because of its various complex behaviors [1–3] and also a lot of theories have been proposed such as car-following theory [4], kinetic theory [5–11] and particle-hopping theory [12,13]. These theories have the advantage of alleviating the traffic congestion and enhance 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 put forward, such as Travel Time Feedback Strategy (TTFS) [14,20] and Mean Velocity Feedback Strategy (MVFS) [14,21] and Congestion Coefficient Feedback Strategy (CCFS) [14,22]. 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] and CCFS is more efficient than that of MVFS because of the fact that the random brake mechanism of the Nagel–Schreckenberg (NS) model [12] brings fragile stability of velocity [22]. However, CCFS is still not the best one due to the fact that its feedback is not in time, so it cannot reflect the road situation immediately and some other reasons which will be discussed delicately in this paper. In order to provide road users with better guidance, a strategy named prediction feedback strategy (PFS) is presented. We report the simulation results adopting four different feedback strategies in a two-route scenario with single route following the NS mechanism.

The paper is arranged as following: In Section 2 the NS model and two-route scenario are briefly introduce, together with four feedback strategies of TTFS, MVFS, CCFS and PFS all depicted in more detail. In Section 3 some simulation results will be presented and discussed based on the comparison of four different feedback strategies. Section 4 will make some conclusions.

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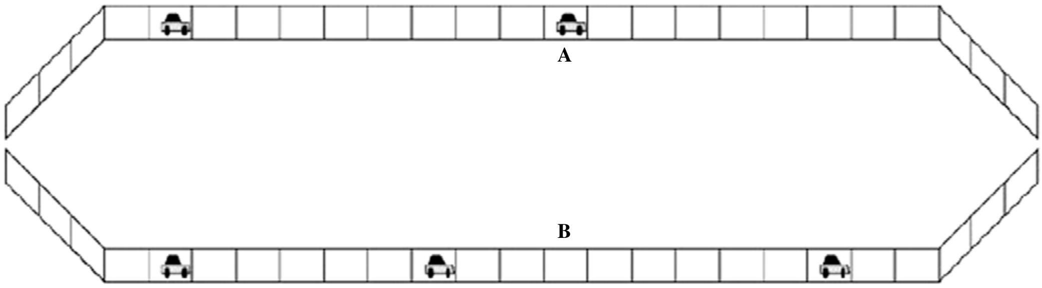

Fig. 1. The two-route system only has one entrance and one exit which is different from the road situation in former work.

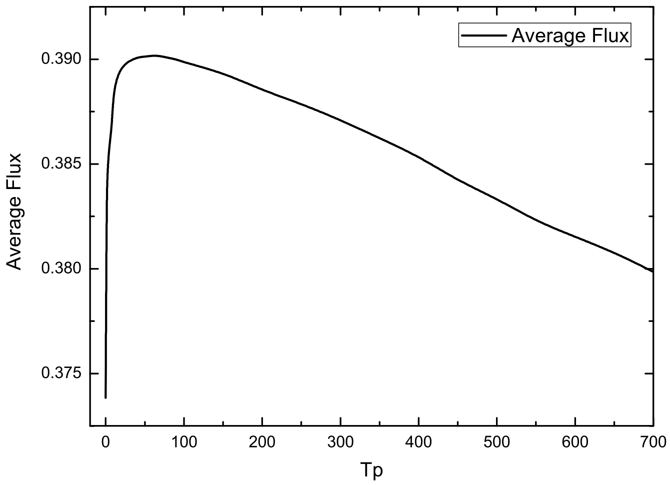

Fig. 2. Average flux by performing different prediction time (T_p). The parameters are $L = 2000$, $p = 0.25$, and $S_{\rm dyn} = 0.5$.

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], 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.

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 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 $S_{\rm dyn}$ and $1 - S_{\rm dyn}$, respectively.

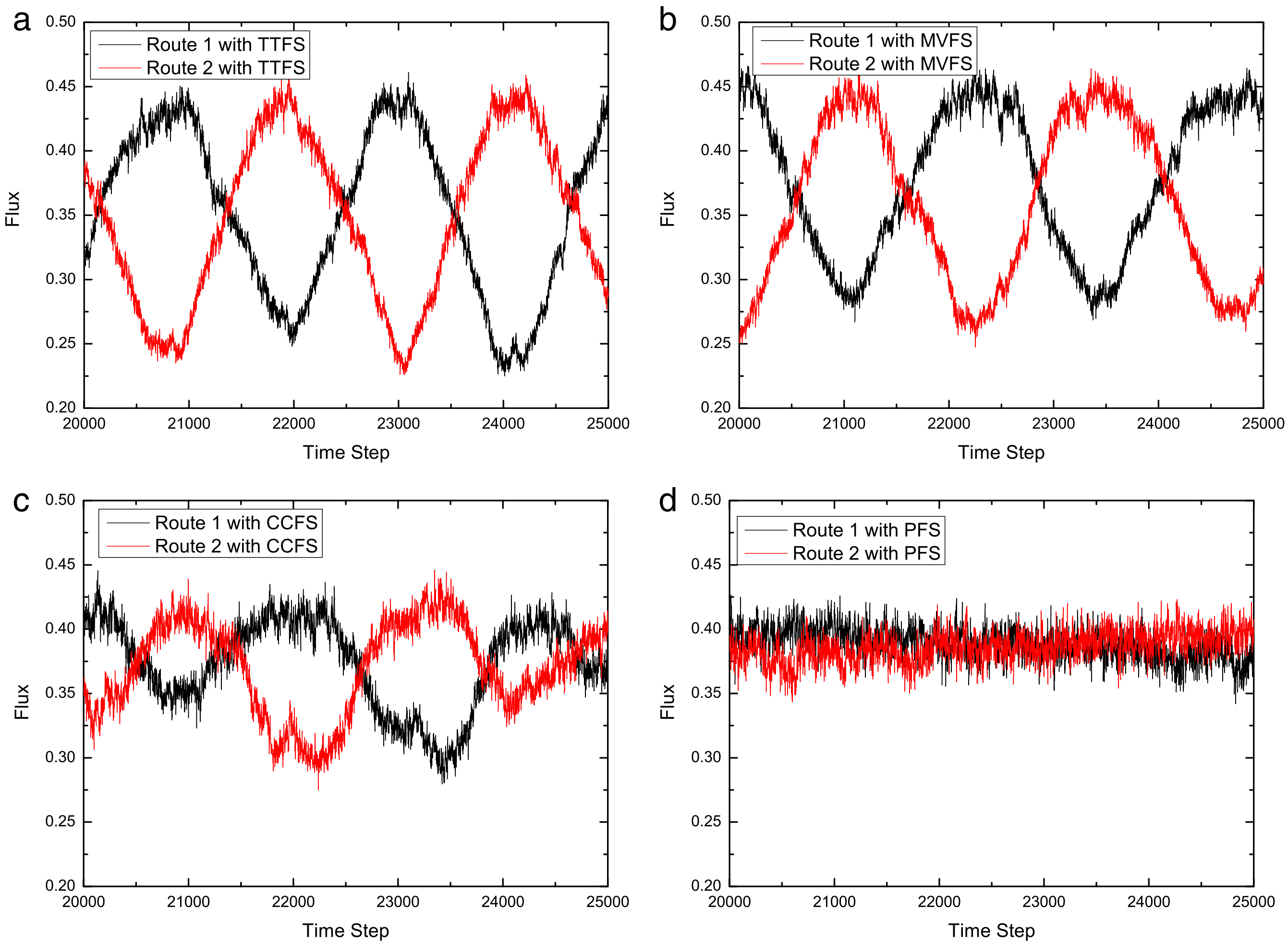

Fig. 3. (Color online) (a) Flux of each route with travel time feedback strategy. (b) Flux of each route with mean velocity feedback strategy. (c) Flux of each route with congestion coefficient feedback strategy. (d) Flux of each route with prediction feedback strategy. The parameters are $L = 2000$, $p = 0.25$, $S_{\text{dyn}} = 0.5$, and $T_p = 60$.

The simulations are performed by the following steps: first, set the routes and board empty; then, after the vehicles enter the routes, according to four 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.

2.3. Related definitions

The road conditions can be characterized by flux 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, 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. Road users at the entrance will choose one road with smaller congestion coefficient.

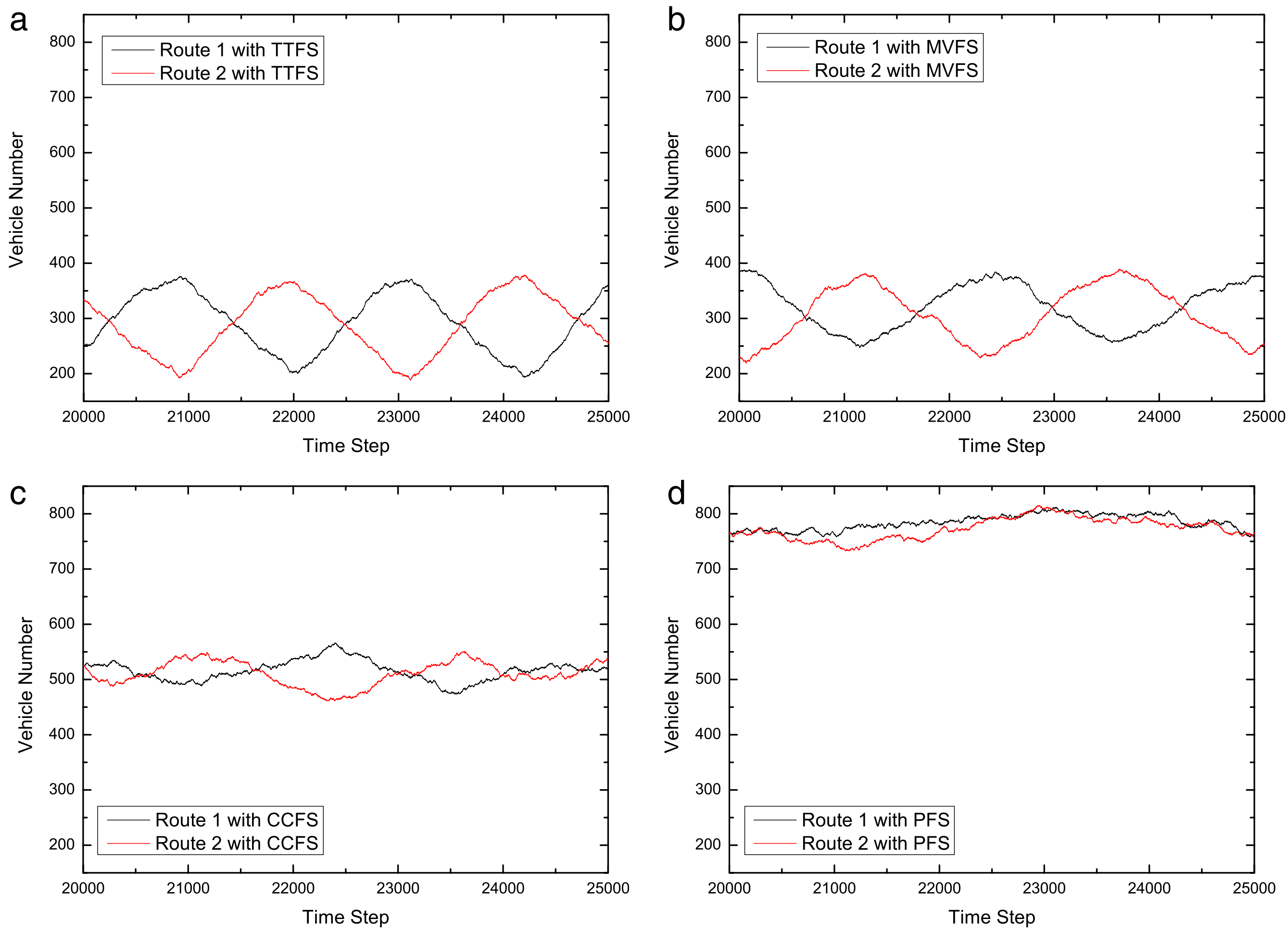

Fig. 4. (Color online) (a) Vehicle number of each route with travel time feedback strategy. (b) Vehicle number of each route with mean velocity feedback strategy. (c) Vehicle number of each route with congestion coefficient feedback strategy. (d) Vehicle number of each route with prediction feedback strategy. The parameters are set the same as in Fig. 3.

The congestion coefficient is defined as

$$C = \sum_{i=1}^{m} n_i^w. \tag{2.2}$$

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 $w = 2$ [22].

PFS: We do the work about PFS on the basis of CCFS, because CCFS is the best one among the three strategies above.

Every time step, the traffic control center will receive data from the navigation system (GPS) like CCFS, and the work of the center is to compute the congestion coefficient of each road and simulate the road situation in the future making use of the current road situation by using CCFS. Then display it on the board. Road users at the entrance will choose one road with smaller congestion coefficient. For example, if the prediction time (T_p) is 50 s and the current time is 100th second, the traffic control center will simulate the road situation at the next 50 s by using CCFS and predict the road situation at 150th second, then show the result on the board at the entrance of the road. Finally the road users at 100th second will choose one road with smaller congestion coefficient at 150th second predicted by the new strategy. So as to analogize, the road user at the entrance at 101th second will choose one road with small congestion coefficient at 151th second predicted by the new strategy like explained above and so on.

Compared with the former work [20–22], another important difference we have done in this paper is that we set the two-route system has only one entrance and one exit as it shows in Fig. 1 while the two-route system before has one entrance and two exits. So we do research work based on the two-route system which is more close to the reality instead of simply repeating other work. The rules at the exit of the two-route system are as follows:

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

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

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

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

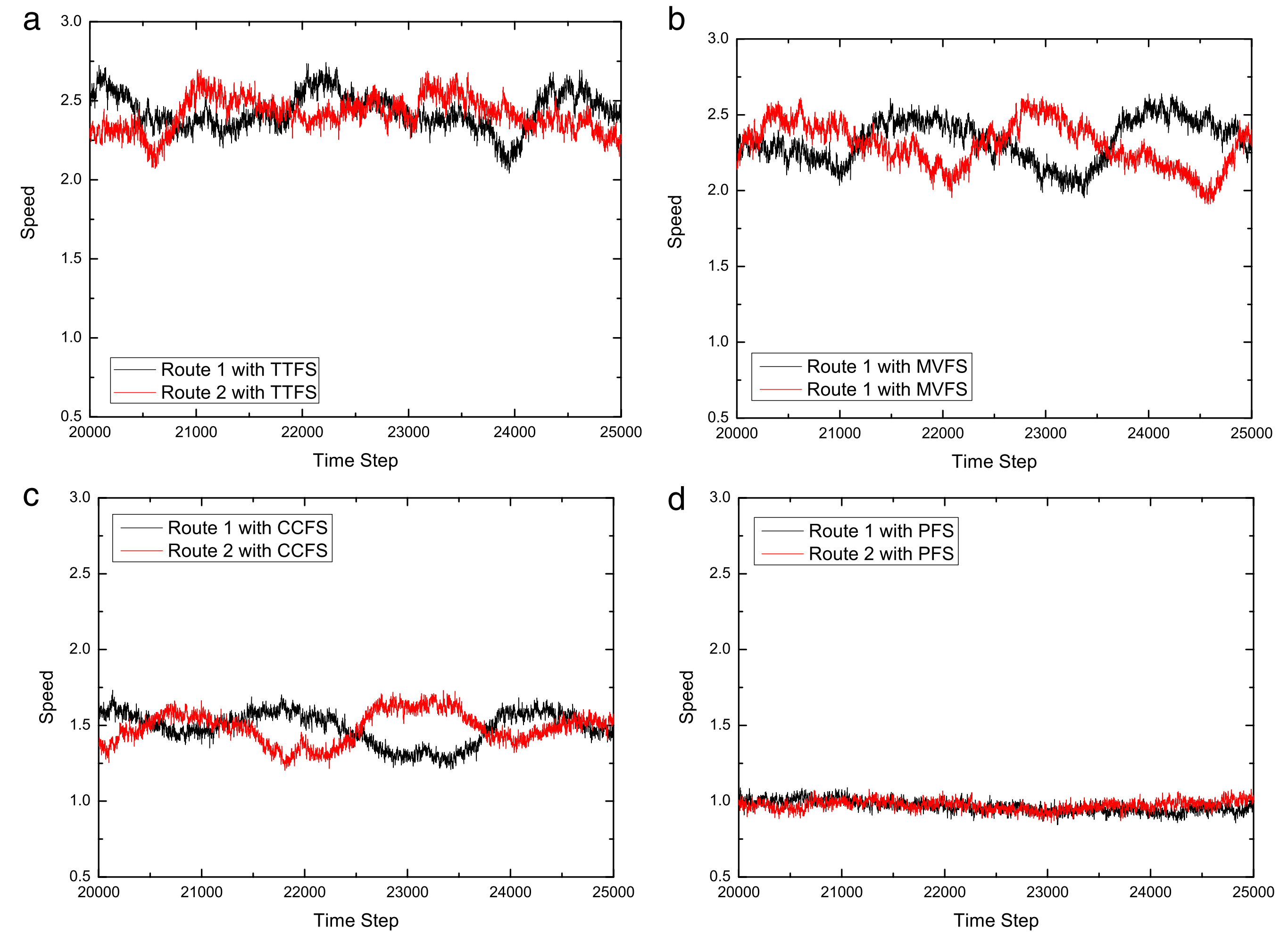

Fig. 5. (Color online) (a) Average speed of each route with travel time feedback strategy. (b) Average speed of each route with mean velocity feedback strategy. (c) Average speed of each route with congestion coefficient feedback strategy. (d) Average speed of each route with prediction feedback strategy. The parameters are set the same as in Fig. 3.

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

3. Simulation results

All simulation results shown here are obtained by 30 000 iterations excluding the initial 5000 time steps. Fig. 2 shows the dependence of average flux and prediction time (T_p) by using the new strategy. As to the routes' processing capacity. We can see that in Fig. 2 there are positive peak structures at the vicinity of $T_p \sim 60$. So we will use $T_p = 60$ in the following paragraphs.

In contrast with PFS, the flux of two routes adopting CCFS, MVFS and TTFS shows oscillation obviously (see Fig. 3) due to the information lag effect [22]. This lag effect can be understood as that the other three strategies cannot reflect the road current situation. Another reason for the oscillation is that two-route system only has one exit, therefore, only one car can go out at one time step which may result in the traffic jam to happen at the end of the routes and the new strategy can predict the effects to the route situation caused by the traffic jam at the end of the route, therefore, the new strategy may improve the road situation. Compared to CCFS, the performance adopting PFS 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, PFS is the best one.

In Fig. 4, vehicle number versus time step shows almost the same tendency as Fig. 3, the routes' accommodating capacity is greatly enhanced with an increase in vehicle number from 290 to 780, so perhaps the high flux of two routes with PFS are mainly due to the increase of vehicle number. Maybe someone will ask why the vehicle number in Fig. 4 using other three strategies is larger than the figures shown in the former work [22]. The reason is that the road situation is different from the work before. The two-route system in this paper only has one exit, therefore, only one car can go out at one time step which will lead to the increasing of vehicle number in each route.

In Fig. 5, 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 strategy and as mentioned above the road has only one exit and only one car can go out at one time step, therefore, the more cars,

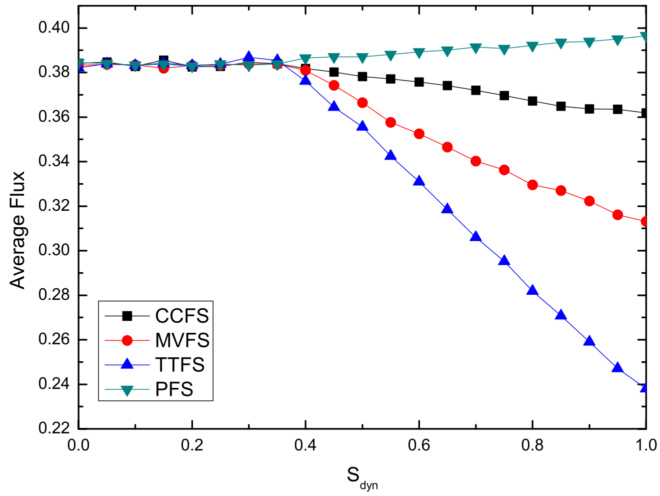

Fig. 6. (Color online) Average flux by performing different strategy vs S_{dyn}; L is fixed to be 2000, and T_p is fixed to be 60.

the lower speed. Fortunately, flux consists of two parts, mean velocity and vehicle density, therefore, as long as the vehicle number (because the vehicle density is $\rho = N/L$, and the L is fixed to be 2000, so $\rho \propto$ vehicle number (N)) is large enough, the flux can also be the largest.

Fig. 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 even increases with a persisting increase of dynamic travelers.

4. Conclusion

We obtain the simulation results of applying four different feedback strategies, i.e., TTFS, MVFS, CCFS and PFS on a two-route scenario all with respect to flux, number of cars, speed, average flux versus T_p and average flux versus S_{dyn}. The results indicates that the PFS strategy has more advantages than the three former ones in the two-route system which has only one entrance and one exit. The highlight of this paper is that it brings forward a new quantity namely prediction time (T_p) to radically improve road conditions. In contrast with the three old strategies, the PFS strategy can bring a significant improvement to the road conditions, including increasing vehicle number and flux, reducing oscillation, and that average flux increases with increase of S_{dyn}. And it can be understood because the new strategy can eliminate the lag effect. The numerical simulations demonstrate that the prediction time (T_p) play a very important role in improving the road situation.

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

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