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A comprehensive study of advanced information feedbacks in real-time intelligent traffic systems

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ABSTRACT

In the intelligent transportation system, an effective feedback strategy is of crucial importance to the improvement of traffic condition and transport capability. Based on the seven previously introduced feedback strategies, a new one is introduced, called vacancy length feedback strategy (VLFS). The simulation results in the symmetrical two-route scenario with two exits suggest that VLFS is the optimal one among all the feedback strategies. It outperforms others in terms of the value, stability, average flux and balance of the vehicle number, and also exceeds others for the convenience of its application in the real traffic condition. The later simulation results in the asymmetrical two-route scenario with one exit also prove that VLFS is the best.

1. Introduction

Transport network and Internet are getting more and more close to our daily life with the development of economy and living conditions. Following is the deterioration of the phenomenon of congestion. Many physicists have applied physics concepts and analytical methods to solve these difficult problems [1–4]. In recent years, study focuses on the research of strategies, such as routing strategies in network and information feedback strategies in intelligent traffic systems. In terms of routing strategies, Wang et al. proposed two routing strategies based on local static and dynamic information [5,6]. In order to solve the cascading failures and traffic congestion in the network, Yang et al. proposed weighted routing strategy in 2009 [7]. As to the feedback information strategy in intelligent traffic system, there are more research findings [8–18]. Intelligent transportation system is a novel one dimensional urban traffic system. To improve the transportation capacity and avoid the congestion, we need to present the feedback information of traffic conditions. Take a two-route scenario as an example; we set a board at the entrance displaying the traffic condition of the routes to instruct the drivers for selection. Therefore, to design a reasonable and efficient feedback information is the pivotal problem. In recent years, some information feedbacks have been presented to investigate in the symmetrical two-route scenario. Wahle et al. first investigated the two-route scenario with travel time feedback strategy (TTFS) [11]. Subsequently, Lee et al. studied the effect of a different type of information feedback, named mean velocity feedback strategy (MVFS) [12], i.e. instantaneous average velocity. Then Wang et al. proposed a third type of information feedback, called congestion coefficient feedback strategy (CCFS) [13]. All the three strategies mentioned above were simulated in the symmetrical two-route scenario with two exits, and Wang et al. demonstrated that CCFS is the best. Recently, Dong et al. proposed four straightforward and concise methods, called prediction feedback strategy (PFS) [14,15], vehicle number feedback strategy (VNFS) [16], weighted congestion coefficient

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feedback strategy (WCCFS) [17] and corresponding angle feedback strategy (CAFS) [18]. They applied these four strategies in the two-route scenario with one exit to test the effects of these feedbacks.

In the strategies based on the two-route scenario with two exits, the researchers have shown that MVFS is better than TTFS [12]. The disadvantage of TTFS results from its information delay which leads to the great fluctuation of physical quantities such as flux and speed. Meanwhile, Wang et al. proved that CCFS is better than MVFS [13], because of the fact that the random brake mechanism of the Nagel–Schreckenberg (NS) model brings about fragile stability of velocity. CCFS proposed by Wang is an initiative research result, in which he posed a new method for feedback strategy design. In the following, Dong improved CCFS and proposed four new strategies. The key of PFS is to forecast the congestion coefficient at a certain time based on the current traffic conditions. VNFS is based on CCFS when the congestion coefficient is 1 and it considers the information on the first 500 cells. WCCFS and CAFS improve the definition of congestion coefficient. As for strategies applied to the two-route scenario with one exit, Dong et al. proved that all the four new strategies they present are better than TTFS, MVFS and CCFS [14,16–18], and CAFS is better than WCCFS [18]. These researches, however, are far from enough. Most seriously, they failed to compare those strategies by applying them to the same route model. That is the reason why we have no way to judge which strategy is the best. In order to provide better traffic guidance to drivers, this paper introduces a new feedback strategy and carries out its simulation, together with the other seven strategies, to the two-route scenario with two exits in which the vehicles on the road will obey the NS mechanism. Afterward, the optimal feedback strategy will be provided according to the simulation results.

2. Related definitions

2.1. NS mechanism

Vehicles on routes move according to Nagel–Schreckenberg (NS) rules [19] as follows:

(1) acceleration: $v_i(t) \rightarrow v_i(t+1/3) = \min\{v_i(t)+1, v_{\max}\}$;
(2) deceleration: $v_i(t+1/3) \rightarrow v_i(t+2/3) = \min\{v_i(t+1/3), d_i(t)\}$;
(3) randomization with probability p: $v_i(t+2/3) \rightarrow v_i(t+1) = \max\{0, v_i(t+2/3)-1\}$;
(4) vehicle motion: $x_i(t+1) = x_i(t) + v_i(t+1)$

where $v_i(t)$ denotes the velocity of the ith vehicle, $v_{\max}$ is the maximum velocity, $d_i(t)$ is defined to be the number of empty sites in front of the ith vehicle at time t and $x_i(t)$ is the position of the ith vehicle at time t.

2.2. Traffic flux and vehicle types

The fluxes of two routes are defined as follows:

$$F = V_{mean}\rho = V_{mean}\frac{N}{L}, \tag{1}$$

where V_{mean} is the average speed of all the vehicles on one route, N denotes the vehicle number on each road, and L is the length of two routes.

The average flux is defined as follows:

$$F_{avg} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{t} F_{ij}}{t \times n}, \tag{2}$$

here F_{ij} stands for the flux on the ith routes at the time j and t stands for the whole time, n is the number of routes.

Two types of vehicles are introduced in the simulation: the dynamic and the static. For a driver called the dynamic one, he selects the route to enter according to the feedback information, while a static one enters the traffic system randomly. The ratio of dynamic and static vehicles are S_{dyn} and $1 - S_{dyn}$, respectively.

2.3. Two-route scenario

The symmetrical two-route model was first investigated by Wahle et al. [9], in which both routes are supposed to be of the same length. A new vehicle is generated at the entrance at each time step, and then it chooses one route to enter. Once the vehicles enters the routes, the motion follows the dynamics of NS mechanism. If the vehicle is unable to enter the desired route, it will be deleted. When the vehicles reach the end, they are removed.

2.4. Information feedback strategies

Travel time feedback strategy (TTFS): at each time step, the passing time of the vehicle that exits the route is displayed on the notice board. The new dynamic vehicle chooses the route with less passing time [11].

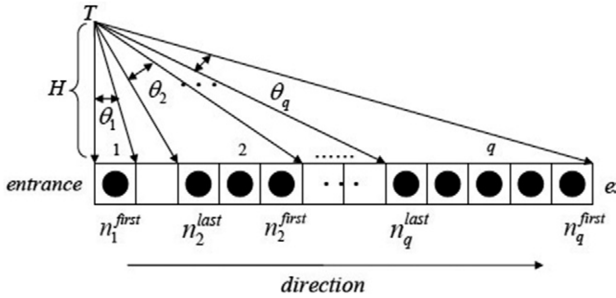

Fig. 1. Angles corresponding to each congestion cluster on the lane.

Mean velocity feedback strategy (MVFS): at each time step, the average velocity of vehicles on each route is displayed on the notice board. The new dynamic vehicle enters the route with larger average speed [12].

Congestion coefficient feedback strategy (CCFS): at each time step, the congestion coefficients of both routes are displayed on the notice board. The new dynamic vehicle chooses the route with smaller congestion coefficient. The congestion coefficient is defined as:

$$C = \sum_{i=1}^{m} n_i^w \tag{3}$$

where 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. Every cluster is evaluated at a weight w; here $w = 2$ [13].

Prediction feedback strategy (PFS): at every time step, the congestion coefficient of each road in a future time is predicted and displayed for instruction. Drivers enter the route with a smaller predicted congestion coefficient [14]. For example, if we set the predictive time to be 50 s and the current time is 100 s, then the congestion coefficient at time 150 s will be calculated based on previous information and shown on the instruction board. According to our simulation, average flux of two routes reaches its maximum when $T_p = 50$.

Vehicle number feedback strategy (VNFS): at each time step, total vehicle number of the first 500 route sites of each route are displayed on the board, and drivers enter the route with smaller number [16].

Weighted congestion coefficient feedback strategy (WCCFS): at each time step, the congestion coefficient of each route with a weighted function is calculated and displayed on the board. Drivers enter the route with a smaller one. The weighted congestion coefficient is defined as:

$$C_w = \sum_{i=1}^{q} F(n_m) n_i^w = \sum_{i=1}^{q} \left(k \times \frac{n_m}{2000} + 2.0 \right) \times n_i^w \tag{4}$$

where n_i is the same as CCFS. n_m denotes the middle position of the ith congestion cluster. $F(x)$ stands for the weighted function and $w = 2$ as CCFS [17]. K represents an indefinite factor, which affects traffic flux. According to our simulation, average flux of two routes reaches maximum when $k = -3.0$.

Corresponding angle feedback strategy (CAFS): at every time step, the work of the traffic control center is to compute the corresponding angle of each congestion cluster (see Fig. 1) on the lane, sum square of each corresponding angle up and display it on the board. Road users at the entrance will choose one road with a smaller corresponding angle coefficient. The corresponding angle coefficient is defined as:

$$C_\theta = \sum_{i=1}^{q} \theta_i^2 = \sum_{i=1}^{q} \left(\arctan\left(\frac{n_i^{first}}{H} \right) - \arctan\left(\frac{n_i^{last} - 1}{H} \right) \right)^2 \tag{5}$$

where n_i^{first} and n_i^{last} stand for the position of the first and last vehicle in the ith congestion cluster, respectively. θ_i stands for the weight (corresponding angle) of the ith congestion cluster. H denotes the vertical distance from the point T to the lane, and in this paper, we set $H = 100$ [18].

Vacancy length feedback strategy (VLFS): at every time step, the center of traffic control calculates the distance from the last vehicle to the entrance of each road and displays the information on the notice board, which guides drives to choose the road with longer vacant length.

3. Simulation results

The length of road for simulation is $L_a = L_b = 2000$ and the velocity of the vehicles cannot exceed $v_{\max} = 3$. The ratio of the dynamic drivers is $S_{dyn} = 0.5$ while random break probability is set to be $p = 0.25$. All the results of vehicle number,

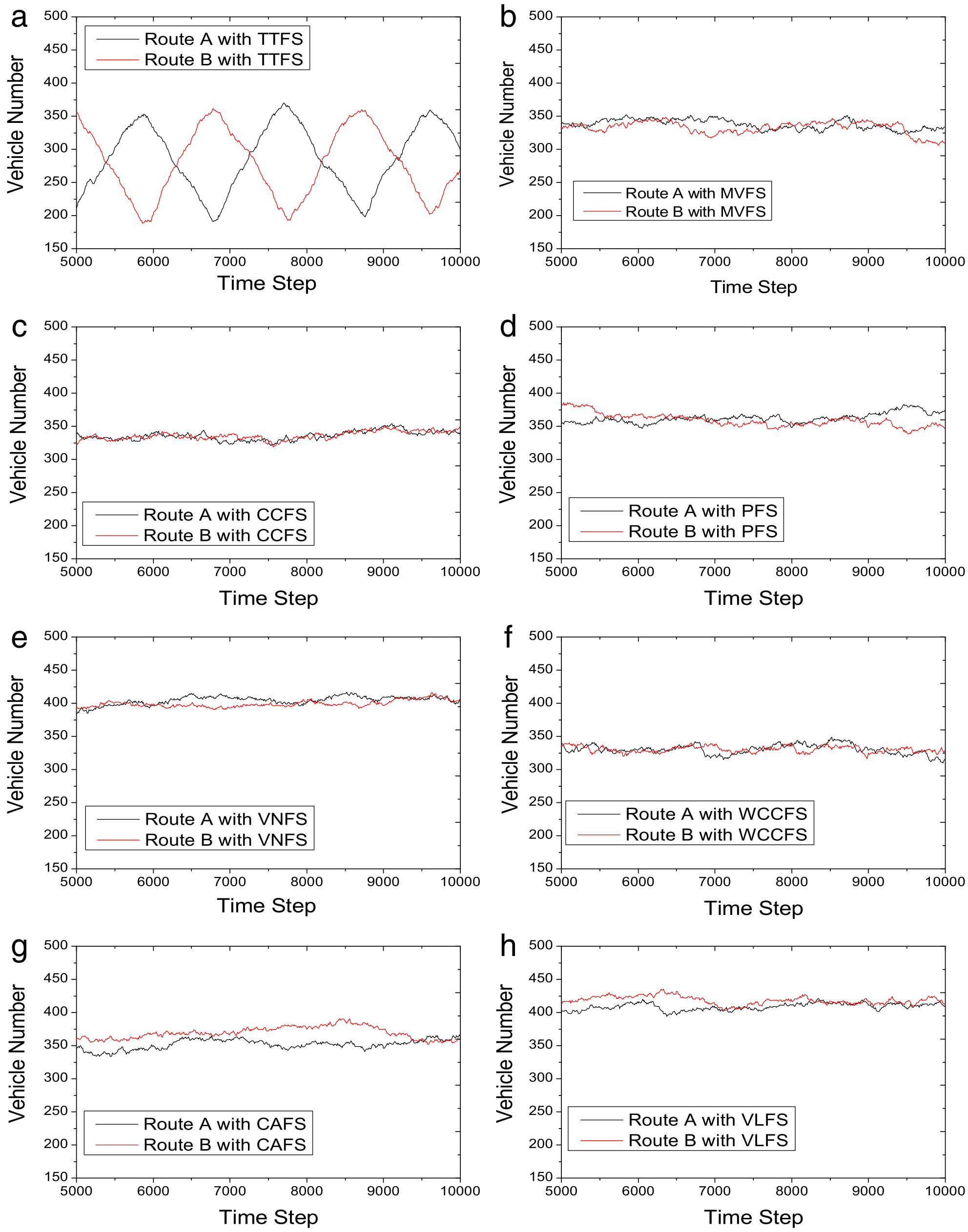

Fig. 2. (Color online) Vehicle number of each route with (a) TTFS, (b) MVFS, (c) CCFS, (d) PFS, (e) VNFS, (f) WCCFS, (g) CAFS, (h) VLFS. The parameters are $L_A = 2000$, $L_B = 2000$, $p = 0.25$, $S_{dyn} = 0.5$, $T_p = 50$ in PFS, $k = -3.0$ in WCCFS and $H = 100$ in CAFS.

velocity and flux are obtained by 10,000 iterations excluding the first 5000 time steps. We simulate ten times and adopt the average value with 100,000 iterations in each for the results of the relation between average flux and the ratio of dynamic vehicles.

Fig. 2 shows the changing of vehicle number according to time when adopting the eight strategies. From it we can see that there is severe amplitude oscillation when TTFS is adopted. This is due to its delay in information feedback. Similarly, the lag effect by TTFS also leads to amplitude oscillation in figures of speed (as shown in Fig. 3(a)) and flux (as shown in Fig. 4(a)). We find that there are most vehicles when VLFS instead of the other seven strategies is adopted, with an increase from 320 to about 420. Moreover, the balance of vehicle number on the two roads is as well as that when the other strategies are adopted. Therefore, we can say that VLFS is the optimal one in terms of vehicle capacity.

Fig. 3 shows the relationship between speed and time by using eight different strategies. From it we can see that the speed of the vehicles fluctuates little and its value is rather high when MVFS is adopted. We do not, however, think this

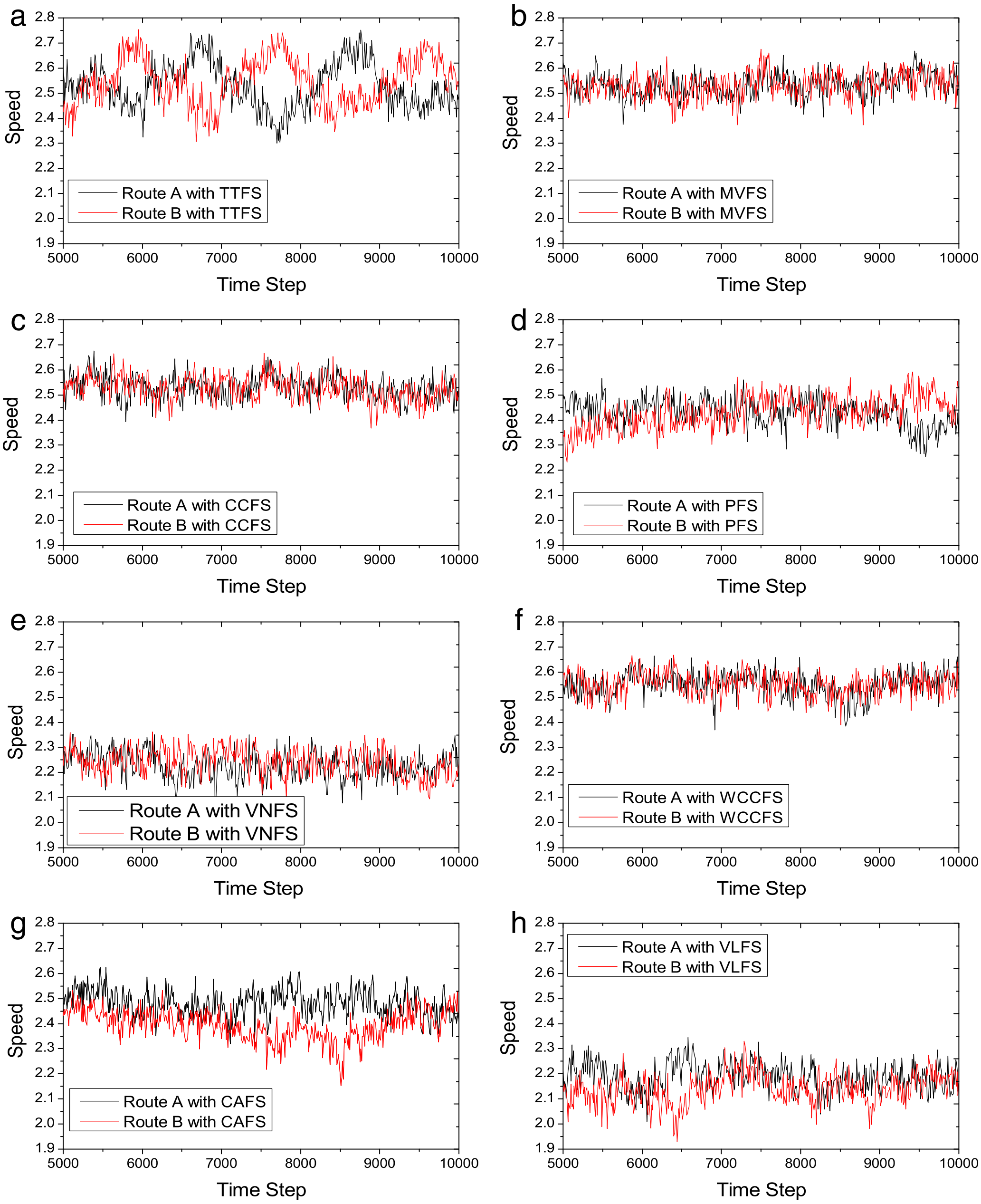

Fig. 3. (Color online) Speed of each route with (a) TTFS, (b) MVFS, (c) CCFS, (d) PFS, (e) VNFS, (f) WCCFS, (g) CAFS, (h) VLFS. The parameters are set the same as that in Fig. 2.

strategy is the best, because the NS model has a random brake probability which causes the fragile stability of velocity, so MVFS cannot completely reflect the real condition of routes [13].

Fig. 4 illustrates the change of flux of each route versus time when using different strategies. We are confident that flux is an index which truly reflects traffic capacity. The following two examples can illustrate this well. From Fig. 2, we learn that there will be most vehicles on the road when VLFS is adopted, but the speed is the slowest, as is shown in Fig. 3. Similarly, Fig. 3 shows that the speed is advantageous when MVFS is adopted, but the vehicle number is the smallest, as is shown in Fig. 2. Fortunately, the fact is that the flux consists of two parts: average speed as well as vehicle density. Therefore, we can judge a strategy according to flux. From Fig. 4, we find that in terms of flow stability, CCFS, PFS, VNFS, CAFS and VLFS are better than the other strategies, while in terms of flow value, VNFS and VLFS are better strategies. From Fig. 4, however, it is difficult for us to decide which is better, the VNFS or VLFS.

In the former research, the average flux (see Eq. (2)) is regarded as an important standard to evaluate the capacity of roads, so we use the average flux as criterion. Fig. 5(a) shows how the average flux changes along with the fraction of

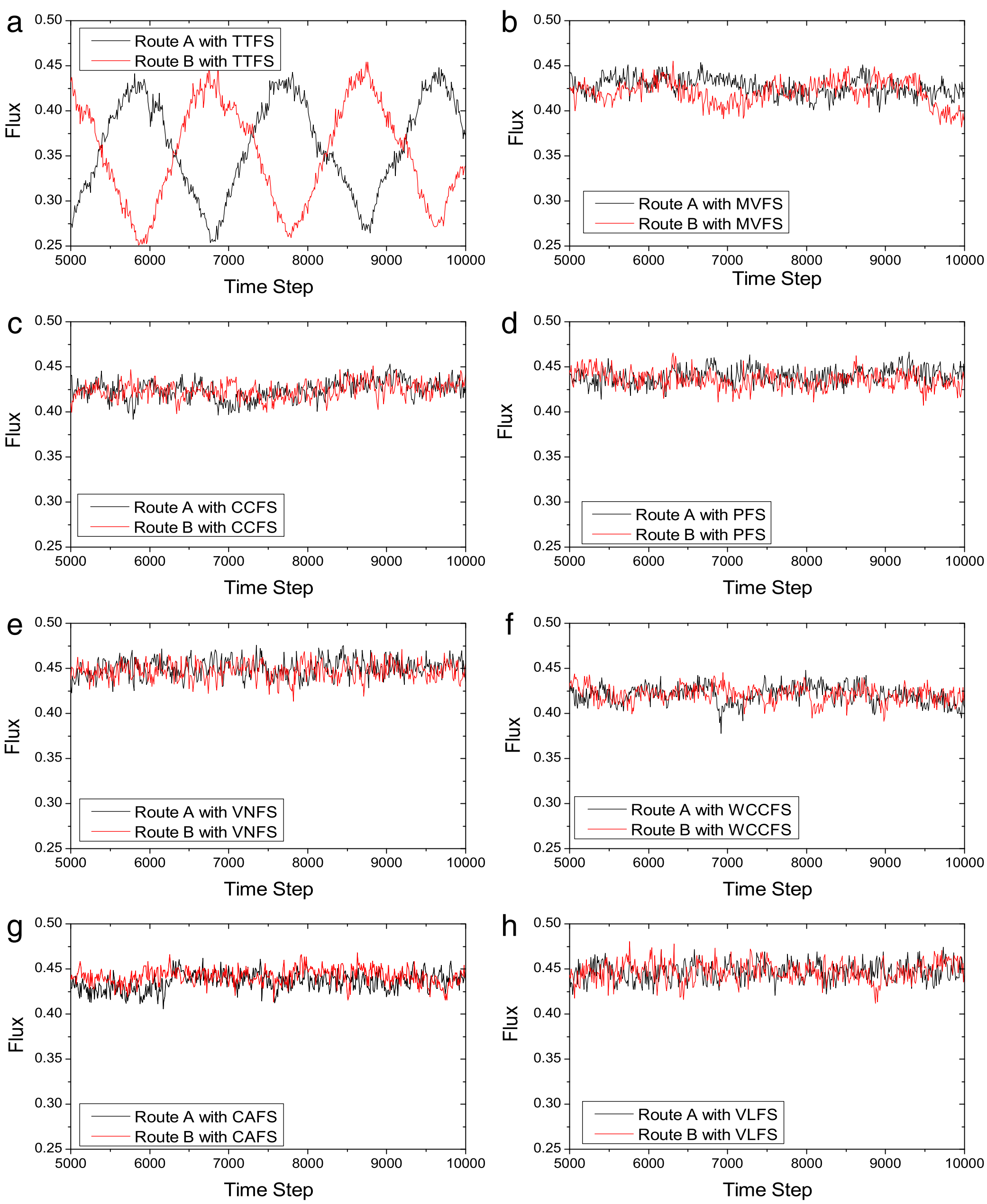

Fig. 4. (Color online) Flux of each route with (a) TTFS, (b) MVFS, (c) CCFS, (d) PFS, (e) VNFS, (f) WCCFS, (g) CAFS, (h) VLFS. The parameters are set the same as that in Fig. 2.

dynamic vehicles when adopting the eight strategies. From it we can easily find that when TTFS is adopted, the average flux on the routes decreases when S_{dyn} increases. The main reason is that TTFS does not take the delay of information into consideration. That is to say, when the vehicles exit the two-route scenario, the information they return can only stand for the current condition of the traffic. If more drivers choose the route with less passing time, the condition will be worse if there is congestion on the routes or there are too many vehicles. Such situation cannot be reflected in TTFS. As to MVFS, CCFS or WCCFS, when we use these strategies, the more drivers choose roads according to the prompt message, the smaller the average flow on the road will be. In other words, drivers have better choose roads randomly instead of deciding their routes according to the offered information, which will be more beneficial to the improvement of traffic condition. This is similar with TTFS, but the amplitude of decrease is not so obvious as TTFS. As to PFS, VNFS, CAFS and VLFS, it is difficult to judge their advantages and disadvantages from Fig. 5(a). From Fig. 5(b), which is the enlarged version of Fig. 5(a), however, we can see that VLFS is the best. When PFS and CAFS are adopted, there appears no increase in average flux on the road according to the increase of dynamic vehicle proportion but when VNFS is adopted, average flux increases sharply. The increase degree,

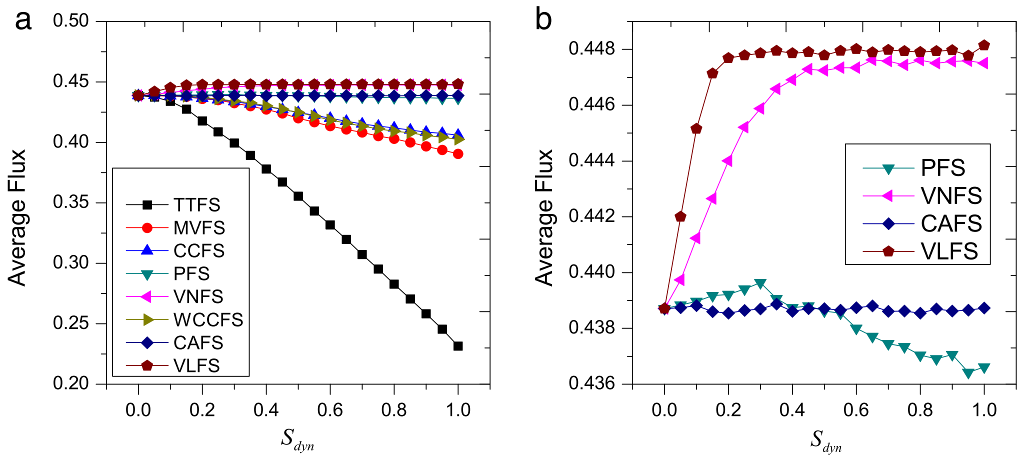

Fig. 5. (Color online) (a) Average flux by performing different strategy versus S_{dyn}. (b) To amplify figure of (a).

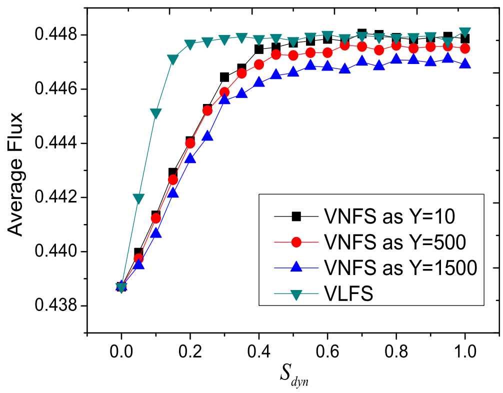

Fig. 6. (Color online) Average flux versus S_{dyn} by summing the vehicle number between the different route site and the entrance when adopting VNFS and average flux versus S_{dyn} by using VLFS.

however, is not as great as that when VLFS is adopted, because for each S_{dyn}, VLFS's average flux is the largest. Therefore, we believe VLFS is the best in a symmetrical two-route scenario with two exits. Then what is the reason for VLFS being the best? The answer will be given in the following discussion.

From Fig. 5(a) we can conclude that when $S_{dyn} > 0.3$, the average flux of PFS is greater than CCFS regardless of the value of S_{dyn}. This can be accounted by the fact that when taking the congestion coefficient of a certain future time as the feedback information, the delay of information can be averted. Therefore, to quickly send back the information of the routes is a factor to improve the traffic capacity. VLFS can do well in this aspect, because we can directly compare the distance between the last vehicle and the entrance and no information delay exists. However, this is not the critical reason of VLFS's outperformance, for the sake that the average flux might remain the same when S_{dyn} increases, the same as PFS, even if the information delay has been averted.

Perhaps people will ask why the trends of curve are so similar when adopting VNFS and VLFS (see Fig. 5(b)). That is because VNFS calculates the vehicle number on the first 500 cells of each road, while VLFS calculates the vacant length from the last vehicle to the entrance of each road. These two strategies share a common principle: their statistical information is collected near the entrance. Fig. 6 shows the changing of average flux on the road according to the ratio of dynamic vehicles when VLFS and VNFS are adopted. About VNFS, there are three simulative curves, each of which respectively represents the changing of average flux on the road according to the fraction of dynamic vehicles on the first Y cells of each road. We set $Y = 1500$, $Y = 500$, $Y = 10$, respectively. From it we can see that when VNFS is adopted, for the same S_{dyn}, with the decreasing of Y, the average flux on the road increases steadily. When $Y = 10$ and $S_{dyn} > 0.5$, its average flux is nearly the same as that when VLFS is adopted. Thus we can conclude, the further the vehicle is away from the entrance, the less influence its condition imposes on the traffic capability. In order to improve the traffic capability, what we need to do is only to give feedback on the information of the entrance. Compared with the other strategies, VLFS is undoubtedly the most convenient and effective strategy. This is the main reason for VLFS being the best one.

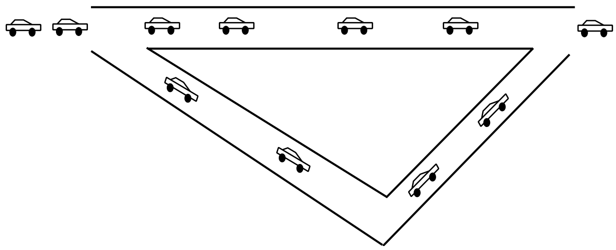

Fig. 7. Asymmetrical two-route scenario with one exit.

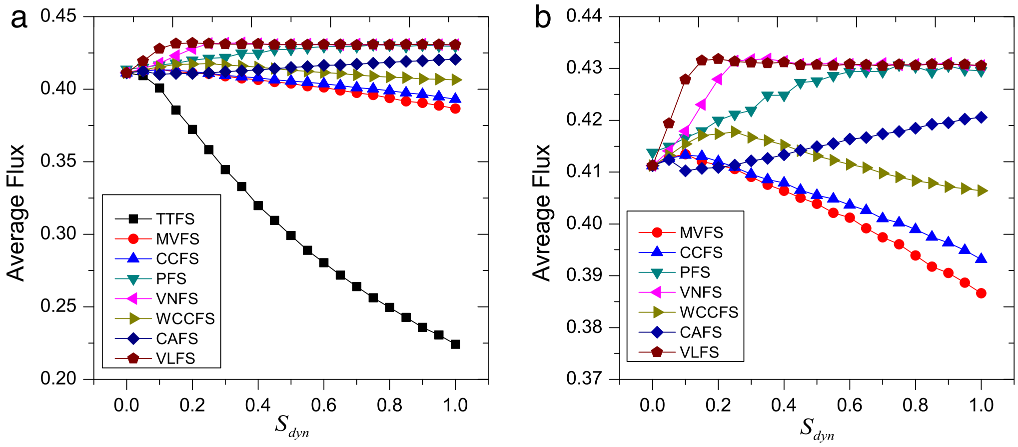

Fig. 8. (Color online) (a) Average flux by performing different strategies versus S_{dyn} in asymmetrical two-route scenario with one exit. (b) To amplify figure of (a).

4. Further application

There are many types of route model in urban transportation network, among which the symmetrical two-route scenario is the simplest. Is VLFS still the optimal one in other route models? We are often countered with such situation that we have to choose between two routes, one longer while the other shorter, towards the same destination. To choose the longer one may lead to a waste of time while the shorter may bring about congestion for too many vehicles. In order to provide better instruction for drivers, we apply these strategies in the asymmetrical two-route scenario with one exit (see Fig. 7).

First, we need to set rules for the vehicles exiting the scenario.

(a) At the exit, the vehicle closer to the exit has the priority to leave the scenario.
(b) If two last vehicles on the two routes are of the same distance towards the exit, the faster vehicle has the priority to leave the scenario.
(c) At the exit, if conditions (a) and (b) are both met, vehicles leave the scenario randomly.

Second, before applying all the strategies to the asymmetrical two-route scenario, TTFS, CCFS, PFS, WCCFS and CAFS need improvement as follows.

(a) CCFS: feedback information should be changed to C/L, where L stands for related route length and C is the congestion coefficient in CCFS.
(b) PFS: the CCFS congestion coefficient which is used in PFS should be changed as (a).
(c) WCCFS: feedback information should be changed to C_w/L, where L stands for related route length and C_w is the congestion coefficient in WCCFS.
(d) CAFS: feedback information should be changed to C_a/L, where L stands for related route length and C_a is the congestion coefficient in CAFS.

In the simulation, we set the length of routes $L_A = 4000$ and $L_B = 7000$, respectively, and all the other parameters are the same as above. While applying WCCFS and PFS into new scenario, the undetermined parameters should be set again for best performance. Results indicate that when applying WCCFS and $k = -2.4$, the average flux reaches the peak; when applying PFS and $T_p = 420$, the average flux reaches the peak.

Fig. 8 shows the relationship of average flux and S_{dyn} when applying eight different strategies. When TTFS is used, average flux decreases dramatically when S_{dyn} increases. This is similar with that in symmetrical two-route scenario with two exits. Therefore, average passing time is not a suitable feedback information. The change of average flux adopting

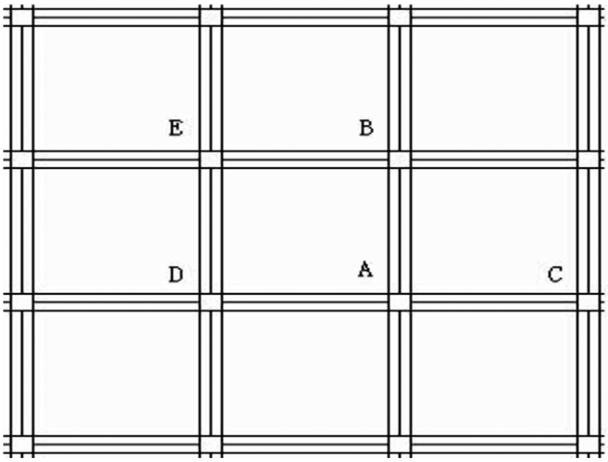

Fig. 9. Urban traffic network model.

all the other strategies is more obviously shown in Fig. 8(b). All the other seven strategies can be divided into two parts. The first part includes MVFS, CCFS and WCCFS, average flux in all of which decreases while S_{dyn} increases. Therefore, these three information feedback strategies cannot improve the traffic condition. The second part includes CAFS, PFS, VNFS and VLFS, average flux in which increases while S_{dyn} goes up. Therefore, these strategies are significant for transportation improvement. Except for S_{dyn}, the average flux of VLFS is the greatest for all the S_{dyn}. In view of this, we come to the conclusion that VLFS is still the optimal one in the asymmetrical two-route scenario with one exit.

These feedback information strategies can be applied well in urban transportation network. Fig. 9 shows the model of urban traffic network. In the graph, if one starts from A, going shopping at B or C, which are of the same distance from A, it is the symmetrical two-route scenario with two exits. The instructive information will be displayed on the board for drivers to select. On the other hand, if one starts from A and aims to D, one can go to D directly from A or indirectly by passing B and E. In such a situation, it is the asymmetrical two-route scenario with one exit and the feedback information that can offer assistance.

5. Conclusion

A new strategy called vacancy length feedback strategy is introduced in this paper. In addition to other seven proposed by other researchers, there is a total of eight strategies. Adopting NS as the update mechanism of vehicles, we apply these eight strategies into the two-route scenario with two exits, from which we obtain the simulation of the changing of vehicle number, speed and flux according to time together with that of average flux according to the ratio of dynamic vehicles. Besides, we presented the changing of average flux with S_{dyn} according to different feedback length when VNFS is adopted. From the results of stimulation, we find that VLFS enjoys great superiority over other strategies not only in terms of the value, stability and balance of physical quantities such as vehicle number and flux, but in terms of the convenience of its application as well. At the same time, we find that the further the vehicle is away from the entrance, the less influence its condition imposes on the traffic capability. In order to improve the traffic capability, we only need to consider the feedback information of the entrance. Finally, we simulate these strategies in the asymmetrical two-route scenario with one exit, and obtain the relationship of average flux and S_{dyn}. All the results show that VLFS is still the optimal one.

To put vacancy length feedback strategy into practice is not that difficult with the development of technology. We only need to install an array of sonar to measure the vacant length. Therefore, this strategy is quite applicable in terms of the cost and traffic capability.

Acknowledgments

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