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Improvement of driving safety in road traffic system*

Li Ke-Ping(李克平)† and Gao Zi-You(高自友)

School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, *China*

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A road traffic system is a complex system in which humans participate directly. In this system, human factors play a very important role. In this paper, a kind of control signal is designated at a given site (i.e., signal point) of the road. Under the effect of the control signal, the drivers will decrease their velocities when their vehicles pass the signal point. Our aim is to transit the traffic flow states from disorder to order, and then improve the traffic safety. We have tested this technique for the two-lane traffic model that is based on the deterministic Nagel–Schreckenberg (NaSch) traffic model. The simulation results indicate that the traffic flow states can be transited from disorder to order. Different order states can be observed in the system, and these states are safer.

Keywords: cellular automation model, traffic flow, driving safety
PACC: 0550

1. Introduction

In a road traffic system, the decisions made by individual drivers concern with when to accelerate or brake, to overtake or to change lane.[1,2] According to the road and traffic conditions, drivers always try to go as fast as possible, but safely. A number of experiential data and numerical simulations indicate that there is a strong relation between traffic accidents and driving behaviour.

One of the important factors which lead to traffic accidents is the velocity variance of vehicles. When most vehicles are travelling at about the same high or low velocity, if the velocity variance of these vehicles is small, the fatality rate will be low. Ezra[3] suggested that it is safest to drive at the median velocity, and it is increasingly dangerous to deviate from this velocity. Lave[4] proposed that since the velocity variance has more effect on fatalities than does velocity, coordinating the traffic flow is more important than limiting it. Helbing and Huberman[5] presented that coherent moving states in highway traffic is safer because it has a reduced lane-changing rate, and the traffic flow is high and stable.

In this paper, we suggest an approach in which a type of control signal is designated at a given site of the road to control the disorder states of traffic flow. With the control signal, the traffic flow states can be turned from disorder to order. In this case, we note that the velocity variance is small, and the traffic accident can be decreased. This paper is organized as follows. In Section 2, we introduce the traffic model and the control method. The numerical and analytical results are presented in Section 3. Finally, conclusions of this approach are presented.

2. Model and method

2.1. Two-lane traffic model

In the last decade, many traffic simulation models were developed to simulate the multi-lane traffic, such as the queueing model, fluid-dynamical model, traditional car-following model and cellular automation (CA) model. The simplest case is the two-lane traffic. In the two-lane traffic model, the updating is generally divided into two sub-steps: firstly, the vehicles may change lanes in parallel, and secondly, each vehicle may move forward effectively as in the single-

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†E-mail: kpli@eyou.com.

lane traffic model. In changing lane, the incentive and safety criteria must be fulfilled. So far, there have been a number of attempts in these directions. Rickert *et al*[6] proposed a lane changing rule for the CA traffic model consisting of two parallel single-lane traffic models with periodic boundaries. According to their scheme, the vehicles are allowed to change lane if the following four criteria are all satisfied: (1) $\mathrm{gap}(i) < l$; (2) $\mathrm{gap}_0(i) > l_0$; (3) $\mathrm{gap}_{0,\mathrm{back}}(i) > l_{0,\mathrm{back}}$; (4) rand() $< p_\mathrm{c}$. Here $\mathrm{gap}(i)$ and $\mathrm{gap}_0(i)$ are the numbers of empty sites in front of vehicle i in the same lane and the other lane, respectively. $\mathrm{gap}_{0,\mathrm{back}}(i)$ is the backward gap on the other lane. l, l_0 and $l_{0,\mathrm{back}}$ are the parameters which decide how far you can look ahead on your lane, ahead on the other lane, or back on the other lane, respectively. P_c is the probability the vehicles change lane. The first and the second rules represent the incentive criterion. The third rule represents the safety criterion.

For two-lane traffic, the lane changing rules can be symmetric or asymmetric with respect to lanes.[6] As the lane changing rules are symmetric, the update rules do not depend on the direction of the lane changing maneuver. Here we apply the symmetric lane changing rules to our simulations.

Using simple discrete CA models to simulate multi-lane traffic is helpful for understanding the fundamental relations between microscopic rules and macroscopic measurements. In order to compare the simulation results with field measurements, one CA iteration roughly corresponds to 1s, and the length of a cell is about 7.5m. This means, for example, that $v_{\max}$=5 cells/update corresponds to 135km/h.

2.2. Control method

One of the important CA models is the Nagel–Schreckenberg (NaSch) traffic model,[7] it has been successfully used to simulate high volume of traffic with shorter execution time.[8−10] Here we use the two-lane traffic model proposed by Rickert *et al* to simulate multi-way traffic flow, which is based on the single-lane NaSch traffic model. In our method, a type of control signal is designated on the right lane. The site where the control signal is designated is called the signal point. When the vehicle in the right lane passes the signal point at time t, under the effect of control signal, the velocity of the vehicle will be disturbed at the next time step, i.e. $v_i \to v_i - 1$ if $d_i < v_{\max}$ and $v_i \geq 1$, where d_i is the number of empty cells in front of the vehicle i. Explicitly, when the vehicle passes the signal point on the right lane, the second update rules at which the vehicle moves forward is as follows:

(1) Acceleration: increase v_i by 1 if $v_i < v_{\max}$,

(2) Slowing down: decrease v_i to $v_i = d_i$ if necessary,

(3) Perturbation: $v_i \to v_i - 1$ if $d_i < v_{\max}$ and $v_i \geq 1$, otherwise $v_i = v_i$,

(4) Movement: move vehicle v_i sites forward.

At step (3), a type of control signal is added to the traffic system. As time proceeds, under the effect of the control signal, if the number of empty cells in front of vehicle i is smaller than the parameter $v_{\max}$, the velocity of the vehicle will be disturbed. When the number of empty cells in front of the vehicle is larger than or equal to the maximum velocity $v_{\max}$, the vehicle will go over the signal point without perturbation. In our work, we take the randomization probability for the single-lane NaSch model p= 0, and the investigations are mainly focused on $v_{\max}$=5.

3. Simulations

The two-lane CA model proposed by Rickert *et al* has been used to simulate the multi-lane traffic flow. As an example, we start with $l = \min(v_i + 1, v_{\max})$, $l_0 = l$ and $l_{0,\mathrm{back}}$=5. The random parameter p_c is taken to be p_c=1. Since the system is closed, the average density per lane is ρ=$N/(2L)$, where N is the number of vehicles on the road. The control signal is designated at the middle of the right lane, and is added to the traffic system after sufficient transient time.

The numerical simulations start from random initial conditions. A system of L=400 is considered. The evolution time of T=1000 is recorded, and the first 500 are discarded to avoid transient effect. A small section of the road is designated as the observation post, which has a length of M sites and $M \ll L$. The average velocity v_t is obtained by averaging the velocities of vehicles which are on the post of the left lane or right lane at time t. The traffic series $\{x_i\}, i = 1, ..., K$, is recorded as the distance-headway at a given time t, where x_i is the distance from the ith vehicle to the $(i+1)$th vehicle.

In our work, the control signal is designated on the right lane. It not only affects the traffic flow states of the right lane, but also affects the traffic flow states of the left lane. Figure 1 presents the local space–time diagrams of traffic flow of the left and right lanes. Here we plot 400 sites in 300 consecutive time steps. From Fig.1, we can clearly observe that the diagram of the

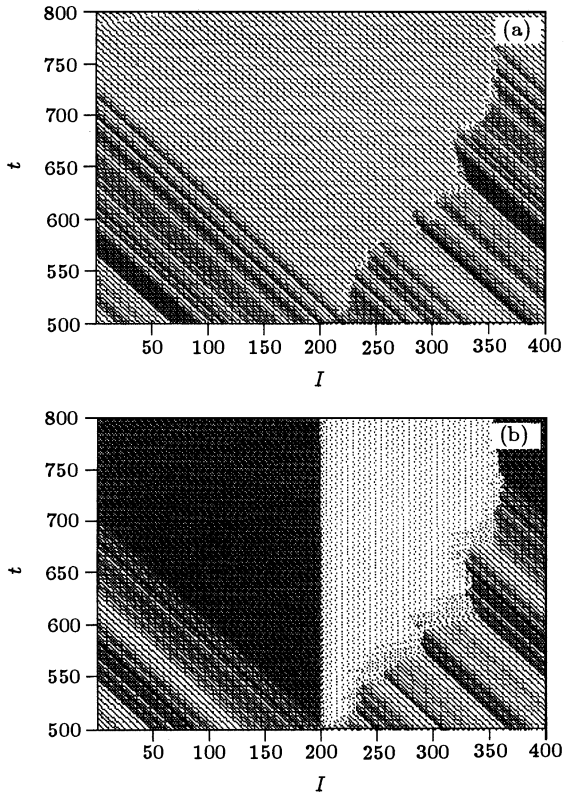


Fig.1. Local space–time diagram of two-lane traffic for ρ=0.3: (a) left lane; (b) right lane.

left lane plotted in Fig.1(a) is at homogeneous states after sufficient transient time, and the diagram of the right lane plotted in Fig.1(b) exhibits macroscopic phase segregation into high-density and low-density regions as the time proceeds. In two-lane traffic model, the single-lane dynamics on the right lane (or left lane) affects the configuration on the left lane (or right lane). On the right lane, when the speed of the vehicle that passes the signal point is decreased, the vehicles behind the signal point will be delayed. This kind of delayed-effect leads to the formation of high-density and low density regions as shown in Fig.1(b). Changing the lane of vehicles can lead to the formation of the homogeneous states plotted in Fig.1(a).

Figure 2 shows the traffic series of the distance-headway at time t=1000. Figure 2(a) shows the traffic series of the left lane. In Fig.2(a), it can be observed that the variance of the distance-headway is very small. Figure 2(b) shows the traffic series of the right lane. From Fig.2(b), we can see that the variance of the distance-headway is periodic with different amplitudes. The periodic variance of the distance-headway means that the distribution of local density is periodic, i.e. the distribution of vehicles is in order on the road. The simulation results indicate that at a given time, the distribution of vehicles on the road can be controlled from disorder to order by the control signal. In fact, when the traffic flow is in periodic states, some regular traffic patterns can be observed in the space–time diagram, and the variance of local flux varying with time is periodic. Theoretically, the effect of the control signal is related to the structure of the braking rule of the single-lane velocity.

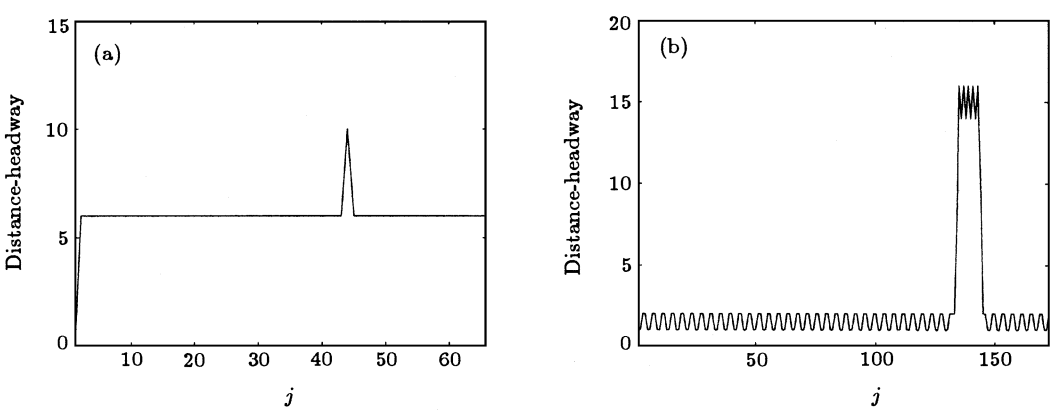


Fig.2. The traffic series of the distance-headway for ρ=0.3. (a) left lane; (b) right lane.

In real traffic, to reduce the main sources of traffic accidents, one of the major considerations is to reduce the velocity variance.[4] Figure 3(a) plots the average velocity of vehicles of the left lane. The observation site is at l=50. From Fig.3(a), it can be clearly seen that under the effect of control signal, there is a transition into a highly ordered state characterized by all vehicles having the same average velocity and a very small dispersion around this value. The reason is that the left-lane space is almost used up by the safe vehicle distance. Consequently, the vehicles on the right lane have no opportunities to change lane. This leads to the result that all vehicles on the left lane will move at a velocity which is close to the maximum velocity $v_{\max}$.

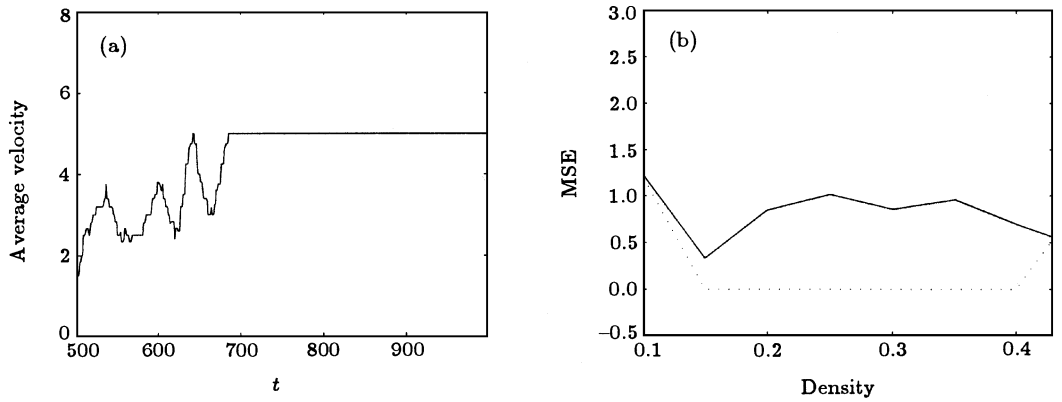


Fig.3. (a) The average velocity of the left lane for ρ=0.3, l=50 and M=20. (b) The S errors of the average velocity of the left lane are described as functions of density ρ for l=50 and M=20.

Numerical simulation results indicate that: (1) when the density of vehicles is very low or very high, the effect of control signal is not obvious; (2) for a broad range of intermediate densities, the traffic flow states can be controlled effectively. In order to investigate the velocity variance of vehicles, for different intermediate densities, we measure the standard deviation of the time series $\{v_t\}$,

$$S = \sqrt{\left(\frac{1}{n}\right)\sum_{t=1}^{n}(v_t - \bar{v})^2}, \qquad (1)$$

where $\bar{v}$ is the mean value of the time series $\{v_t\}$, and n is the length of the test set. Figure 3(b) shows how the standard deviation of the average velocity of the left lane varies with the density ρ. It is obtained by averaging 10 instances. Here the dotted line denotes the S errors of the average velocity with control signal, and the solid line denotes the S errors of the average velocities without control signal. From Fig.3(b), it is obvious that under the effect of control signal, the velocity variance with control signal is smaller than that without control signal. In this case, the traffic safety can be improved effectively.

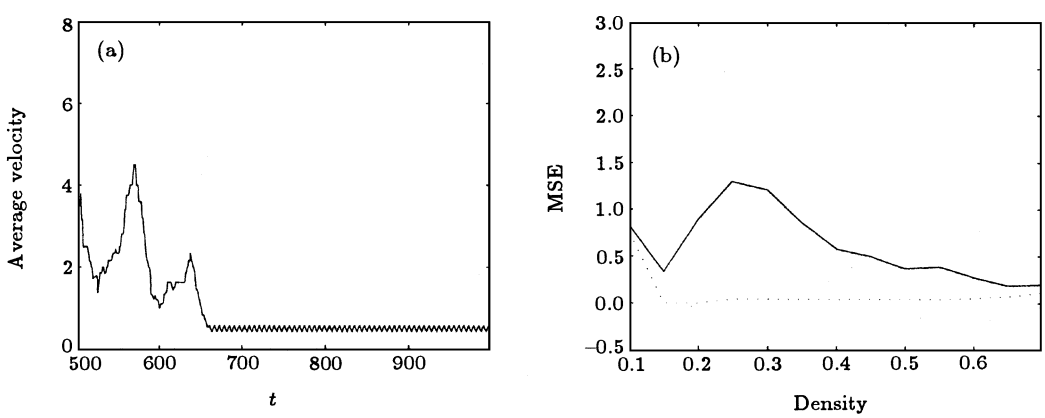


Fig.4. (a) The average velocity of the right lane for ρ=0.3, l=50 and M=20. (b) The S errors of the average velocity of the right lane are described as a function of density ρ for l=50 and M=20.

Figure 4(a) illustrates the average velocity of vehicles of the right lane. The observation site is taken to be l=50. In Fig.4(a), the variance of the average velocity is random at first, and then transits from random to periodic state. Apart from this, in Fig.4(a), we find that the variance of the average velocity obtained from periodic states is smaller than that obtained from random states. Figure 4(b) shows how the standard deviations of the average velocity of the right lane vary with density ρ. It is obtained by averaging 10 instances. Here the dotted line denotes the S errors of the average velocity with control signal, and the solid line denotes the S errors of the average velocity without control signal. In Fig.4(b), we can see clearly that the velocity variance with control signal is also smaller than that without control signal. The results mean that on the right lane, the velocity variance of vehicles can be decreased effectively with

the control signal, and the traffic safety can also be improved. In the above simulations, the observation site is within the high-density region in the space–time diagram. If it is selected within the low-density region in the space–time diagram, we can obtain similar results. Figure 5 shows the average velocity of vehicles at the observation site l=250. In this figure, we see that the variance of the average velocity is random at first, and then keep a constant value for which the velocity of vehicles is close to the maximum velocity $v_{\max}$.

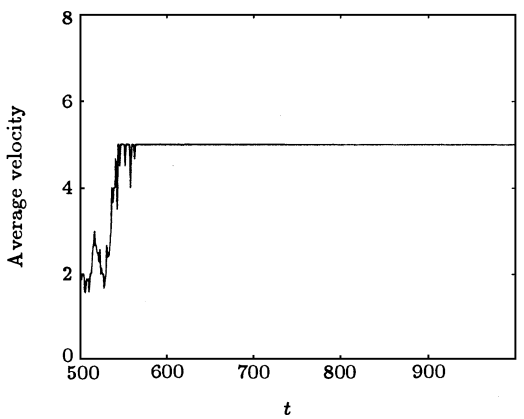


Fig.5. The average velocity of vehicles of the left lane for ρ=0.25, l=250 and M=20.

4. Conclusion

In a road traffic system, the vehicle velocity and the vehicle velocity variance are related to the consequence of collision and the probability of collision, respectively. The fatality rate can be considered as a function of crash velocity and the variance of velocities on a given road. Here, we designate a type of control signal to control the traffic flow states, and make them transit from disorder to order. In this case, we find that the velocity variance of vehicles can be decreased, and the traffic accident can also be decreased. From the view point of practical application, it is possible to implement traffic rules to design traffic control that will lead to the dynamical transition from disorder to order, and then improve the traffic safety.

In our work, one of the conditions that the velocity of vehicle will be decreased is $d_i < v_{\max}$. In fact, if this condition is cancelled, all vehicles that are on the right lane will be delayed. As a result, all vehicles on the right lane will be in a motionless state. This will lead to wide traffic jams on the right lane. However, it is insignificant for our study. On the other hand, the simulations demonstrate that if the condition $d_i < v_{\max}$ is cancelled, the traffic flow state cannot be controlled effectively.

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