The effect of moving bottlenecks on a two-lane traffic flow*

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In this paper, we study the effect of moving bottlenecks on traffic flow. The full velocity difference (FVD) model is extended to the traffic flow on a two-lane highway, and new lane changing rule is proposed to reproduce the vehicular lane changing behavior. Using this model, we derive the fundamental current–density diagrams for the traffic flow with the effect of moving bottleneck. Moreover, typical time–space diagram for a two-lane highway shows the formation and dissipation of a moving bottleneck. Results demonstrate that the effect of moving bottleneck enlarges with the increase of traffic density, but the effect can be reduced by increasing the maximum velocity of heavy truck. The effects of multiple moving bottlenecks under different conditions are investigated. The effect becomes more remarkable when the coupling effect of multiple moving bottlenecks occurs.

Keywords: traffic flow, moving bottleneck, lane changing, coupling effect

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1. Introduction

Nowadays, motor vehicles are one of the most important parts of modern transportation. With the development of economy and social demand, vehicles have already caused some serious problems, especially in big cities. When traffic networks exceed the capacity, traffic jams occur. Transportation issues have attracted widespread concerns in the fields of engineering and physics. Traffic flow has been investigated by various classical models: car-following model, macroscopic model, cellular automaton (CA) model, gas kinetic model, and hydrodynamic model.[1–23] But there are still several complex traffic phenomena which have not been well studied.

In real road traffic, fast vehicles and heavy trucks are often mixed on the highway. Particularly in China, the proportion of trucks often exceeds 30% and the overloading phenomenon of trucks is quite serious.[24,25] The above factors often cause congestion and safety problems on the highway. Several studies suggested that the heavy trucks often block the fast vehicles, and the scope and mechanism of this effect are both of dynamic process.[26] When the traffic density is low, vehicles move freely. When the density is higher than a threshold, the fast vehicles cannot pass over the heavy trucks by changing lanes, and platoon phenomena form just behind the heavy trucks.

In order to address this problem, Gazis and Herman[27] first presented the concept of moving bottleneck. Later, Newell[28] proposed a more complete theory and presented a set of assumptions based on kinematic wave model. This theory was improved by Muñoz and Daganzo,[29] because it did not completely accord with observation. Although these models could analyze the effect of moving bottlenecks, a nice method of discretizing these models has not been introduced. Recently, Juran *et al.*[30] developed a dynamic traffic assignment (DTA) model that could evaluate the effect of moving bottleneck based on a mesoscopic simulation network-loading procedure. Kerner and Klenov[31] studied the critical speed of a moving bottleneck at which traffic breakdown occurs. Masukura *et al.*[32] studied the effect of a slow vehicle on traffic flow. However, several more complex traffic phenomena induced by moving bottlenecks have not been sufficiently studied by microscopic models. Moreover, how to eliminate the influence of moving bottleneck on the highway has become an urgent need in our road transport sector.

In this paper, the full velocity difference (FVD) model is extended to the traffic flow of mixed vehicles on a two-lane highway. Based on this model, vehicular movements are clearly analyzed. We derive the current diagrams for the two-lane traffic flow to analyze the mechanism of moving bottleneck. The formation and dissipation of a moving bottleneck are also studied by the time–space diagrams. Moreover, we investigate the current and average number of lane changing against density with the coupling effect of multiple moving bottlenecks. Numerical simulations demonstrate the effect of moving bottlenecks on the two-lane traffic flow.

2. Model

In this section, we extend the FVD model[33] to analyze the effect of moving bottleneck on the traffic flow of mixed vehicles. Using this model, we can obtain each vehicular movement situation at each time step, and unrealistically high

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acceleration will not occur unlike the optimal velocity (OV) model.[34] Two kinds of vehicles are introduced: fast vehicles and heavy trucks. We assume that the maximal velocity of the heavy trucks is invariably slower than that of the fast vehicles. In order to analyze the mechanism of moving bottlenecks more clearly, we applied a simple but flexible lane changing rule to the traffic flow. Fast vehicles pass over other vehicles by changing lanes when the lane changing rule is satisfied. The vehicular motion is divided into two parts: one is the forward motion and the other is the oblique lateral motion. The forward motion is described by the FVD model, which can be written as

$$\frac{\mathrm{d}^2 x_i}{\mathrm{d}t^2} = \kappa\left\{V(\Delta x_i) - \frac{\mathrm{d}x_i}{\mathrm{d}t}\right\} + \lambda \Delta v_i, \tag{1}$$

where x_i is the position of vehicle i at time t, $\Delta x_i = x_{i+1} - x_i$ denotes the headway of vehicle i, $\Delta v_i = v_{i+1} - v_i$ is the speed difference of vehicle i, $V(\Delta x_i)$ represents the OV function, λ is the reaction coefficient of speed difference, and $\kappa = 1/\tau$ is the sensitivity, with τ representing the delay time for adjustment of the vehicle velocities to the OV.

The OV function of fast vehicles is chosen as follows:

$$V(\Delta x_i) = \frac{v_{\mathrm{f,max}}}{2}\left[\tanh(\Delta x_i - x_{\mathrm{s,c}}) + \tanh(x_{\mathrm{s,c}})\right], \tag{2}$$

where $v_{\mathrm{f,max}}$ is the maximal velocity of fast vehicles and $x_{\mathrm{s,c}}$ is the vehicular safety distance. The OV function of heavy trucks is similar to Eq. (2) but the different maximal velocity is

$$V(\Delta x_i) = \frac{v_{\mathrm{h,max}}}{2}\left[\tanh(\Delta x_i - x_{\mathrm{s,c}}) + \tanh(x_{\mathrm{s,c}})\right], \tag{3}$$

where $v_{\mathrm{h,max}}$ is the maximal velocity of heavy trucks, which is smaller than $v_{\mathrm{f,max}}$. In our simulations, we take $x_{\mathrm{s,c}} = 3$. It indicates that a vehicle can decelerate or accelerate better at this minimal distance. When the headway between two vehicles is less than the safety distance, traffic flow will be congested.

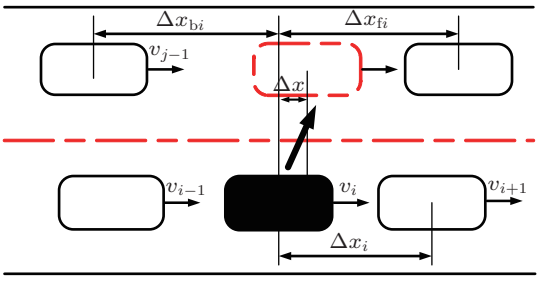


Fig. 1. (color online) Schematic illustration of lane changing for the two-lane highway.

The symmetric lane changing rule is used to achieve the oblique lateral motion of fast vehicles. A schematic illustration of lane changing for the two-lane highway is shown in Fig. 1, where Δx_i is the vehicular headway between vehicle i and the vehicle ahead on its own lane, $\Delta x_{\mathrm{f}i}$ is the headway between vehicle i and the vehicle ahead on the target lane, $\Delta x_{\mathrm{b}i}$ is the headway between vehicle i and the vehicle behind on the target lane, and Δx is the offset of the forward motion when a driver changes lane.

We adopt the following lane changing rule for the two-lane highway:

$$\Delta x_i < 2x_{\mathrm{s,c}} \quad \text{for the incentive criterion,} \tag{4}$$

$$\Delta x_{\mathrm{f}i} > \Delta x_i \ \text{ and } \ \Delta x_{\mathrm{b}i} > x_{\mathrm{s,c}}$$
$$\text{for the security criterion,}$$

$$\text{random} < p \quad \text{for the probability criterion.} \tag{5}$$

A vehicle is able to change lane if two conditions are satisfied: the lane changing criterion Eq. (4) and probability criterion Eq. (5). We propose the following lane changing probability p

$$p = \begin{cases} p_1, & \frac{v_i}{v_{\mathrm{f,max}}} \geq \frac{1}{2}, \\ p_2, & \frac{v_i}{v_{\mathrm{f,max}}} < \frac{1}{2}, \end{cases} \tag{6}$$

where p_1 and p_2 are both constant. We assume that heavy trucks always run on their own lane without lane changing. We consider $p_1 < p_2$ for the probability criterion, because a driver chooses to change lane with greater probability when the vehicular speed is smaller. We assume that $\Delta x = \alpha \Delta x_i$ is the offset of the forward motion when a driver changes lane, where α $(0 \leq \alpha < 1)$ is a constant parameter. In addition, α should not be close to 1, because vehicles must ensure safety in the process of lane changing. When the lane changing criterion is satisfied, the driver considers changing original lane to the other lane if he wishes to achieve a greater speed. Moreover, it is successful for this vehicle to change lane if the probability criterion is satisfied. In the process of lane changing, the vehicle will achieve an offset of the forward motion in order to pass over the leading vehicle quickly. The parameter α indicates the desire degree of overtaking the leading vehicle. A driver is willing to pass over the leading vehicle faster when α is large. On the contrary, the driver does not hurry to pass over the leading vehicle. This rule reproduces well the vehicular lane changing behavior.

3. Simulation and result

In this section, we perform numerical simulations under the periodic boundary condition. For comparison, we first study the effect of heavy trucks on a single-lane traffic flow. Figure 2 shows a schematic illustration of the heavy trucks on the single-lane highway. Black vehicles represent the heavy trucks which block the fast vehicles moving forward freely. Platoon phenomena form as time goes on without lane changing. Figure 3 shows the fundamental current–density diagrams in traffic flow where $v_{\mathrm{h,max}} = 1.0$, $v_{\mathrm{f,max}} = 2.0$, the sensitivity $\kappa = 3.0$, and the coefficient of speed difference $\lambda = 0.1$. The total number of vehicles is $N = 100$, and the number of heavy trucks is one or two. The heavy trucks are evenly placed along

the freeway. The simulation time is $T = 6000$. Equation (1) with the OV functions Eqs. (2) and (3) is solved using the Euler method where the time interval is $\Delta t = 1/100$. In Fig. 3, the upper and lower solid curves indicate the current in the case including only fast vehicles and in the other case including heavy trucks, respectively. The simulation result is depicted by open squares. Figure 3(a) shows the current diagram when one heavy truck moves on the lane. Figure 3(b) shows the current–density diagram when two heavy trucks move on the lane. It can be seen that the currents are approximately equal in the above two cases when the equilibrium states are reached. The simulation results indicate that fast vehicles are blocked by heavy trucks and move together with the heavy trucks. This would lead to the decrease of total current. Figure 4(a) shows the velocity of a fast vehicle against time for a single-lane highway when one heavy truck moves on the lane. Figure 4(b) shows the velocity of a fast vehicle against time when two heavy trucks move on the lane. The results show that for the more heavy trucks, the fast vehicular speed decreases faster.

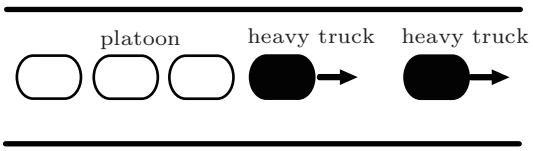


Fig. 2. Schematic illustration of the heavy trucks on a single-lane highway. Black vehicles represent the heavy trucks which block the fast vehicles moving forward freely.

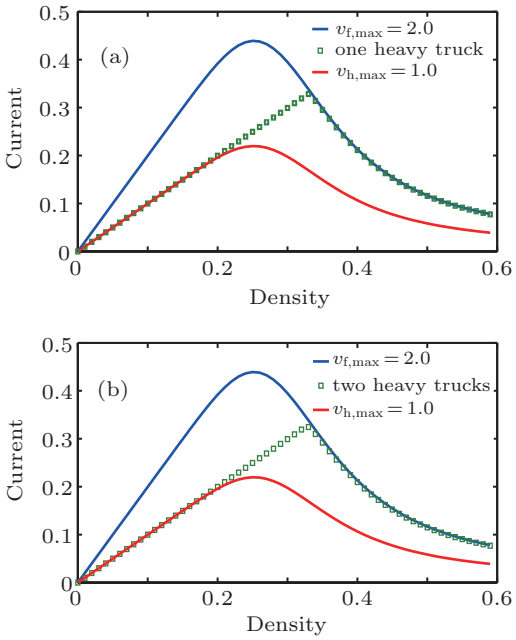


Fig. 3. (color online) Current–density diagram for a single-lane highway for $v_{h,max} = 1.0$. (a) The current–density diagram when one heavy truck moves on the lane. (b) The current–density diagram when two heavy trucks move on the lane.

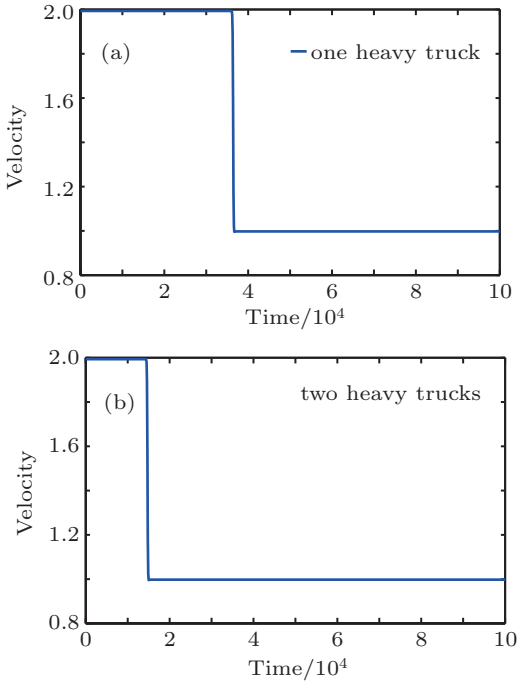


Fig. 4. (color online) Velocity diagram against time for a single-lane highway for $v_{h,max} = 1.0$. The initial density $\rho = 0.15$. (a) Velocity diagram of a fast vehicle against time for single-lane highway when one heavy truck moves on the lane. (b) Velocity diagram of a fast vehicle against time for single-lane highway when two heavy trucks move on the lane.

Next, we consider the traffic flow on a two-lane highway. We arrange 100 vehicles on each lane with the maximal velocity $v_{f,max} = 2.0$ for fast vehicles and the maximal velocity $v_{h,max} = 1.0$ for a heavy truck. We choose the lane changing probabilities p_1=0.5 and $p_2 = 0.8$. The offset coefficient is set to be $\alpha = 0.1$. The other parameter values are the same as those in the above case. Initially, vehicles are positioned with approximately the same headway but an extra random small difference on each lane, and one heavy truck is positioned on the second lane. In Fig. 5, we study typical time–space diagrams on a two-lane highway for $v_{h,max} = 1.0$. The upper and lower diagrams represent the trajectories of vehicles on the first and second lanes respectively. The light dot represents a fast vehicle, and the black dot represents a heavy truck.

Figures 5(a) and 5(d) show the time–space diagrams at low density $\rho = 0.1$. A fast vehicle is close to the heavy truck on the second lane after a period of time. In order to achieve the greater velocity, it will choose to change lane if the lane changing rule is satisfied. Slight perturbation is generated on the first lane when the fast vehicle changes to the first lane successfully. Figures 5(b) and 5(e) show the time–space diagrams at density $\rho = 0.15$. The upper and lower diagrams indicate that several fast vehicles change to the first lane when the heavy truck blocks the fast vehicles moving forward freely. A moving bottleneck forms behind the heavy truck when the first lane becomes congested. Figure 5(c) and 5(f) show the time–

space diagrams at density $\rho = 0.2$. The heavy truck blocks the fast vehicles moving forward, however fast vehicles cannot change lane because the density of the target lane is large and the lane changing rule is not satisfied. The diagrams show the queue quickly spreads to upstream and the traffic condition becomes very terrible under the effect of a moving bottleneck.

We study the typical time–space diagrams for a two-lane highway with different velocities of a heavy truck. The upper and lower diagrams represent the trajectories of vehicles on the first and second lanes respectively. The light dot represents a fast vehicle, and the black dot represents a heavy truck. Figures 6(a) and 6(d) show time–space diagrams for $v_{\mathrm{h,max}} = 1.0$. A moving bottleneck forms behind the heavy truck when fast vehicles cannot change to adjacent lane. Figure 6(b) and figure 6(e) show time–space diagrams for $v_{\mathrm{h,max}} = 1.5$. The diagrams indicate that the effect of the moving bottleneck lessens because of a larger velocity of the heavy truck. In comparison with Fig. 6(b) and Fig. 6(e), figure 6(c) and figure 6(f) show that the queuing phenomenon is not significant and the propagation speed of traffic congestion becomes slower. Simulation results indicate that the velocity of the heavy truck has a great influence on traffic flow. Therefore we should increase the maximum speed of the heavy truck to reduce the effect of moving bottleneck.

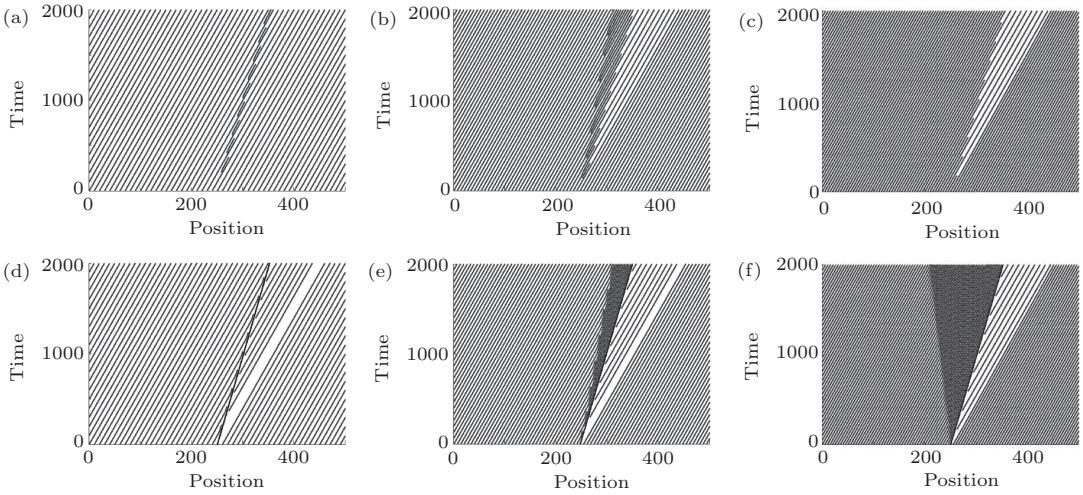


Fig. 5. Typical time–space diagrams on a two-lane highway for $v_{\mathrm{h,max}} = 1.0$. One heavy truck is positioned on the second lane. The light dot represents a fast vehicle, and the black dot represents a heavy truck. The upper and lower diagrams represent the trajectories of vehicles on the first and second lanes respectively. (a) and (d) Typical time–space diagrams at low density $\rho = 0.1$. (b) and (e) Typical time–space diagrams at density $\rho = 0.15$. (c) and (f) Typical time–space diagrams for a two-lane traffic flow at density $\rho = 0.2$.

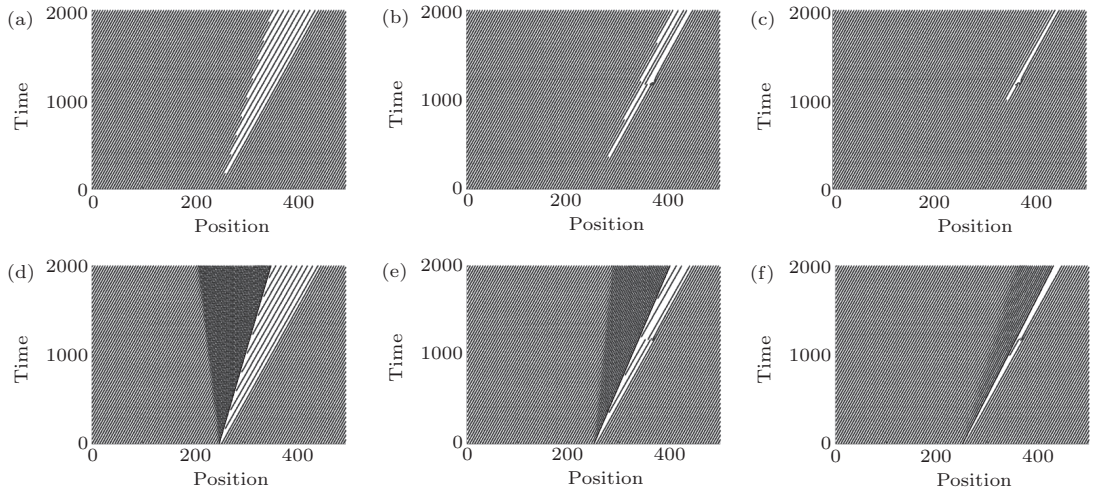


Fig. 6. Typical time–space diagrams for a two-lane highway at density $\rho = 0.2$. One heavy truck is positioned on the second lane. The light dot represents a fast vehicle, and the black dot represents a heavy truck. The upper and lower diagrams represent the trajectories of vehicles on the first and second lanes respectively. (a) and (d) Typical time–space diagrams for $v_{\mathrm{h,max}} = 1.0$. (b) and (e) Typical time–space diagrams for $v_{\mathrm{h,max}} = 1.5$. (c) and (f) Typical time–space diagrams for $v_{\mathrm{h,max}} = 1.8$.

We also study the typical time–space diagrams for the dissipation of a moving bottleneck in Fig. 7. The moving bottleneck forms quickly on the second lane with a large initial density as time goes on, and the traffic congestion begins to propagate upstream. We assume that the density of the first lane begins to decrease after a period of time. In Fig. 7(b), it can be found that the moving bottleneck dissipates because several vehicles change to the first lane successfully. Obviously, the decrease of density can lessen effectively the influence of heavy truck. Simulation results indicate that controlling the number of vehicles entering into the lanes can lessen effectively the effect of a moving bottleneck.

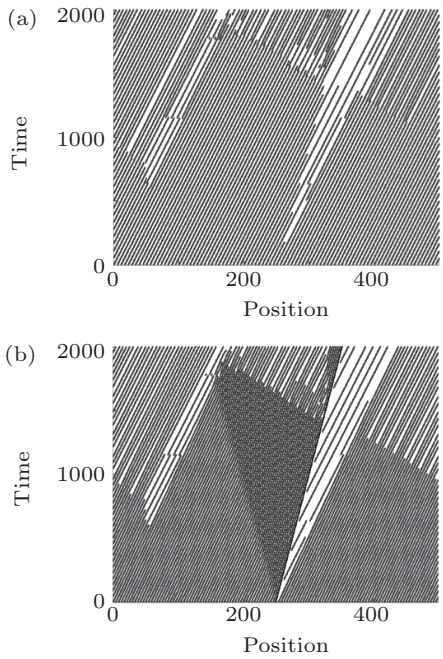


Fig. 7. Typical time–space diagrams for the dissipation of a moving bottleneck. One heavy truck is positioned on the second lane. The light dot represents a fast vehicle, and the black dot represents a heavy truck. (a) Typical time–space diagram for the first lane. (b) Typical time–space diagrams for the second lane.

To illustrate the effect of a moving bottleneck more clearly, we study the current diagram against density for $v_{\mathrm{h,max}}=1.0$ in Fig. 8(a). The upper solid curve represents the current in the case including only fast vehicles. The open squares represent the simulation result. When the density is low, the current increases with the density. The vehicles can move forward easily and fast vehicles are able to pass over the heavy truck by changing lanes if the lane changing rule is satisfied. Compared with Fig. 3(a), figure 8(a) shows that a higher current is obtained before the transition point because the moving bottleneck does not occur in two-lane traffic flow. When the density is higher than the transition point, the moving bottleneck occurs. The open squares show the current that is lower than that in the case including only fast vehicles, because the fast vehicles move behind the heavy trucks but cannot pass over the moving bottleneck. Figure 8(b) shows the plots of vehicular number on each lane against density on the two-lane highway. The asterisks and open circles indicate the number of vehicles on the first lane and the second lane respectively. The traffic is classified into four traffic states. In traffic state I, vehicles move ahead freely, and no moving bottleneck occurs. In traffic state II, traffic becomes congested. A platoon forms behind the heavy truck, therefore a moving bottleneck occurs. Moreover, more vehicles concentrate on the second lane. In traffic state III, vehicles reduce the number of changing lanes as density increases. In traffic state IV, vehicles do not change lanes and traffic is in the congested state with the vehicular number being the same on each lane. Figure 8(c) shows the velocity of a fast vehicle against time for two-lane traffic flow for $v_{\mathrm{h,max}}=1.0$, and initial density $\rho=0.05$. The result indicates that the fast vehicular speed approximately stabilizes at the maximal velocity and the effect of heavy truck is small when traffic density is low. Fast vehicles move ahead freely with lane changing, and no moving bottleneck occurs. Figure 8(d) shows the velocity of a fast vehicle against time for a two-lane highway for $v_{\mathrm{h,max}}=1.0$, and initial density $\rho=0.18$. The result indicates that the velocity of fast vehicle decreases gradually and approximately stabilizes at the maximal velocity of heavy truck when traffic density is larger than the transition point. Because the moving bottleneck occurs when density is large, fast vehicles cannot move forward freely by changing lanes and hence move together with the heavy truck. Simulation results indicate that traffic congestion will occur under the effect of a moving bottleneck when traffic density is larger than the transition point.

In order to study the effect of moving bottlenecks more sufficiently, we arrange one heavy truck on each lane, and the number of total vehicles is 100 on each lane. The other parameter values are the same as those in the above case. Figure 9 shows the schematic illustration of coupling effect of multiple moving bottlenecks on a two-lane highway. Black vehicles represent the heavy trucks which block the fast vehicles moving forward freely. Platoon phenomena form as time goes on because the headway between two moving bottlenecks is too small, and this leads to lanes changing difficultly. Figure 10 shows the current diagram against density for two-lane traffic flow for $v_{\mathrm{h,max}}=1.0$. The asterisks represent the current for the case where the initial headway of two heavy trucks is large. The open squares represent the current for the case where the initial headway of the two heavy trucks is small. For this case, the current is lower than that in another case where the density reaches the transition point, because of the coupling effect of multiple moving bottlenecks on the two-lane traffic flow. When two heavy trucks move closely, fast vehicles behind the heavy trucks are difficult to change lanes. Figure 11 shows

the average number of lane changing per 10^4 unit time against density for $v_{\mathrm{h,max}}=1.0$. Compared with Fig. 11(a), Fig. 11(b) shows that the average number of lane changing decreases observably when density exceeds the transition point. The headway of two heavy trucks is too small, thereby leading to lanes changing difficultly. These are consistent with the results from Fig. 10. Numerical results demonstrate the coupling effect of multiple moving bottlenecks clearly.

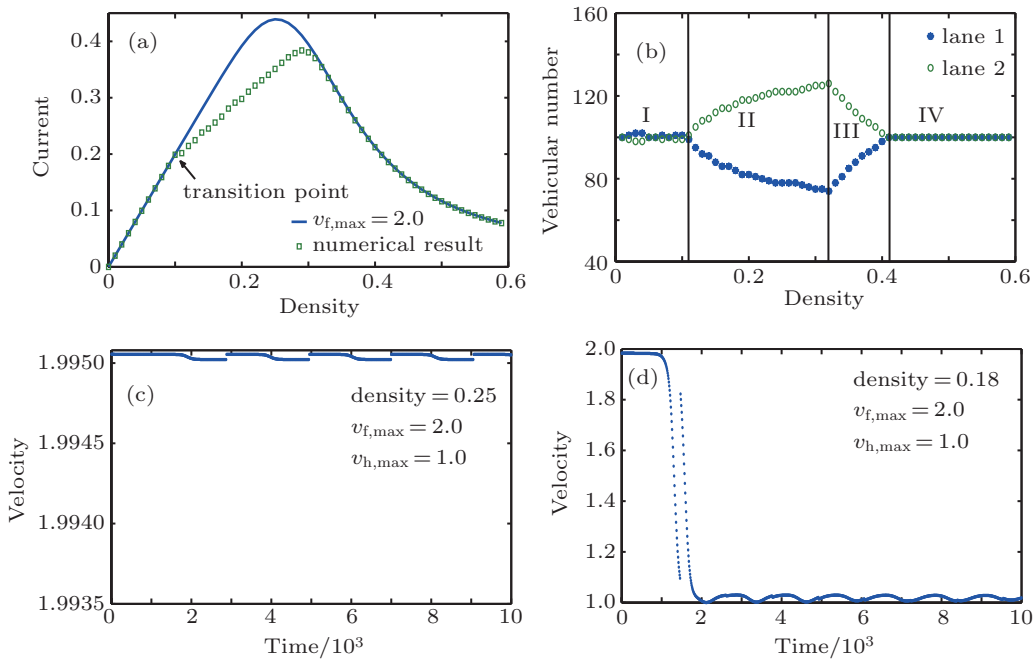


Fig. 8. (color online) (a) Plots of current against density for two-lane traffic flow for $v_{\mathrm{h,max}}=1.0$. (b) Plots of vehicular number on each lane against density in the two-lane traffic flow. (c) Velocity diagram of a fast vehicle against time for the two-lane highway for $v_{\mathrm{h,max}}=1.0$. (d) Velocity diagram of a fast vehicle against time for the two-lane highway for $v_{\mathrm{h,max}}=1.0$.

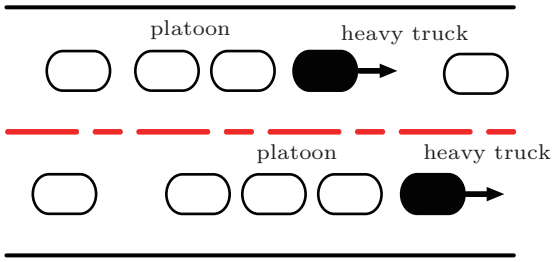


Fig. 9. (color online) Schematic illustration of coupling effect of multiple moving bottlenecks on a two-lane highway.

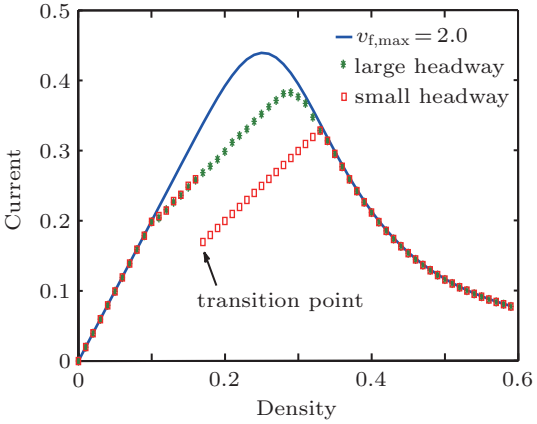


Fig. 10. (color online) Plots of current against density for two-lane traffic flow for $v_{\mathrm{h,max}}=1.0$. The asterisks and open squares indicate the currents, respectively, for large and small initial headway of the two heavy trucks for same density.

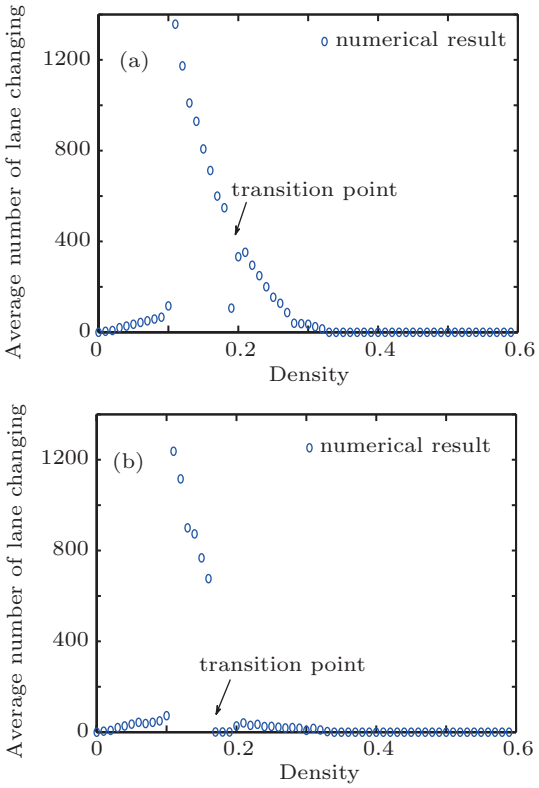


Fig. 11. (color online) Plots of average number of lane changing per 10^4 unit time against density for $v_{\mathrm{h,max}}=1.0$. (a) The initial headway of the two heavy trucks is large in two-lane traffic flow. (b) The initial headway of the two heavy trucks is small in two-lane traffic flow.

In order to illustrate concretely the coupling effect of multiple moving bottlenecks, we study the typical time–space diagrams for a two-lane highway at density $\rho = 0.2$ in Fig. 12. One heavy truck is positioned on each lane. The upper and lower diagrams represent the trajectories of vehicles on the first and second lane respectively. Figures 12(a) and 12(c) show the time–space diagrams for the case where the initial headway of the two heavy trucks is large. A moving bottleneck forms behind the heavy truck on the first lane and traffic congestion begins to propagate upstream when fast vehicles cannot change to the adjacent lane. However, it can be found that the scope of moving bottleneck does not expand on the second lane after a period of time, because several vehicles can change to the adjacent lane. Figures 12(b) and 12(d) show the time–space diagrams for the case where the initial headway of the two heavy trucks is small. Compared with Figs. 12(a) and 12(c), figures 12(b) and 12(d) show that traffic congestion begins to propagate upstream on each lane as time goes on. When two heavy trucks move closely, fast vehicles behind the heavy trucks are difficult to change lanes, and the coupling effect of multiple moving bottlenecks occurs when the traffic density exceeds the transition point. These are consistent with results from Fig. 10. Simulation results indicate that the heavy truck should avoid overtaking the other heavy trucks, because the overtaking process will induce a coupling effect of multiple moving bottlenecks.

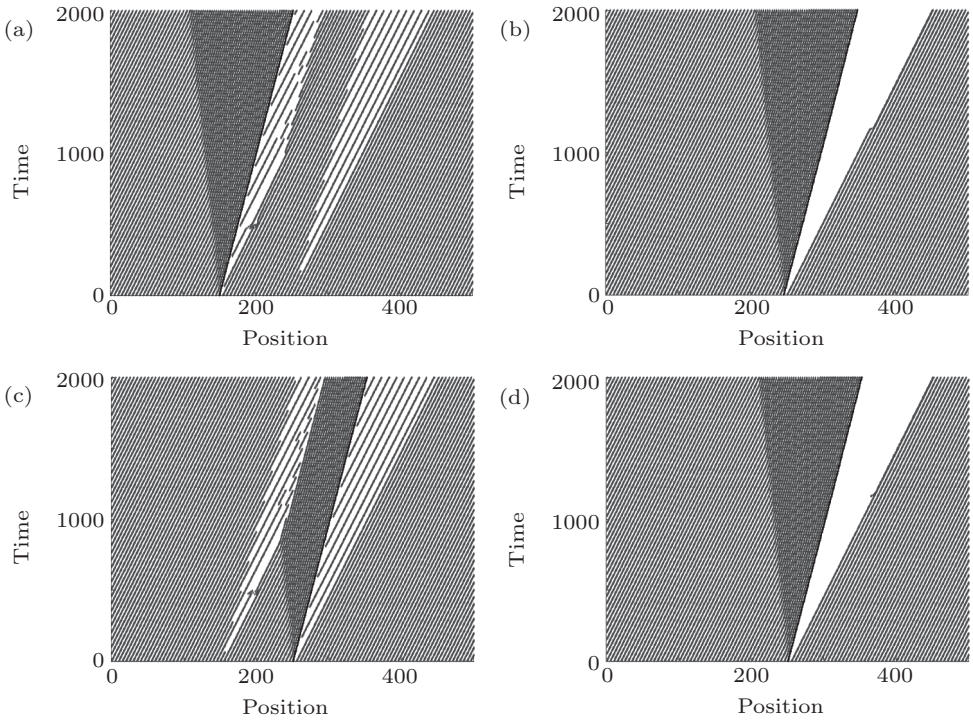


Fig. 12. Typical time–space diagrams for a two-lane highway at density $\rho = 0.2$. One heavy truck is positioned on each lane. The light dot represents a fast vehicle, and the black dot represents a heavy truck. The upper and lower diagrams represent the trajectories of vehicles on the first and second lanes respectively. (a) and (c) Typical time–space diagrams for the case where the initial headway of the two heavy trucks is large. (b) and (d) Typical time–space diagrams for the case where the initial headway of the two heavy trucks is small.

For further comparison, we consider the traffic flow when the maximal velocities of two heavy trucks are different for $v_{\mathrm{h,max}\,1} = 1.0$ and $v_{\mathrm{h,max}\,2} = 0.8$. Figure 13 shows the schematic illustration of coupling effect of multiple moving bottlenecks on a two-lane highway. The initial headway of two heavy trucks is small. Figure 14(a) shows the current against density for two cases in traffic flow. The open squares indicate that the currents with the maximal velocities of two heavy trucks are the same for $v_{\mathrm{h,max}} = 1.0$, and asterisks indicate the current in the case where the maximal velocities of two heavy trucks are different. Although one heavy truck velocity is $v_{\mathrm{h,max}\,2} = 0.8(< v_{\mathrm{h,max}})$, the higher current is obtained for this case. Because the headway of two heavy trucks becomes larger as time goes on, and fast vehicles can change lane easier than that in the other case where the density is larger than the second transition point. Numerical results verify that higher current is obtained if there is no coupling effect of multiple moving bottlenecks. Figure 14(b) shows the velocity diagram of a fast vehicle against time on the highway. The solid curve indicates the velocity of a fast vehicle which decreases to the heavy truck's velocity for the case where the maximal velocities of two heavy trucks are same for $v_{\mathrm{h,max}} = 1.0$. The dotted curve indicates the velocity of a fast vehicle which is affected is smaller for the case where the maximal velocities of two heavy trucks are different because no coupling effect of multiple moving bottlenecks occurs. These are consistent with results from Fig. 14(a). Numerical simulation results demonstrate the coupling effect of moving bottlenecks clearly.

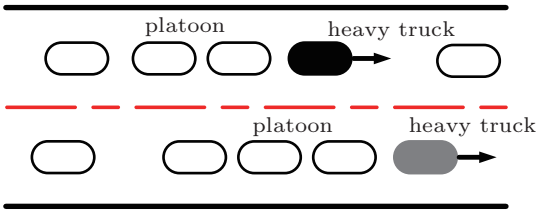


Fig. 13. (color online) Schematic illustration of coupling effect of multiple moving bottlenecks on a two-lane highway. Black vehicle represents the heavy truck of which the truck maximal velocity is $v_{\mathrm{h,max}} = 1.0$, gray vehicle represents the heavy truck of which the truck maximal velocity is $v_{\mathrm{h,max}} = 0.8$.

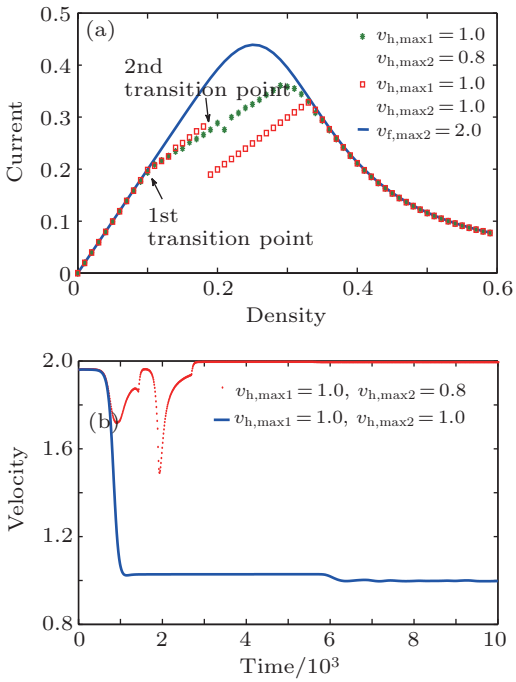


Fig. 14. (color online) (a) Plots of current against density for two-lane traffic flow. The asterisks and open squares indicate, the current, respectively, for the different and the same maximal velocities of two heavy trucks. (b) Velocity diagram of a fast vehicle against time with initial density $\rho = 0.20$. The dotted curve and solid curve denote, respectively, the velocities for the different and the same maximal velocities of two heavy trucks.

4. Conclusions

Moving bottlenecks have an important influence on the traffic flow. To address this problem, in this paper the FVD model is extended to two-lane traffic flow, and a new lane changing rule is proposed to reproduce preferably the vehicular lane changing behavior. Using this extended model, we obtain the current diagrams for the traffic flow with the effect of a moving bottleneck and multiple moving bottlenecks. Simulation results show that the moving bottlenecks can reduce the traffic capacity observably. Moreover, this effect becomes more remarkable when the coupling effect of multiple moving bottlenecks occurs. The velocity diagrams indicate that the moving bottlenecks block the fast vehicles moving forward freely, and they are consistent with the results from current diagrams. The traffic states are studied on each lane with the effect of a moving bottleneck from the plots of vehicular number.

We study the time–space diagrams for a two-lane highway, which show the formation of a moving bottleneck. Results indicate that the traffic condition becomes very terrible and the congestion propagates upstream when traffic density is larger than the transition point. We also investigate the time–space diagrams for the dissipation of a moving bottleneck. Simulation results indicate that the velocity of heavy truck has a great influence on traffic flow. Increasing the maximum speed of heavy truck can reduce the effect of moving bottleneck. The traffic state with the coupling effect of multiple moving bottlenecks is studied from the time–space diagrams. Simulation results show that the coupling effect occurs when the heavy trucks move closely. It is indicated that the heavy truck should avoid overtaking other heavy trucks, because the overtaking process can induce a coupling effect of multiple moving bottlenecks.

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