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Study on traffic states and jamming transitions for two-lane highway including a bus by using a model with calibrated optimal velocity function

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HIGHLIGHTS

- Traffic states and jamming transitions are studied for two-lane highway.
- Four distinct traffic states can be separated for two-lane traffic with a bus.
- Spatio-temporal diagrams are used to explain characteristics of each state.
- Some characteristics observed from empirical investigations can be reproduced.
- Lane-changing is important reason of forming of the synchronized flow.

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ABSTRACT

In this paper, traffic states and jamming transitions on two-lane highway including a bus are studied by using a car following model with a calibrated optimal velocity function. We derive a new flow-density diagram with four distinctly separated traffic states, which is different from that of the earlier study obtained by applying the OVM with theoretical optimal velocity function. The spatio-temporal diagrams are presented to illustrate phase characteristics of each traffic state. It is found that the phase characteristic features of two of four states are different from any state of the earlier result, and traffic flow of state 2 and state 3 can reproduce some characteristics observed from empirical investigations such as centralized lane-changing, hanging tail of cluster, and synchronized flow. In addition, we have clarified the lane-changing behaviors and their effects on two-lane traffic flow including a bus. It is shown that the velocity oscillations behind the bus can help the lane-changing in state 2 and the behaviors of lane-changing are the important reason of forming of the synchronized flow in state 3. It is also concluded that lane-changing can only improve the current in the region of middle density.

1. Introduction

Many scholars have done much research on the traffic problems in order to improve the mobility of traffic system, which has been one of the most significant factors of city traffic system. However, traffic system is a self-driven many-particle system of strongly interacting vehicles [1–5] and too many complicated ingredients should be considered in shaping the real traffic states. Traffic jams are distinctive characteristics of complex behavior of traffic flow and they cannot be ignored in

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rebranding the transportation of big cities in the world in the years to come. Apart from the traffic engineers, many scholars with extensive education in physical devoted themselves to the research of traffic problems existing in the city traffic system by proposing some kinds of traffic flow models, which can reproduce real traffic states [6–21] and have applied it into the research of traffic jams appearing in the traffic flow of high density. With the fast development of the intelligent transportation, scholars are no longer satisfied with simulating real traffic driving behavior by some traffic flow models, they want to model some common traffic behaviors such as changing lane behavior. For such reasons, some scholars devoted themselves to the lane-changing behavior modeling and have got some important academic achievements [22–25].

In real field, traffic congestion can be induced by many outside reasons, one of which is that the slow car runs on a road with fast cars. In city traffic system, the bus is chosen as the most common traffic tool by the public every day for its road priority, and it usually makes the traffic flow into congestion which often manifests as stop-and-go behaviors. In the real traffic system, a bus on high-speed road can be regarded as a traffic bottleneck and hence the fast cars following the bus want to overtake the bus ahead by changing lane. Recently, Nagai et al. have studied the traffic status and jams in two-lane highway where a bus (slow car) moves on one lane while other fast cars move on both lanes with lane changing all the time [26]. When a car moves faster than the preceding bus, it wants to get rid of the bus in front by changing to the other lane if the security criterion is satisfied. They have found three more traffic states besides the conventional three states due to the participation of the low-speed bus. However, they only explored the traffic states and jamming transitions induced by the bus by using an original car-following model. In their simulations, they applied the theoretical optimal velocity function, however, it is unknown to all that whether the traffic flow changes or not on two-lane including a bus (slow car) with vehicles changing lane in real urban traffic, which is more realistic and practical to our driving behaviors and strategies. And we also wonder how do the formation and propagation of traffic jams develop on the two-lane highway with a bus by using a practical optimal velocity function, whose parameters are calibrated by actual measurement data in traffic fields. Due to the different optimal velocity functions of application, the traffic states may be changed and it is a question to us. In addition, it is little known what the mechanism of lane-changing is, and what the distributions of the relative position of lane-changing between the bus (slow car) and the car which wants to change lane are. It is still unknown that whether frequent lane-changing will improve the current of road or not. Here we concentrate on these topics.

In this paper, we attempt to study the traffic states and jamming transition induced by a slow–speed bus using an extended microscopic model which uses a calibrated optimal velocity function and takes into account lane-changing on the two-lane highway. We try to obtain the fundamental diagram on the two-lane highway with a bus moving on it by using an improved car-following model with practical and calibrated optimal velocity function. Dynamical changes of traffic states and traffic jams among different traffic states are clarified in our new consideration. We also show the changes of traffic states under different densities of cars. What is more, we clarify the lane-changing behaviors and their effects on two-lane traffic flow including a bus. The density–current diagram after dynamical balance for the case with lane-changing and that for the case without changing lane are compared to explore the influence of frequent lane-changing on traffic current on both lanes.

In the following section, an existing microscopic car-following model with practical optimal velocity function is applied into the simulation of traffic flow on two-lane highway including a bus. In Section 3, computer simulation is performed to study the different traffic states of traffic flow and how the traffic jams form and propagate by the use of the car-following model with practical optimal velocity function. The lane-changing behaviors and their effects are studied for two-lane traffic flow with a bus in Section 4. Section 5 is assigned to the conclusions.

2. Model

In real urban traffic system, driving behaviors on the two-lane roadway consist of two parts: car-following behavior and lane-changing behavior. Car-following behavior can be simulated by the vehicular motion equation of car-following, and lane-changing behavior will happen when some criteria are met. Next, we will introduce the microscopic traffic flow model of car-following and the rules of lane-changing in turn.

The optimal velocity model (OVM, for short), which has been put forward by Bando in 1995 [24], may be one of the most representative car-following models for its simplicity and good performance. The model can be denoted as follows:

$$\frac{\mathrm{d}v_n(t)}{\mathrm{d}t} = k[V(\Delta x_n(t)) - v_n] \tag{1}$$

where $V(\Delta x_n)$ is the optimal velocity function which depends on the headway Δx_n, k is the sensitivity coefficient.

The simulation results show that the OVM has the defects of over-high acceleration and unrealistic minus velocity. To solve these problems, Jiang modified the model to take the influence of the positive velocity difference on vehicle dynamics into consideration and achieved a new model [27]:

$$\frac{\mathrm{d}v_n(t)}{\mathrm{d}t} = k[V(\Delta x_n(t)) - v_n] + \lambda\Delta v \tag{2}$$

which is called full velocity difference model (FVDM for short), Δv means the velocity difference between the current vehicle and the vehicle ahead and λ is another sensitivity coefficient. This model has overcome the problem of too-high acceleration and can predict the delay time of vehicle moving and the starting velocity well. Though it has excellent performance, this model cannot remove the unpractical minus velocity of vehicles in the regime of unstable stop-and-go waves. In 2006 Li improved the full velocity difference model to solve the problem of minus velocity and acquired a more comprehensive