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Influence of the traffic interruption probability on traffic stability in lattice model for two-lane freeway

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HIGHLIGHTS

- An extended lattice model is proposed by incorporating the traffic interruption probability for two-lane freeway.
- The interruption probability can efficiently suppress traffic jams under high response coefficient with lane changing.
- The traffic interruption probability plays an important role on the mKdV equation.
- The traffic interruption factor can improve the stability of traffic flow with lane changing under intense response to traffic interruption incident.

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ABSTRACT

In this paper, a new lattice model is proposed with the traffic interruption probability term in two-lane traffic system. The linear stability condition and the mKdV equation are derived from linear stability analysis and nonlinear analysis by introducing the traffic interruption probability of optimal current for two-lane traffic freeway, respectively. Numerical simulation shows that the traffic interruption probability corresponding to high reaction coefficient can efficiently improve the stability of two-lane traffic flow as traffic interruption occurs with lane changing.

1. Introduction

In the past several decades, many traffic models [1–13] have been proposed to study traffic problems resulted from a variety of traffic factors. Recently, traffic interruption which results in serious traffic problem has attracted considerable attention of some scholars [14–18]. Tang et al. [19,20] proposed a macroscopic continuum model and a car-following model to investigate the traffic interruption probability explicitly on the car-following behaviors. Subsequently, Tian et al. [21] derived a two-lane macroscopic continuum model from Tang's single lane macroscopic continuum model by integrating the traffic interruption probability and lane changing behaviors. Very recently, Peng et al. [22,23] also studied the effect of traffic interruption of traffic flux and optimal current on the stability of traffic flow in single lane lattice model. However, the traffic interruption probability of optimal current has not been investigated in two-lane traffic lattice models. In this paper, we proposed a new lattice model with the traffic interruption probability of optimal current term under lane changing condition for two-lane freeway. The traffic interruption probability of optimal current will be investigated by theoretic analysis and numerical simulation on the traffic stability and jamming transition.

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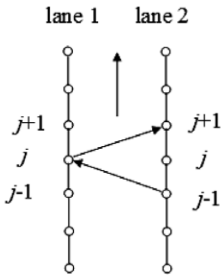

Fig. 1. The schematic model of traffic flow on a two-lane highway.

2. The new model

In recent years, based on lattice model firstly proposed by Nagatani [24,25], many extended lattice models [26–39] have been developed to explore complicated traffic phenomena resulting from different traffic factors. Furthermore, a two-lane lattice model of traffic flow [40] was proposed with lane changing behaviors term. Fig. 1 shows the schematic model of traffic flow on a two-lane highway [40]. The lane changing rate $\gamma\left|\rho_0^2V'(\rho_0)\right|(\rho_{2,j-1}-\rho_{1,j})$ happens from lane 2 to lane 1 as the density at site $j-1$ on lane 2 is higher than that at site j on lane 1, where γ means the rate constant coefficient with dimensionless. Similarly, lane changing rate $\gamma\left|\rho_0^2V'(\rho_0)\right|(\rho_{1,j}-\rho_{2,j+1})$ takes place from lane 1 to lane 2 as the density at site j on lane 1 is higher than that at site $j+1$ on lane 2. Therefore, the continuity equations on two-lane highway were shown as follows [40]:

$$\partial_t\rho_{1,j}+\rho_0(\rho_{1,j}v_{1,j}-\rho_{1,j-1}v_{1,j-1})=\gamma\left|\rho_0^2V'(\rho_0)\right|(\rho_{2,j+1}-2\rho_{1,j}+\rho_{2,j-1}) \tag{1}$$

$$\partial_t\rho_{2,j}+\rho_0(\rho_{2,j}v_{2,j}-\rho_{2,j-1}v_{2,j-1})=\gamma\left|\rho_0^2V'(\rho_0)\right|(\rho_{1,j+1}-2\rho_{2,j}+\rho_{1,j-1}). \tag{2}$$

When Eq. (1) adds (2), one can obtain the following continuity equation:

$$\partial_t\rho_j+\rho_0(\rho_jv_j-\rho_{j-1}v_{j-1})=\gamma\left|\rho_0^2V'(\rho_0)\right|(\rho_{j+1}-2\rho_j+\rho_{j-1}) \tag{3}$$

where ρ_0, ρ and v are the average density, the local density and local velocity, respectively. $\rho_j=(\rho_{1,j}+\rho_{2,j})/2$, $\rho_jv_j=(\rho_{1,j}v_{1,j}+\rho_{2,j}v_{2,j})/2$ and $V_e(\rho_j)=(V(\rho_{1,j})+V(\rho_{2,j}))/2$. In addition, the evolution equation [40] was incorporated as follows:

$$\rho_j(t+\tau)v_j(t+\tau)=\rho_0V(\rho_{j+1}). \tag{4}$$

Tang et al. [41] improved lane changing rate for two-lane lattice model. Subsequently, a lattice model of two-lane traffic flow [42] has been proposed with the consideration of optimal current difference as follows.

$$\rho_j(t+\tau)v_j(t+\tau)=\rho_0V(\rho_{j+1})+\lambda_1(\rho_0V(\rho_{j+2})-\rho_0V(\rho_{j+1})) \tag{5}$$

where $\rho_0V(\rho_{j+1})$ and $(\rho_0V(\rho_{j+2})-\rho_0V(\rho_{j+1}))$ mean the optimal current and the optimal current difference, respectively. λ_1 represents reaction coefficient to the optimal current difference on site $j+1$ at time t. But these models did not consider the traffic interruption probability of optimal current since the effect plays an important role on traffic flow for two-lane freeway. Therefore, we proposed a new evolution equation with the consideration of the traffic interruption probability of optimal current as follows:

$$\rho_j(t+\tau)v_j(t+\tau)=\rho_0V(\rho_{j+1})+\lambda_1(1-p_{j+2})(\rho_0V(\rho_{j+2})-\rho_0V(\rho_{j+1}))+\lambda_2p_{j+2}(-\rho_0V(\rho_{j+1})) \tag{6}$$

where p_{j+2} represents the traffic interruption probability of optimal current on site $j+2$; λ_2 means the reaction coefficient corresponding to the traffic interruption of optimal current on site $j+2$ as traffic interruption occurs. We suppose the optimal current of the $(j+2)$th lattice as zero when traffic interruption happens. Thus, the optimal current difference between the $(j+2)$th site and the $(j+1)$th site is $-\rho_0V(\rho_{j+1})$. For simplicity, the traffic interruption probability is set a constant, i.e., $p_{j+2}=p$. The optimal velocity function $V(\rho)$ is adopted as follows [24,25]:

$$V(\rho)=(v_{\max}/2)[\tanh(1/\rho-h_c)+\tanh(h_c)] \tag{7}$$

where h_c and $v_{\max}$ represent the safety distance and the maximal velocity, respectively. According to Eqs. (3) and (6), one eliminates the speed v to obtain the density equation:

$$\begin{aligned}&\rho_j(t+2\tau)-\rho_j(t+\tau)+\tau\rho_0^2(1-\lambda_2p)[V(\rho_{j+1})-V(\rho_j)]+\lambda_1\tau\rho_0^2(1-p)[V(\rho_{j+2})-2V(\rho_{j+1})+V(\rho_j)]\\&\quad-\tau\gamma\left|\rho_0^2V'(\rho_0)\right|(\rho_{j+1}(t+\tau)-2\rho_j(t+\tau)+\rho_{j-1}(t+\tau))=0.\end{aligned} \tag{8}$$