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Effects of the lattice point drivers' heterogeneity of the disturbance risk preference on traffic flow instability

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HIGHLIGHTS

- We define the lattice point drivers' disturbance risk preference and its heterogeneity.
- We propose a new one-dimensional traffic flow lattice model.
- We research the effects of the lattice point drivers' heterogeneity of the disturbance risk preference on traffic flow instability.
- The new model yields some insights to reduce traffic flow instability.

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ABSTRACT

This paper defines the lattice point drivers' heterogeneity of the disturbance risk preference and proposes a new one-dimensional traffic flow lattice model to research the effects of the lattice point drivers' heterogeneity of the disturbance risk preference on traffic flow instability. By the analytical analysis, we obtain the traffic flow instability condition and the modified Korteweg–de Vries (mKdV) equation and the calculation formula of the unstable area density range, and the calculation method of the probability of traffic congestion caused by a small disturbance. Both the analytical and the simulation analysis show that there are important effects of the lattice point drivers' heterogeneity of the disturbance risk preference on traffic flow instability, namely the smaller the ratio of the preceding lattice point drivers' coefficient of the disturbance risk preference to the following lattice point drivers' coefficient of the disturbance risk preference is, the smaller the traffic flow instability is and vice versa. It provides a viable idea to ease traffic congestion.

1. Introduction

In modern society, traffic congestion has become an extremely serious social problem to be urgently solved. Traffic congestion is a phenomenon of traffic flow instability and therefore easing and inhibiting traffic congestion are equivalent to reducing traffic flow instability. Traffic flow is a complex artificial system composed of many drivers and vehicles, and therefore drivers' behavior and traits have absolute effects on traffic flow instability. In real traffic, for the same disturbance, different drivers have different reactions, namely drivers' disturbance risk preference is heterogeneous, which will affect traffic flow instability obviously. To strengthen traffic flow instability research is one of the effective measures to solve traffic congestion. According to the research hierarchy, modern traffic flow models which research traffic flow instability can be divided into macroscopic, mesoscopic and microscopic traffic flow models. The advantages of the macroscopic model are that it just needs to consider several partial differential equations composed of a few variables, which describe the collective behavior of

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traffic flow and its simulation time only depends on road space, the length of the discrete time-step, regardless of the specific number of vehicles and therefore less computation; its disadvantages are that it is difficult to analyze the transitions and the separation of the traffic flow phases and cannot describe various traffic waves. For the mesoscopic model and the cellular automata model of the microscopic model, the former has too many parameters and the latter is difficult to obtain the analytical results, which make both very complex in solving and usually have to carry out the numerical simulation. The car-following model of the microscopic model solves above defects of the macroscopic model, but it only applies to analyzing the behavior of the traffic including a small number of vehicles and does not apply to the one of the traffic including a large number of vehicles. The traffic flow lattice model combines the above advantages of the macroscopic model and the car-following model, like the car-following model, it can analyze the transitions and the separation of the traffic flow phases and can describe various traffic waves; like the macroscopic models, it just needs to consider several partial differential equations composed of a few variables, which describe the collective behavior of traffic flow and its simulation time only depends on road space, the length of the discrete time-step, regardless of the specific number of vehicles and therefore has less computation.

The car-following model researches traffic flow characteristics by dealing with traffic flow composed of the dispersed particles and studying the effects of the preceding vehicles on the following vehicles. In 1950, Reuschel [1] and in 1953, Pipes [2] proposed the earliest car-following model, respectively. Chandler et al. [3] conducted a further research and called their model as California model. The optimal velocity car-following model has gained more attention due to its good traffic physical and mathematical characteristics such as it makes drivers adaptively react to the preceding vehicles state change and adjust the velocity to the optimal velocity. In 1961, Newell [4] proposed a car-following model considering drivers' reaction delay time and firstly defined the optimal velocity function. In 1995, Bando et al. [5] proposed the optimal velocity (OV) model, whose results were basically consistent with the measured results. The research of the macroscopic model began with LWR model, which was proposed by Lighthill and Whitham [6,7] in 1955 and Richards [8] in 1956, respectively. LWR model can reproduce the generation and the dissipation of traffic congestion, but it assumes the vehicle velocity is always in the equilibrium, so it cannot reproduce the non-equilibrium traffic phenomena, such as go and stop, and phantom jam. For this, some scholars put forward high-order models. The first high-order model was proposed by Payne [9,10], based on Newell's car-following model [4], it uses the dynamic equation of velocity to replace the equilibrium relationship of velocity of LWR model, which allows velocity could deviate from the equilibrium relationship. Payne's model can well describe the local cluster effect of traffic flow and other non-equilibrium traffic phenomena, but it is not easy to get the evolution equation by the analytical method, which describes traffic jam phase transitions. For this, in 1998, Nagatani [11] learning from the optimal velocity model [5] and Payne's model [9,10], thought that traffic flow could be optimized and achieved the optimal state, and proposed a one-dimensional traffic flow lattice model which made the continuity equation of traffic flow discrete, and then derived the traffic jam phase transitions evolution equation. Since Nagatani [11], many extended model were proposed [12–26]. Based on Nagatani [11], considering the relaxation time and TDGL (time-dependent Ginzburg–Landau) equation [27,28], Nagatani [12] proposed two extended forms and obtained the neutral stability conditions and mKdV equation and TDGL equation by the stability analysis and the nonlinear analysis, and proved the jamming transition could be described by both the TDGL equation with a nontravelling solution and the mKdV equation with a propagating solution. Xue et al. [13] proposed two lattice models which considered the next-nearest-neighbor flow on traffic and paid attention to the following vehicle as well as the preceding vehicle, respectively and the analysis indicated that the model considering the next-nearest-neighbor interaction could stabilize traffic flow, but the other model was just in opposition to the former model. Based on Ref. [13], Ge et al. [14] proposed an extended model considering the effects of the more preceding lattice point traffic flow and proved that traffic flow instability was reduced. Li et al. [15] proposed a lattice model with consideration of the relative current and proved it reduced traffic flow instability. Sun et al. [16] considered the effects of drivers' anticipation on traffic flow and proved it could reduce traffic flow instability. Peng et al. [17–20] proposed some extended models considering the anticipation effect of potential lane changing [17], the individual difference of anticipation driving behavior [18], the driver's forecast effects [19] and the traffic interruption probability [20] on traffic flow respectively, and proved that all these factors reduced traffic flow instability. Nagatani [21] considered the effects of lane changing and put forward a two-lane traffic flow lattice model. Research showed that the lane changing could improve the traffic system stability, and the higher the flow changing rate, the better the traffic system stability. Tang et al. [22] thought that although Nagatani's model [21] could describe traffic lane changing, the phenomenon of vehicle backward movement might appear, for this, they introduced a new flow changing function [29], and put forward an improved two-lane model. They proved that their model could reproduce the lane changing behavior induced by a small disturbance. Peng [23] proposed a two-lane traffic flow lattice model considering the effects of two-lane coupling and lane changing and proved that the model could better reproduce the lane changing of traffic flow. Peng [24] proposed a new traffic flow lattice model considering the optimal current difference for two-lane system and the analysis confirmed that traffic congestion could be suppressed more efficiently. Arvind [25,26] proposed two extended two-lane lattice models considering driver's anticipation effect in sensing relative flux [25] and the density difference effect [26], respectively and proved that all these factors reduced traffic flow instability.

In conclusion, the common factors considered by the traffic flow lattice model are the nearest preceding, the more preceding or the nearest following lattice point traffic flow and the relaxation time, drivers' anticipation, driver's forecast effects, lane changing and the flow changing rate and so on. Few consider the effects of the heterogeneity of various traffic factors on traffic flow instability. For the heterogeneity of various traffic factors, based on the car-following model, scholars have conducted some research [30–38], which also proved there were important effects of drivers' heterogeneity on traffic flow instability. Although the research of the traffic flow lattice model has achieved great progress, few investigate the lattice