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A modified two-lane traffic model considering drivers' personality

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HIGHLIGHTS

- A modified two-lane CA traffic model considering drivers' personality is proposed.
- The vehicle updating rules taking into account dynamic headway are introduced.
- The proposed new symmetric lane changing rules are proved more realistically.
- The dynamic properties of the free flow and the congested traffic are analyzed.
- The phenomenon of high speed car-following is exhibited by using the new model.

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ABSTRACT

Based on the two-lane traffic model proposed by Chowdhury et al., a modified traffic model (R-STCA model, for short) is presented, in which the new symmetric lane changing rules are introduced by considering driving behavioral difference and dynamic headway. After the numerical simulation, a broad scattering of simulated points is exhibited in the moderate density region on the flow-density plane. The synchronized flow phase accompanied with the wide moving jam phase is reproduced. The spatial–temporal profiles indicate that the vehicles move according to the R-STCA model can change lane more easily and more realistically. Then vehicles are convenient to get rid of the slow vehicles that turn into plugs ahead, and hence the capacity increases. Furthermore the phenomenon of the high speed car-following is discovered by using the R-STCA model, which has been already observed in the traffic measured data. All these results indicate that the presented model is reasonable and more realistic.

1. Introduction

With the development of modern society, traffic congestion problems have attracted considerable attention by many fields of scholars. Some traffic researches believe that there is a unique relationship between the flow rate and the traffic density (or equivalently between traffic speed and vehicle spacing) under steady state conditions [1–10]. This kind of traffic theory is known as the traditional traffic flow theory. The corresponding traffic models, including cellular automaton (CA) models, car-following models, gas kinetic models, and hydrodynamic models, have been proposed. Through theoretical analysis and computer simulation with these models, people have gained some understanding of the dynamical characteristics of traffic systems and the complex phenomena observed in real traffic.

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Among these models, the cellular automata (CA) model is one of the most efficient treatments. The NaSch model [3] dealing with single-lane traffic flow has become classic. Afterwards, a number of modified models based on the NaSch model have been proposed to deal with different phenomena of traffic and provide a simple physical picture of the traffic system [4–7]. Although most investigations consider homogeneous systems with one type of vehicles on one lane road, real traffic is usually inhomogeneous and has more than one lane. Then several two-lane extensions of the NaSch model were proposed [8,9], among which the STCA model (Symmetric Two-lane Cellular Automata) and the ATCA model (Asymmetric Two-lane Cellular Automata) proposed by Chowdhury [8] are applied in many simulations. These two models were symmetric and asymmetric with respect to the two lanes as well as with respect to the two types of vehicles respectively. It is shown that some empirically observed phenomena can be reproduced by application of these models to the detailed representation of infrastructure such as multi-lane traffic, on- and off-ramps and highway intersections [10–13].

As we know, the psychological actions of drivers make traffic complex and different from any other flow [14]. But the lane changing rules included in the STCA or ATCA model are not so meticulous and take little account of the driving behavioral difference between various drivers. This makes the simulation result cannot reflect some actual traffic situation, such as the high speed car-following phenomenon that has been detected in the measurement research of traffic [15].

Besides, in contrast to the traditional traffic flow theory, there is another traffic theory. It is called the three-phase traffic theory proposed by Kerner [16,17]. He pointed out that traffic flow consists of free flow and congested traffic. Congested traffic consists of the synchronized flow phase and the wide moving jam phase. Thus, there are three traffic phases: (1) free flow, (2) synchronized flow, (3) wide moving jam [17]. It is supposed that the steady state of congested traffic occupied a two-dimensional region in the flow-density plane. It is far more agreement with the traffic measured data [18–20]. However, the dynamical properties of traffic have not been indicated thoroughly in the theoretical point of view.

For all the above motivations, we propose a modified two-lane traffic model that can reflect drivers speed adaptation, by taking into account driving behavioral difference and dynamic headway. We aim to simulate the actual traffic more realistically, and exhibit the traffic property to the greatest extent.

The paper is organized as follows. The descriptions of a modified two-lane traffic model are given in Section 2, in which the new symmetric lane changing rules and vehicle updating rules are introduced by considering driving behavioral difference and dynamic headway. In Section 3, simulation results in the forms of fundamental diagrams, evolution diagrams of velocities, the spatial–temporal profiles and the diagrams of the high speed car-following rate are presented, and the underlying dynamic mechanism of traffic flow are analyzed. Finally, concluding remarks and a summary of findings are contained in Section 4.

2. Outline of the model

2.1. Updating rules of vehicles

The updating rules of vehicles are revised based on the NaSch model [3] and the modified NaSch model proposed by Li et al. [6]. In fact, drivers contain radical drivers and cautious drivers. The NaSch model reflects the moving pattern of cautious drivers, and the modified model proposed by Li et al. reflects the moving pattern of radical drivers. They both do not reflect the different behavior between various drivers.

We can find that the radical drivers will usually control the velocity according to the velocity of the preceding vehicle and the headway. When the velocity of the preceding vehicle is large and the driving circumstance is perfect, these drivers will decrease the safety distance and drive in a pattern of high speed car-following that has been observed in the traffic measured data [15]. Actually, the drivers believe that they can obtain the required safety distance when the preceding velocity is large and stable. However the drivers will estimate the motion state of the preceding vehicle in the next step in order to avoid collision. The state of the preceding vehicle at the next time step $t + 1$ could be obtained from the current state by applying the following set of rules which is similar to that proposed by Li et al.:

$$v^e_{n+1} = \min(v^e_{n+1} + 1, v_{\max(n+1)}) \tag{1}$$

$$v^e_{n+1} = \min(v^e_{n+1}, d_{n+1}) \tag{2}$$

$$v^e_{n+1} = \max(v^e_{n+1} - 1, 0) \tag{3}$$

where, v^e_{n+1} denotes the expected velocity of the preceding vehicle, i.e., the $(n + 1)$th vehicle, at the time $t + 1$; d_{n+1} is the empty sites in front of the $(n+1)$th vehicle, $d_{n+1}(t+1) = x_{n+2} - x_{n+1} - 1$; x_{n+1} and x_{n+2} denote the positions of the $(n+1)$th and $(n + 2)$th vehicles at the time $t + 1$ respectively; $v_{\max(n+1)}$ denotes the maximum velocity of the preceding vehicle.

Eq. (1) implies that the preceding vehicle will accelerate at the next time step at first, but its velocity will not exceed the maximum velocity. Eq. (2) implies that the preceding vehicle will decelerate in order to avoid collision. Eq. (3) means that the randomization behavior of the preceding vehicle's deceleration is regarded as the certainty event for the security reason.

Then the deceleration step in the NaSch model is changed into the following type:

$$v_n = \min(v_n, d_n + v^e_{n+1}). \tag{4}$$

The state of the system at the time $t + 1$ could be obtained from the state at the time t by applying the following set of updating rules: