Physica A 468 (2017) 315–321

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

A new lattice model of traffic flow with the consideration of the drivers' aggressive characteristics

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HIGHLIGHTS

- A new lattice model is proposed by incorporating the driver's aggressive effect.
- The driver's aggressive effect on the stability of traffic flow have been explored.
- The modified KdV equation about the driver's aggressive effect is derived to describe the traffic jam.
- The analytical and numerical results show that the driver's aggressive effect can improve the stability of traffic flow in lattice model.

ARTICLE INFO

Article history:
Received 26 August 2016
Received in revised form 4 October 2016
Available online 2 November 2016

Keywords:
Driver's aggressive effect
Traffic flow
Lattice model

ABSTRACT

In real traffic, aggressive driving behaviors often occurs by anticipating the front density of the next-nearest lattice site at next time step to adjust their acceleration in advance. Therefore, a new lattice model is put forward by considering the driver's aggressive effect (DAE). The linear stability condition is derived from the linear stability theory and the modified KdV equation near the critical point is obtained through nonlinear analysis with the consideration of aggressive driving behaviors, respectively. Both the analytical results and numerical simulation indicate that the driver's aggressive effect can increase the traffic stability. Thus driver's aggressive effect should be considered in traffic lattice model.

1. Introduction

With the vigorous growth of vehicles, there arise more and more deteriorative traffic jams to impact on people's daily life. To survey the causes of traffic congestion, some scholars came up with a considerable traffic models [1–10] by estimating the future traffic situation take advantage of the intelligent transportation system (ITS). Recently, Tang et al. [11] probed into the individual difference of the driver's perception ability for fundamental diagram theory. Also, Tang et al. [12] studied the driver's individual property in new stochastic LWR model. Furthermore, Tang et al. [13] proposed a new car-following model by considering the driver's attribution. Moreover, Ref. [14] investigate elementary students' individual properties in a new evacuation model. Very recently, Tang et al. [15,16] deeply discussed the influences of the driver's bounded rationality on micro driving behavior, fuel consumption and emissions under the car-following model. In addition, Zhang et al. [17,18] proposed a new car-following model and a new lattice model to investigate the drivers' characteristics by perceiving the downstream traffic situations. Above results showed that the drivers' characteristics have an important impact on traffic flow. However, above models did not manifest the driver's aggressive effect (DAE) in lattice models of traffic flow. In

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http://dx.doi.org/10.1016/j.physa.2016.10.093
0378-4371/

particular, the factor about the DAE may have important influence on traffic flow. In real traffic, these aggressive drivers always pay attention to the traffic information of the next-nearest car. Therefore, we put forward a new lattice model of traffic flow to explore the influence of the DAE on the evolution of small perturbation.

2. The development of models

In 1998, Nagatani [19,20] firstly proposed the original lattice hydrodynamic model which was based on car-following model. Subsequently, a number of developed lattice models [21–49] appeared on the basis of Nagatani's lattice model. However, the DAE has not been considered in the previous lattice models. In fact, these aggressive drivers, who frequently occur in real traffic, are always very close to the leading car since they are able to anticipate the running information of the next-nearest leading car at next time step to adjust their acceleration in advance with the confidence of their driving skill. Based on this, a new lattice model of traffic flow is proposed with the DAE term (for simplify, DAL model) as follows:

$$\partial_t \rho_j + \rho_0(\rho_j v_j - \rho_{j-1} v_{j-1}) = 0 \tag{1}$$

$$\rho_j(t+\tau)v_j(t+\tau) = \rho_0[(1-p)v_e(\rho_{j+1}(t)) + pv_e(\rho_{j+2}(t+\tau))] \tag{2}$$

where ρ_0, ρ_j and v_j are respectively called for the average density, the local density and its corresponding local velocity on site j at time t. The optimal velocity function $v_e(\rho)$ is adopted as below [19,20]:

$$v_e(\rho) = (v_{\max}/2)[\tanh(1/\rho - h_c) + \tanh(h_c)] \tag{3}$$

where $v_{\max}$ is the maximum velocity; $v_e(\rho_{j+2}(t+\tau))$ is the optimal velocity of the next-nearest site at next time step, which is described for the DAE. p is the proportion of the DAE. As $p = 0$, the DAL model returns to the Nagatani's model [19,20]. To carry out the Taylor expansion of the variables $\rho_{j+2}(t+\tau)$ and neglect the nonlinear terms, i.e.

$$\rho_{j+2}(t+\tau) = \rho_{j+2}(t) + \tau\partial_t\rho_{j+2}(t). \tag{4}$$

Therefore, $v_e(\rho_{j+2}(t+\tau))$ is described as below:

$$v_e(\rho_{j+2}(t+\tau)) = v_e(\rho_{j+2}(t)) + \tau\partial_t\rho_{j+2}(t)v_e'(\rho_{j+2}(t)) \tag{5}$$

where $v_e'(\rho_{j+2}(t)) = \mathrm{d}v_e(\rho_{j+2}(t))/\mathrm{d}\rho_{j+2}(t)$. Then, Eq. (2) can be deduced as below:

$$\rho_j(t+\tau)v_j(t+\tau) = \rho_0[(1-p)v_e(\rho_{j+1}(t)) + pv_e(\rho_{j+2}(t))] + \lambda\partial_t\rho_{j+2}(t) \tag{6}$$

where $\lambda = p\rho_0\tau v_e'(\rho_{j+2}(t))$. By eliminating the speed v both Eqs. (1) and (6), we can obtain the density equations as below:

$$\partial_t\rho_j(t+\tau) + \rho_0^2\{[(1-p)V(\rho_{j+1}) + pV(\rho_{j+2})] - [(1-p)v_e(\rho_j) + pV(\rho_{j+1})]\} - k(\partial_t\rho_{j+2} - \partial_t\rho_{j+1}) = 0 \tag{7}$$

where $k = -p\tau\rho_0^2 v_e'(\rho_{j+2}(t))$.

3. Linear stability analysis

In this section, ξ_j is supposed as a small deviation from the steady state flow: $\rho_j = \rho_0 + \xi_j$. By substituting it into Eq. (7), we get the following equation:

$$\partial_t\xi_j(t+\tau) + \rho_0^2 v_e'(\rho_0)[(1-p)\Delta\xi_j(t) + p\Delta\xi_{j+1}(t)] - k[\partial_t\xi_{j+2}(t) - \partial_t\xi_{j+1}(t)] = 0 \tag{8}$$

where $v_e' = (\mathrm{d}v_e/\mathrm{d}\rho)|_{\rho=\rho_0}$. Set $\xi_j = A\exp(\mathrm{i}kj + zt)$. By substituting it into Eq. (8) and expanding ξ_j, we derived the equation of z as below:

$$ze^{z\tau} + \rho_0^2 v_e'(\rho_0)[(1-p)(\mathrm{e}^{\mathrm{i}k} - 1) + p(\mathrm{e}^{2\mathrm{i}k} - \mathrm{e}^{\mathrm{i}k})] - kz(\mathrm{e}^{2\mathrm{i}k} - \mathrm{e}^{\mathrm{i}k}) = 0. \tag{9}$$

Assume $z = z_1(\mathrm{i}k) + z_2(\mathrm{i}k)^2 + \cdots$. and neglect the terms with order greater than 2 to obtain the two roots of z as follows:

$$z_1 = -\rho_0^2 v_e'(\rho_0) \tag{10a}$$

$$z_2 = -\left[\frac{1+2p}{2} + \rho_0^2 v_e'(\rho_0)\tau + k\right]\rho_0^2 v_e'(\rho_0). \tag{10b}$$

Therefore, the uniform steady-state flow will be unstable for long wavelengths as $z_2 < 0$. On the contrary, the uniform flow will be stable as $z_2 > 0$. Then, one acquires the neutral stability curve as below:

$$\rho_0^2 v_e'(\rho_0)\tau = -\frac{1+2p+2k}{2}. \tag{11}$$

For small perturbation, the stable condition of the uniform traffic flow is obtained as below:

$$\rho_0^2 v_e'(\rho_0)\tau > -\frac{1+2p+2k}{2}. \tag{12}$$

When $p = 0$ and $k = 0$, the result of stable condition is consistent with that of Nagatani's lattice model [19,20].

Fig. 1 reveals the neutral stability curves (solid lines) in the parameter space $(\rho; a)$. According to Fig. 1, the neutral stability lines fall down with the value of the parameter p increasing. The result is better than that of the original Nagatani's lattice model. The above results just imply that the extended model enlarges the stability area of uniform flow.