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Analysis of honk effect on the traffic flow in a cellular automaton model

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ABSTRACT

The paper mainly studies the following vehicle's honk effect on the driver of its predecessors in the single-lane cellular automaton model (CA model); besides, the determined condition of honk's state is investigated in detail, which has seldom been studied before. Then, the influence of honk sensitivity threshold and slow-to-start sensitivity threshold on the traffic flow is examined; the numerical simulations indicate that the smaller the honk sensitivity threshold or the larger the slow-to-start sensitivity threshold, a heavier synchronized flow can be maintained. Three main factors of S $\rightarrow$ J transition are then analyzed and the process of S $\rightarrow$ J transition is observed. Finally, a contrastive study is made on the performances of three different CA models from four aspects, it is evidenced that the performance of the new CA model proposed in the paper is the best and more consistent with the real traffic. Therefore, the following vehicle's honk effect should not be neglected in study of the traffic flow.

1. Introduction

Traffic flow problems have been given much attention with considerable interest for decades. Traffic flow, a kind of many-body systems of strong interacting vehicles, show various complex behaviors. Some empirical data of the highway traffic have been obtained, which indicate the existence of qualitatively distinct dynamic states [1–10]. In particular, three different dynamic phases are observed by Kerner et al. on highways: the free flow, the wide moving jam and the synchronized flow; besides, it has been found out experimentally that three different phase transitions exist in the process of traffic evolution [1–5].

Variety of traffic flow models are brought forward and investigated in order to understand the behavior of the traffic flow, including hydrodynamic models, gas-kinetic models, car-following models and CA models [11–24]. Compared with other approaches, CA models are conceptually simpler, and can be easily implemented on computers for numerical simulations. As a result, they have enjoyed a rapid development in the last decades after the first CA model was presented in 1992 by Nagel and Schreckenberg (NS model) [22]. Some major improvements related to CA models are as follows: braking behavior is studied [23], the preceding vehicle's virtual velocity is introduced [25], the preceding vehicle's brake light is considered [26], security gap between two successive vehicles is investigated [27], the preceding vehicle's predicted moving distance in next time step is introduced [28], three nearest preceding vehicles' cooperative behaviors are studied [29], the desire of the drivers for smooth and comfortable driving is considered (CD model) [30,31]. Later, the CD model is improved by Jiang for a better understanding of the synchronized flows (MCD model) [32]. Apart from this, as for car-following models, the optimal velocity model (OV model) also developed greatly and quickly in the last decades since it was proposed in 1995 by Bando et al. [18]. For example, the general model based on OV model put forth by Lenz takes into account some preceding vehicles' headway distance [33]; full velocity difference model proposed by Jiang considers the headway distance and relative speed [20]; the headway distance, relative speed and the preceding vehicle's acceleration are investigated [34]; the headway distance and

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some preceding vehicles' relative speed are studied [35]. Besides, not only some preceding vehicles' headway distance but also some following vehicles' headway distance are considered in the extended OV model proposed by Hasebe et al. [36,37].

Nevertheless, all of the above CA models neglect the following vehicles' influence on the driver of its predecessors. Fortunately, the extended OV model's numerical simulations [36,37] show that it has the best comprehensive performance if considering its interaction with both the following vehicles and preceding vehicles. Consequently, it is suggested here that the following vehicles' influence should not be neglected when studying the traffic flow problems. Especially in multi-lanes road, if the driver wants to conduct overtaking or lane changing, he should consider the following vehicle's location and velocity fully in order to avoid collision.

Thus, in this paper, we try to study the vehicle's honk effect on its predecessors by presenting a new CA model that can produce both the light and heavy synchronized flow in single-lane road where overtaking and disorder effect are not considered. In Section 2, we introduce the new CA model based on MCD model. Numerical simulations are carried out and the result is analyzed in Section 3, which includes five parts. The conclusions are given in Section 4.

2. The new CA model

In this section, we propose a new CA model considering the vehicle's honk effect, which would cause the deceleration and acceleration of vehicles to be influenced by their successors. Before the presentation of the model, we first discuss the concept of honk effect rule. The rule is introduced for description of the driver's reaction to his following vehicle's honk stimulation. Generally different drivers have different behaviors to his following vehicles' honk effect: insensitive drivers have higher honk sensitivity threshold r_l; in contrast, sensitive drivers have lower r_l. However, in this paper, it is assumed that all drivers' r_l is the same. And a realistic case should be like this: the driver still remains insensitive if the continuous honked times of his following vehicle's horn is lower than his r_l; otherwise, the driver becomes sensitive and takes actions to move forward as soon as possible.

Besides, the determined condition of honk's state is also investigated: only when the gap between consecutive vehicles is not greater than security gap $\text{gap}_{\text{safety}}$ and the velocity of vehicle $n-1$ is larger than that of the vehicle n (here vehicle n precedes vehicle $n-1$), the driver of vehicle $n-1$ will honk the horn. Thus, in our new model, the honk effect rule is described as follows

if $[d_n^b(t) \leq \text{gap}_{\text{safety}}]$ and $[v_{n-1}(t) > v_n(t)]$ then: $r_n^c(t) = r_n^c(t-1) + 1$;
else: $r_n^c(t) = 0$;
if $r_n^c(t) \geq r_l$ then: $c_n(t) = 1$
else: $c_n(t) = 0$

where $r_n^c(t)$ is the continuous honked times of vehicle n's following vehicle's horn until time step t. $c_n(t) = 1$ illustrates that $r_n^c(t)$ exceeds r_l and the vehicle $n-1$'s honk stimulation has an effect on the driver of vehicle n; otherwise, it does not have. And $d_n^b(t) = x_n(t) - x_{n-1}(t) - 1$ denotes the gap between consecutive vehicles; $x_n(t)$ is the position of vehicle n at time step t; $v_n(t)$ is the velocity of vehicle n at time step t, and $v_{n-1}(t)$ is the velocity of vehicle $n-1$ at time step t.

Then, we discuss the slow-to-start rule [23,24], which is introduced for describing the drivers' insensitive action. Same as the slow-to-start analysis in Ref. [32], only when the vehicle has stopped for certain t_c (which is called the slow-to-start sensitivity threshold) does the driver become insensitive. So the randomization function in our new CA model is also formed as follows

$$p = p[v_n(t), b_{n+1}(t), t_n^h(t), t_n^s(t)] = \begin{cases} p_b: & \text{if } b_{n+1}(t) = 1 \text{ and } t_n^h(t) < t_n^s(t) \\ p_0: & \text{if } v_n(t) = 0 \text{ and } t_n^{st}(t) \geq t_c \\ p_d: & \text{in all other cases} \end{cases}$$

where $b_n(t)$ is the status of the vehicle n's brake light at time step t(on(off) $\to b_n(t) = 1(0)$), $t_n^{st}(t)$ is the stopped time of vehicle n until time step t. The two terms $t_n^h(t) = d_n(t)/v_n(t)$ and $t_n^s(t) = \min(v_n(t), h)$, where h determines the range of interaction with the brake light, are introduced to compare $t_n^h(t)$ which is the time needed to reach the position of the preceding vehicle with a velocity-dependent interaction horizon $t_n^s(t)$. $t_n^s(t)$ introduces a cutoff which prevents drivers from reacting to the brake light of a predecessor which is very far away [30].

Now we present our new CA model (abbreviated as MMCD model) as follows.

1: Determination of the continuous honked time $r_n^c(t)$

if $[d_n^b(t) \leq \text{gap}_{\text{safety}}]$ and $[v_{n-1}(t) > v_n(t)]$ then : $r_n^c(t) = r_n^c(t-1) + 1$;
else : $r_n^c(t) = 0$;
if $r_n^c(t) \geq r_l$ then : $c_n(t) = 1$
else : $c_n(t) = 0$.

2: Determination of the stopped time $t_n^{st}(t)$

if $[v_n(t) = 0]$ then: $t_n^{st}(t) = t_n^{st}(t-1) + 1$;
if $[v_n(t) > 0]$ then: $t_n^{st}(t) = 0$.