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A CELLULAR AUTOMATON MODEL FOR CAR-TRUCK MIXED TRAFFIC FLOW

Jing Ma, Haichen Wang, Huiqi Liu and Xiangmo Zhao

School of Information Engineering
Chang'an University
Middle Section of South Erhuan Road, Xi'an 710064, P. R. China
icesmile1983@163.com

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Abstract. *Based on the analysis of mixed traffic flow affected by truck, a two-lane cellular automaton model is established. The lane-change and update rules of velocity of a vehicle depend not only on its positions and its neighbor lane vehicle ahead of it, but also on their speed of the two cars, so we improved lane change and update rules. We introduced the concept of virtual speed from update rules of velocity of a vehicle in VE model, to extend two-lane change rules of STCA model. In this paper, we research and compare mixed traffic flow affected by truck based on STCA model and improved model. Through computer simulation we obtained the space-time diagram and the fundamental diagram of the proposed model. The results demonstrate that the new model increases the lane-changing probability of vehicle under different truck rates and the fundamental diagram is more consistent with the results measured in the real traffic, in comparison with symmetric two-lane cellular automaton model (STCA model).*
Keywords: Traffic flow models, Cellular automaton, Mixed traffic flow

1. **Introduction.** In recent years, cellular automation (CA) model is widely adopted in the field of traffic flow research, which is deemed as an effective means to simulate the non-linear complex systems [1]. In 1992, Nagel and Schreckenberg firstly proposed the famous NaSch model, which was a kind of minimal model to reproduce the basic features of the road traffic flow [2]. On this basis, if one wants to capture and further to analyze more complex traffic condition, this model allows to supplement new rules. For example, a new model that can approximately include the preceding vehicle-speed effect (VE) is discussed in 2001 [3]. Although the above models can explain homogeneous multi-lane traffic, they definitely fail when vehicles on different lanes behave differently. As we know, the biggest problem of single traffic lane is no overtaking; however, such phenomenon is common in real road traffic, especially for the case when different types of vehicles travel on the road. In 1996, Rickert et al. introduced a series of lane-change rules which extended the single lane NaSch model into the double lane system [4]. Later, the work constructed a symmetrical two lane CA model (STCA) [5], and then utilized lane-change rules to promote the CA model with mixed traffic flow [6].

CA model consists of two simple components, i.e., local rules and neighborhood. Local rules are responsible for calculating the next state of the cell according to the influence of neighborhood cell. For conventional CA, there exists a common feature: during each time step, the lane changing distance only depends on the static distance between the front vehicle and neighborhood lanes, which will result in the simulated traffic data far less than the actual data. In addition, the updating rules of both NaSch and STCA models assume different types of vehicles occupy the same cell space and neglect many conditions in the real road traffic flow. In order to simulate the actual road traffic much more accurate, researchers put forward various two-lane CA traffic flow models to study many different actual cases, for example, two-lane CA model with horns effect [7], the interference between pedestrians and vehicles [8], mixed traffic flow with erratic motorcycles' behaviors [9], the problem of traffic flow in congested cities [10], and multi-lane traffic flow with emergency vehicle [11].

The aforementioned researches provided some basic aspects of CA model in simulating traffic flow. Based on it, we try to step forward to look for systematic logical structures in the rule sets for lane changing.

Namely the time step $t \to t+1$, speed updating rules of STCA model only consider distance between two vehicles under t moment and do not consider the velocity of the front vehicle. For example, when the position of this car and the car ahead of it is zero, but the velocity of the car ahead of it is large enough, this car still moves ahead.

The above discussions lead us to present a different two-lane CA model based on the thought that the velocity updates rules depend on both the velocities as well as the gap of two cars. So we borrow virtual velocity of updating lane in VE model which is one-lane CA model, to extend rules of STCA model. In addition, we take the trucks' effects on mixed traffic flow into account, which few previous researchers studied.

In this paper, we proposed an improved STCA model, named STCA-V model, for mixed traffic flow. This model considers the effect of the front vehicle as that in VE to achieve more realistic simulation of the road condition.

In the next section, the STCA-V model lane-changing and updating rules are introduced. Their simulation comparative results are presented and discussed in latter sections.

2. **STCA Model.** STCA model introduced the two-lane changing rules, and each time step is usually divided into two phases: in the first phase, vehicles may change lane in accordance with the lane changing rules; in the second phase, vehicles are updating on two lanes in accordance with the one lane updating rules.

(1) The lane changing rules

$$d_n < \min(v_n + 1, v_{\max}) \text{ and } d_{n,other} > d_n \text{ and } d_{n,back} > d_{safe} \tag{1}$$

When Formula (1) is established, vehicles from this lane change to the neighbor lane. d_n, $d_{n,other}$, $d_{n,back}$ represent the space between the nth vehicle and the vehicle in front of it, the space between the nth vehicle and the vehicle in front of it on the neighborhood lanes, and the space between the nth vehicle and the vehicle in the rear of it on the neighborhood lanes, respectively. d_{safe} represents a limited safe changing lane distance in the model, and in STCA model $d_{safe} = v_{\max}$.

(2) Lane updating rules

Lane updating rules of STCA model are the same as NaSch model. In NaSch model, lane updating rules use acceleration, deceleration, randomization and vehicle update of the vehicle to describe the phenomenon of vehicle updating on one lane, and the updating rules are as follows.

Acceleration:

$$v_n \to \min(v_n + 1, v_{\max}) \tag{2}$$

Deceleration:

$$v_n \to \min(v_n, d_n) \tag{3}$$

Randomization, with probability p:

$$v_n \to \max(v_n - 1, 0) \tag{4}$$

Vehicle motion:

$$x_n \to x_n + v_n \tag{5}$$

where x_n, v_n represent the position and velocity of the nth vehicle respectively, $d_n = x_{n+1} - x_n - l_{veh}$ represents empty cell number between the nth vehicle and the $(n+1)$th vehicle ahead, l_{veh} represents the length of the vehicle, and the speed $v_i \in [0, v_{\max}]$, at the same time parameter p is introduced to represent the vehicle's random deceleration probability.

3. **Proposed STCA-V Model.** In the STCA-V model, we introduce concepts of virtual speed from VE model [3]. In the cases studied, vehicles may occupy different cell lengths, that is, a car occupies one cell length and a truck occupies two cell lengths.

(1) The lane changing rules

We consider the virtual speeds of front vehicles v'_{n+1} and the front vehicles in its neighborhood lanes $v'_{n+1,other}$ to improve lane changing rules in STCA model, so Formula (1) will be substituted with Formula (6):

$$d_n < \min(v_n + 1, v_{\max}) \ \text{ and } \ d_{n,other} + v'_{n+1,other} > d_n + v'_{n+1} \ \text{ and } \ d_{n,back} > d_{safe} \tag{6}$$

Vehicles from this lane change to the neighbor lane.

In Formula (6), v'_{n+1} is:

$$v'_{n+1} = \min[v_{\max} - 1, v_{n+1}, \max(0, d_{n+1} - 1)] \tag{7}$$

Formula (7) considers the velocity influence of the front vehicle and ensures that crash will not happen in the updating process of the model.

(2) The lane updating rules

In this research the vehicles are simplified into two types: trucks and cars. Typically, compared with the cars, the size of the truck is bigger, so a truck is set to take two cells space while a car holds one cell space, and it joins the possible influences of the velocity, and deceleration step (3) will be substituted with Formula (8):

$$v_n \to \begin{cases} \min(v_n - 1, d_n + v'_{n+1}), & \text{when } (n+1)\text{th vehicle is car} \\ \min(v_n - 1, d_n - 1 + v'_{n+1}), & \text{when } (n+1)\text{th vehicle is truck} \end{cases} \tag{8}$$

4. **Simulation and Analysis.** Here, the two-lane cellular automaton model is established that consists of N_A moving in one direction on a two-dimensional lattice of $L = 10^3$ cells arranged in a ring topology where the typical length of a cell is around 7.5 m and accordingly the simulated road is 7.5 km. The total number of vehicles is fixed, assuming that there are N_T trucks and N_C cars on the road, and that the position and velocity of all vehicles are in random distribution on the initial moment with the top speed of vehicle is 5 (cell/s), traffic density $\rho = (N_T + N_C)/L$, and traffic flow $Q = \rho v$. Each cell is either empty or is occupied by trucks or cars traveling with velocity v ranging from 0 to $v_{\max}$. For simplicity, the same maximum velocity will be used for trucks and cars, R is the truck rate, and $R = N_T/N_A$. Through the total number of vehicles N_A, random deceleration probability p, keep continuous running 10^5 time step. To eliminate the influence of the transient, we do not keep statistics for the first 5×10^4 time step, and then we run the simulation of the two-lane road traffic.

4.1. **Space-time figure.** Figures 1 and 2 are space-time plot figures of STCA model and STCA-V model when $\rho = 0.3$, $p = 0.3$, and $R = 0.2$.

All vehicles are free traffic flow. From Figure 1 to Figure 2, we can see that the space-time figure of STCA-V is sparser than the space-time figure of STCA model, and that STCA model congestion is more severe and STCA-V model vehicle distribution is more uniform and more orderly. From the above two figures, the two models can simulate traffic "stop-go" phenomenon, but Figure 2 shows that, when road traffic flow density is large, there does not appear obvious traffic "stop-go" phenomenon of the vehicle on the road, thereby improving the traffic congestion.

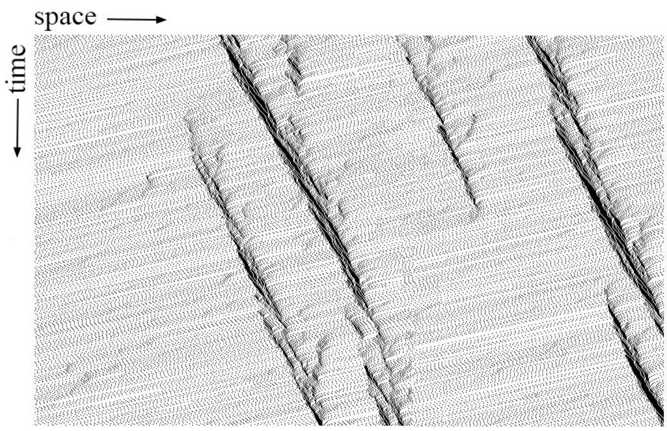

FIGURE 1. Space-time plot of STCA model

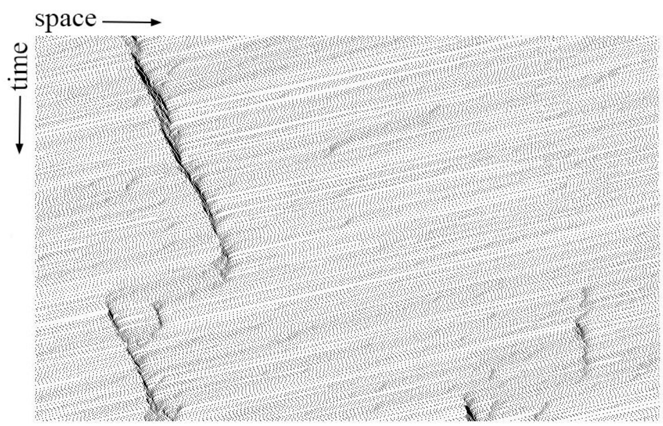

FIGURE 2. Space-time plot of STCA-V model

4.2. **Traffic fundamental figure under different rates of truck.** Figure 3 shows the average speed diagram of STCA and STCA-V models under different truck rates with random deceleration probability $p = 0.3$. From Figure 3, we can see the curve slope is smaller when the truck rate R is less than 0.05. The number of trucks had a smaller influence on the average speed of mixed traffic flow, and the curve slope is bigger when the truck rate R is greater than 0.05, and the numbers of truck had a greater influence on

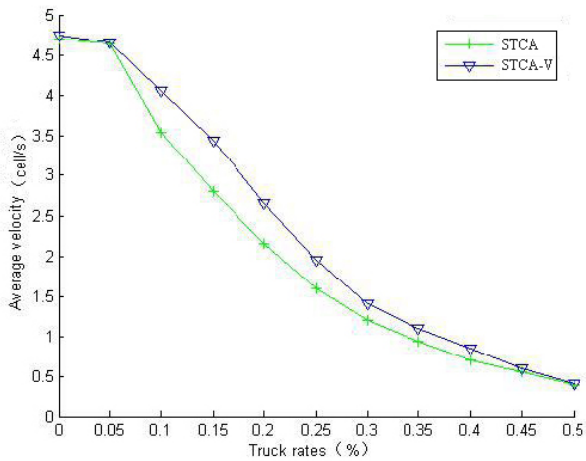

FIGURE 3. Average velocity under different truck rates

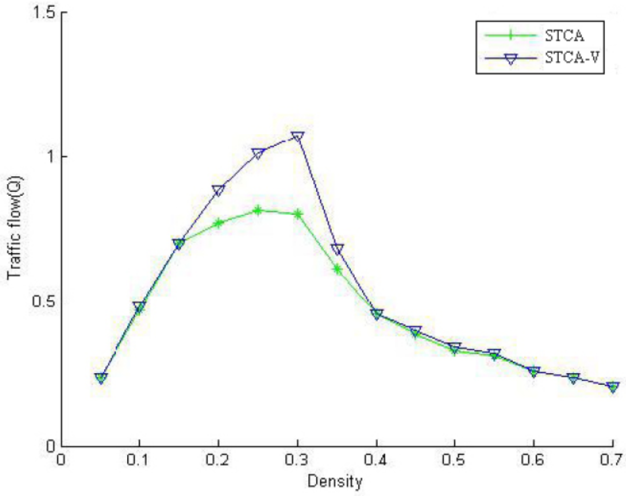

Figure 4. Traffic flow-density

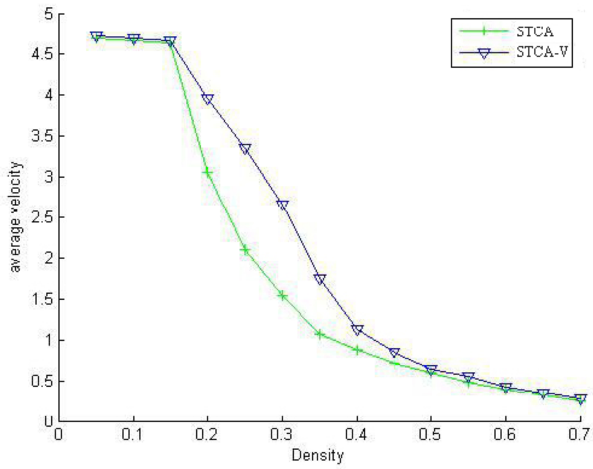

Figure 5. Average velocity-density

the average speed of mixed traffic flow. From Figure 3, STCA-V model can more truly to reflect the road lane changing situation.

Figure 4 shows the relationship between traffic flow density ρ and traffic flow Q. When traffic density is extremely small ($\rho < 0.1$), the effect of traffic flow of different models is small. From Figure 4, we can see that traffic flow as the density increases with the linear increase. In medium density areas, traffic flow of STCA-V model is larger to illustrate road traffic more smoothly. In the high-density region, the two curves substantially coincide.

Figure 5 shows the relationship between traffic flow density ρ and average speed v with the same traffic conditions. When the density $\rho < 0.1$, the traffic flow is free flow state, multiple curves are essentially coincident, and average speed v changes little. However, when the density is extremely small, the speed is not equal to the maximum speed $V_{\max}$ but is slightly less than $V_{\max}$, which is caused by random slowdown in the process of vehicle updating. With increasing traffic flow density, different models have big difference in speed, with a higher STCA-V model speed.

5. **Conclusions.** In this study, we have investigated a traffic system consisting of a mixture of cars and trucks. The vehicles may change lane when hindered by preceding vehicles, and the car and the truck occupy different space sizes. We proposed a two-lane

cellular automaton model for the car-truck mixed traffic flow. Firstly, we introduced lane-change rules in different cellular automaton models of traffic flow. Secondly, we presented lane-change rules and updating rules in basic STCA model and proposed STCA-V model. Next, we simulated space-time diagram of STCA and STCA-V model in the same traffic flow conditions. Finally, we analyzed the relationship between velocity, flow and density with the STCA-V model simulation.

Based on these experiments, it has shown that the proposed model is efficient in reducing urban traffic congestion. Furthermore, the STCA-V model can be improved by setting more detailed rules to simulate the realistic road traffic, for example, more division of vehicle type and more complex traffic conditions in the STCA-V model.

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