A Cellular Automata Traffic Flow Model Based on Safe Lane-Changing Distance Constraint Rule

Hongxue Xu
School of Information Engineering
Shenyang University
Shenyang, China
hongxuexu@163.com

Mingtong Xu
Development department
Meituan.com
Beijing, China
xuhongxue@sina.com

***Abstract*—Based on the further research of STCA and F-STCA cellular automata traffic flow model, combined with the actual situation of the symmetric same direction two-lane traffic flow, improved the risk description of vehicle lane-changing in the driving, a more perfect distance constraint rule and cellular automata traffic flow model are proposed, which are more in line with the actual situation of symmetric same direction two-lane traffic flow. The simulation experiment has been done based on the MATLAB simulation environment, the experimental results show that the distance constraint rule and traffic flow model can greatly increase the frequency of vehicle acceleration and lane-changing, which is beneficial to the improvement of traffic speed, reduce the density of traffic flow and reduce road congestion, under the premise of ensuring the safety of symmetric same direction two-lane safe lane-changing. From the point of view of traffic safety and improving traffic environment, the new rule and model are more conform to the actual situation of the symmetric same direction two-lane traffic flow.**

Keywords—cellular automata; symmetric same direction two-lane; safe lane-changing; traffic flow.

I. INTRODUCTION

Cellular automata (CA) theory can be applied to the traffic flow management system [1]. Mr. Negel and Mr. Schreckenberg proposed the NS (Nagel-Schreckenberg) cellular automata traffic flow model in 1992 [2].

NS model can clearly express the vehicle traffic flow situation in same direction one-lane, but NS model has the limitation of not overtaking, so many scholars have put forward a variety of improvement measures.

One of the most important improvement measures is the STCA (Symmetric Two-lane Cellular Automata) traffic flow model which was proposed by Chowdhury [3].

The biggest feature of STCA traffic flow model is that the lane-changing rule is introduced, and the reference of this rule is more in line with the reality of traffic flow [4].

But in STCA traffic flow model, the main basis of lane-changing rule is that the lane-changing distance must be fixed, however it is not appropriate in the actual traffic flow.

Based on the STCA model, Mr. Wang Yongming .et al proposed the concept of elastic safe lane-changing distance and the safe lane-changing distance constraint rule, and the F-STCA model was also proposed which is a cellular automata traffic flow model based on the safe lane-changing rule [5-6].

The F-STCA traffic flow model considers the influence of the rear vehicle in the adjacent lane and it can simulate the actual traffic flow situation better.

But in actual traffic flow, when the driver decided to change the lane, he should not only consider the influence from the rear vehicle in the adjacent lane, but also consider the influence from the front vehicle in the adjacent lane.

Literature [7] had concerned about this issue, and through analysis and research, a new cellular automata traffic flow model was proposed, it is based on an improved safe lane-changing distance constraint rule.

However, in this model, the risk value of lane-changing is only for the specific circumstances, it is not universal.

In this paper, we are based on the STCA and F-STCA traffic flow model, consider the possible conflict between the lane-changing vehicle and the rear vehicle or front vehicle in the adjacent lane, further research on distance constraint rule and traffic flow model of symmetric same direction two-lane.

An improved safe lane-changing distance constraint rule is proposed, and a new model of symmetric same direction two-lane cellular automaton is also proposed based on the safe lane-changing distance constraint rule.

II. STCA AND F-STCA MODEL INTRODUCTION

A. STCA model

The STCA traffic flow model proposed by Chowdhury is an extension of the NS traffic flow model.

The biggest feature of this model is the introduction of distance constraint of symmetric same direction two-lane safe lane-changing, which meets following traffic flow rule:

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

Then $C_n(t+1) = 1 - C_n(t)$

Else $C_n(t+1) = C_n(t)$ (1)

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Among this rule, the $d_n(t)$ represents the distance between the *n-th* vehicle and the front vehicle in the current lane at the moment *t*.

And the $d_{n,\ other}(t)$ represents the distance between the *n-th* vehicle and the front vehicle in the adjacent lane at the moment *t*.

And the $d_{n,\ back}(t)$ represents the distance between the *n-th* vehicle and the rear vehicle in the adjacent lane at the moment *t*.

And the v_{max} represents the maximum speed limit of vehicle.

And the d_{safe} represents the safe distance, and sets $d_{safe} = v_{max}$, v_{max} is a fixed constant value. So it is the deficiencies of STCA model.

And the $C_n(t)$ represents the lane where the *n-th* vehicle is located at the moment *t*, and $C_n(t) = 1$ or 0.

In addition, $d_n(t) < min(v_n(t+1), v_{max})$ represents that the *n-th* vehicle will be blocked when it is increasing speed in the original lane at the moment *t*.

And $d_{n,\ other}(t) > d_n(t)$ represents that the blocked vehicles are likely to reach a much faster speed in the adjacent lane (with a spatial probability) at the moment *t*.

And $d_{n,\ back}(t) > d_{safe}$ represents the necessary safe distance between lane-changing vehicle and the rear vehicle in the adjacent lane at the moment *t*.

So expression $d_{n,\ back}(t) > d_{safe}$ becomes the safe lane-changing distance constraint condition that the lane-changing vehicle must comply with.

B. F-STCA model

Based the lack of the STCA traffic flow model, a cellular automaton traffic flow model is proposed in the literature [4-6], named F-STCA traffic flow model, which is more line with the actual state of driving, and this model is based on the following safe lane-changing distance constraint rule:

If $(min(v_n(t+1), v_{max}) > d_n(t)$ and $d_{n,\ other}(t) > d_n(t)$ and $d_{n,\ back}(t) > 1 + min(v_{n,\ back}(t+1), v_{max}) - min(v_n(t+1), v_{max}))$

Then $C_n(t+1) = 1 - C_n(t)$

Else $C_n(t+1) = C_n(t)$ (2)

Usually, drivers are often difficult to accurately judge the speed of the rear vehicle in the adjacent lane, the F-STCA traffic flow model can only be used for driving experience.

In order to further improve the safety of lane-changing, literature [6] gave the following assumptions: the rear vehicle of the adjacent lane is moving in the maximum speed of v_{max}.

Based on this assumption, the safe lane-changing distance constraint rule is further improved:

If $(min(v_n(t+1), v_{max}) > d_n(t)$ and $d_{n,\ other}(t) > d_n(t)$ and $d_{n,\ back}(t) > 1 + v_{max} - min(v_n(t+1), v_{max}))$

Then $C_n(t+1) = 1 - C_n(t)$

Else $C_n(t+1) = C_n(t)$ (3)

C. Problem analysis of lane-changing rule in F-STCA model

We reference to the following traffic flow instance of symmetric same direction two-lane, and consider the imaginary lane-changing scenario as shown in Fig. 1.

In the Fig. 1, all digital cells represent that these positions are occupied by the vehicle, and the digital represents the speed of vehicle.

Assumes $v_{max} = 5$, then at the moment *t*, $d_b(t) = 0 < min(v_b(t+1), 5)$, $d_{b,\ other}(t) = 2 > d_b(t)$, and $d_{b,\ back}(t) = 6 > d_{safe} = 5$, that is, the vehicle *b* follows the STCA model rule.

And at the same moment *t*, $d_{b,\ back}(t) = 6 > 1 + 5 - min(v_b(t+1), v_{max})$, that is, the vehicle *b* follows the F-STCA model rule too, as shown in Fig.1(i).

At the moment *t*, if the vehicle *b* and the vehicle *c* are accelerating, and the vehicle *b* is changing lane, as shown in Fig. 1 (ii), then the next step will represent the state of the *t* + 1 moment, as shown in Fig. 1 (iii).

At the moment *t* + 1, vehicle *b* will face the dilemma of conflict with vehicle *c* or vehicle *d*:

If the vehicle *b* continues to speed up, then it will likely rear end the vehicle *d*, and if the vehicle *b* is changing lane, then it will have the possibility of collision with the vehicle *c*.

Unless the vehicle *b* to give up the acceleration process.

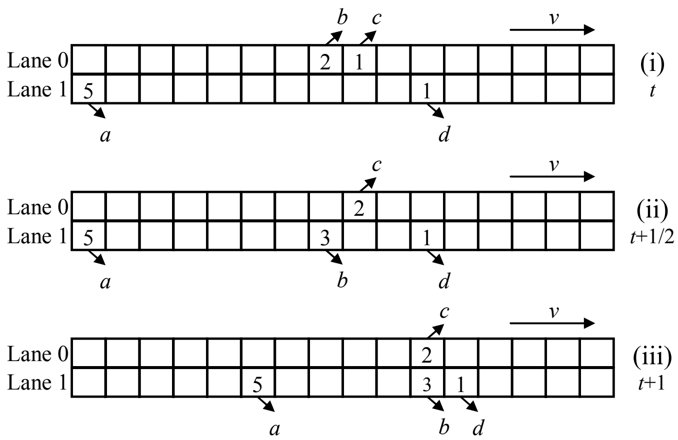


Fig. 1. The problem analysis of lane-changing rule in F-STCA model

III. X-STCA MODEL

Based on the above analysis, a new traffic flow model of symmetric same direction two-lane cellular automaton and an improved safe lane-changing distance constraint rule are proposed, which are consistent with the actual situation of traffic flow.

This safe lane-changing distance constraint rule both takes into account the possible potential conflict between the lane-changing vehicle and the rear vehicle of the adjacent lane.

And also takes into account the possible potential conflict between the lane-changing vehicle and the front vehicle of the adjacent lane.

Combining the actual situation of traffic flow, we introduce the lane minimum limit speed v_{min}, so the speed value range of vehicle satisfies: $v_n \in [v_{min}, v_{max}]$.

First, we redefine the lane-changing risk description of vehicle in the driving, which proposed in the literature [6]:

The vehicle has a certain risk when the lane is changed, and the risk comes mainly from the conflict which caused by front vehicle and rear vehicle in the adjacent lane.

When the lane of vehicle is changing and the vehicle is driving a time step, the conflict degree depends on two factors:

(1) The distance factor between the lane-changing vehicle and the rear vehicle in the adjacent lane, that is $d_{\delta,\, back}(t + 1)$;

(2) The distance factor between the lane-changing vehicle and the front vehicle in the adjacent lane, that is $d_{\delta,\, other}(t + 1)$.

To ensure traffic safety, we make the $d_{\delta,\, back}(t + 1) \geq 1$ as the buffer distance constraint between the lane-changing vehicle and the rear vehicle in the adjacent lane.

And make the $d_{\delta,\, other}(t + 1) \geq 1$ as the buffer distance constraint between the lane-changing vehicle and the front vehicle in the adjacent lane.

We use above distance constraints to deduce the safe lane-changing distance constraint rule and traffic flow model.

The safe lane-changing rule and the corresponding cellular automata model based on $d_{\delta,\, back}(t + 1) \geq 1$ distance constraint are such as rule (2) and rule (3), and the micro scene diagram of lane-changing is shown in Fig. 2.

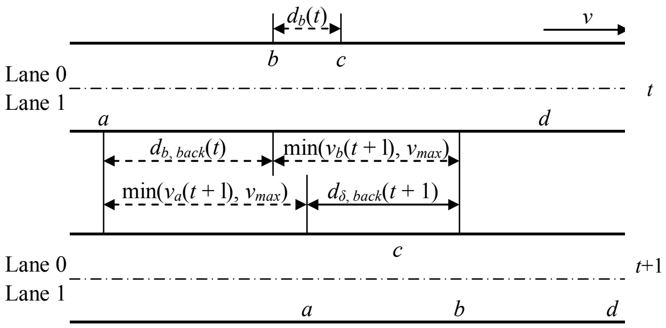


Fig. 2. Lane-changing situation ($d_{\delta,\, back}(t + 1) \geq 1$ constraint)

The derivation process is also found in literature [6].

In this paper, we based on the $d_{\delta,\, other}(t + 1) \geq 1$ distance constraint to deduce the safe lane-changing distance constraint rule that F-STCA traffic flow model is not involved.

And a cellular automata model X-STCA is proposed based on this distance constraint rule.

The micro scene diagram of lane-changing based on the $d_{\delta,other}(t + 1) \geq 1$ distance constraint as shown in Fig. 3.

As shown in Fig. 3, the vehicle b is changing lane at the moment t and driven a time unit.

Based on Fig. 3, we can build the relation formula (4):

$$d_{b,other}(t) + min(v_d(t + 1), v_{max}) = min(v_b(t + 1), v_{max}) + d_{\delta,other}(t + 1) \quad (4)$$

Set $d_{\delta,\, other}(t+1) \geq 1$, we can obtain the inequality relation formula (5) based on the formula (4):

$$d_{b,other}(t) \geq 1 + min(v_b(t + 1), v_{max}) - min(v_d(t + 1), v_{max}) \quad (5)$$

Thus, we can obtain the safe lane-changing rule based on the distance constraint $d_{\delta,other}(t + 1) \geq 1$ by (4) and (5) :

If ($min(v_n(t + 1), v_{max}) > d_n(t)$ and $d_{n,\, other}(t) > 1 + min(v_n(t + 1), v_{max}) - min(v_{n,\, other}(t + 1), v_{max})$ and $d_{n,\, back}(t) > 1 + min(v_{n,\, back}(t + 1), v_{max}) - min(v_n(t + 1), v_{max})$)

Then $C_n(t + 1) = 1 - C_n(t)$

Else $C_n(t + 1) = C_n(t)$ (6)

Usually, drivers are often difficult to accurately judge the speed of the rear vehicle and the front vehicle in the adjacent lane, the X-STCA traffic flow model can only be used for driving experience.

In order to further improve the safety of safe lane-changing, in this paper, we give the following assumptions:

The rear vehicle of the adjacent lane is moving in the maximum speed of v_{max}, and the front vehicle of the adjacent lane is moving in the minimum speed of v_{min}.

Based on this assumption, the lane-changing rule is further improved:

If ($min(v_n(t + 1), v_{max}) > d_n(t)$ and $d_{n,\, other}(t) > 1 + min(v_n(t + 1), v_{max}) - v_{min}$ and $d_{n,\, back}(t) > 1 + v_{max} - min\ (v_n(t + 1), v_{max})$)

Then $C_n(t + 1) = 1 - C_n(t)$

Else $C_n(t + 1) = C_n(t)$ (7)

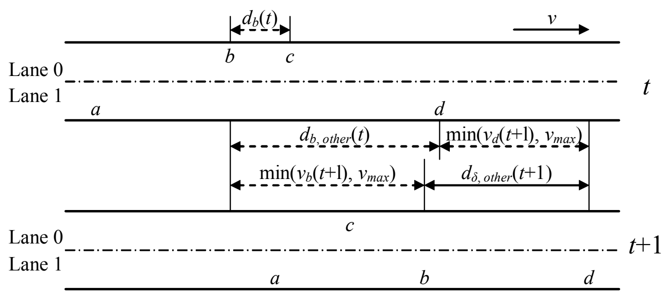


Fig. 3. Lane-changing situation ($d_{\delta,\, other}(t + 1) \geq 1$ constraint)

IV. Numerical Simulation and Analysis

The value simulation and analysis of X-STCA traffic flow model is made based on the MATLAB environment.

We focus on the relationship between the change of traffic flow density and the vehicle numbers of safe lane-changing.

And we use the relationship to describe the actual problem and compare the difference of rule (1), rule (3) and rule (7).

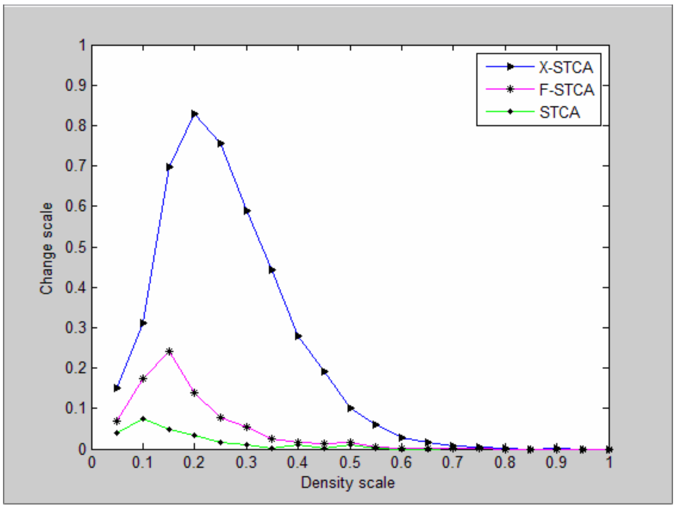
We assume all vehicles are random distribution on two lanes and are continuously running multiple time steps at the initial moment, and format a multi-speed mixed traffic flow which mixed with different speed of vehicle.

We define two one-dimensional cellular chains to represent the symmetric same direction two-lane.

The length of cellular chain is L=1000 kilometers, and the actual length of each cell is represented 7.5 kilometers.

All vehicles are distributed in the cellular chains, the speed value range of the *n-th* vehicle satisfies: $v_n \in [0, 5 \times 7.5]$, the speed unit is kilometers per hour, and the boundary condition using periodic boundary conditions.

Fig.4 shows the comparison relationship of the vehicle numbers of acceleration lane-changing and the traffic flow density between the models of X-STCA, F-STCA and STCA based on the rule (1), rule (3) and rule (7).



From Fig.4, we can obtain the following result:

In the low density region [0.05-0.75], based on the same traffic flow density, the lane-changing vehicle numbers of X-STCA traffic flow model is larger than other two models;

And in the high density region [0.75-1], the curves of the three models are basically coincident.

So when the traffic flow density is too large, the vehicles are rarely changed lane to form a blockage area.

V. CONCLUSION

In this paper, we combined with the actual situation of the symmetric same direction two-lane safe lane-changing, based on the analysis of STCA and F-STCA model, redefined the concept of lane-changing risk degree.

And further proposed a distance constraint rule of safe lane-changing, build a symmetric same direction two-lane cellular automata traffic flow model (X-STCA) based on the distance constraint rule of safe lane-changing.

The value simulation and analysis of X-STCA traffic flow model are made based on the MATLAB environment in a mixed traffic flow, and the model focuses on the relationship between the changes of traffic flow density and the vehicle numbers of acceleration lane-changing.

Simulation experiment results show that this model greatly increased the vehicle numbers of acceleration lane-changing under the premise of ensuring the safety of vehicles, so as to improve the speed of traffic, reduce the density of traffic flow and reduce lane congestion and possibility of accidents.

From the point of view of traffic safety and improving traffic environment, the new rule and model are more conform to the actual situation of the symmetric same direction two-lane traffic flow.

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