Study on the traffic capacity of Expressway Based on cellular automata model

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***Abstract*—Based on the Nagel-Schrekenbercellular automaton model of traffic flow, the article analyzed the influence that driving on the right side takes to the traffic flow (practical capacity) in the condition of light and heavy traffic. With the combination of fluid dynamics and vehicle dynamics, we established the Cellular Automata model (referred to as C) for mixed speed two-lane traffic flow on the rule driving on the right side. We also got the relationship among speed, density and traffic though the traffic simulation platform and MatLab numerical simulation. Then we used the method to find out the large bus share rate, the number of vehicles changing lanes and the influence law of safety factors on traffic flow. And we came to a conclusion that the relationship between traffic flow and load are inverted U shape changes in the low load and high load conditions,The conclusion, which provides a theoretical basis for the reasonable organization of expressway traffic management.**

Keywords-- Cellular Automata; Analytic Hierarchy Process;the Theory of Fuzzy Mathematics; Change Line Initiatively; Numerical Simulation

I. INTRODUCTION

Recently, the traffic problem has become a topic which are very concerned about ,experts in many areas have written many theses about it specially also built a lot of models to make an analysis or a prediction.

However, at present, the analysis of the traffic capacity of expressway is a more important class in the models of the traffic flow, there are many more classic models: fluid mechanics model, queuing theory, etc.. Transportation research in the main traditional method is to reproduce the observed flow--density relationship and unstable traffic flow area, but due to the different area, traffic rules will be slightly different, and the actual situation of different roads are not all the same and road conditions, weather conditions and so on. These models are not able to perfect describe and predict the change of the vehicle flow and the characteristics of freeway. Poor adaptability and transplantation.

Therefore, the most important traffic model is able to describe the nonlinear phenomenon and its characteristics. Cellular automata model is one of a class of optimization model, the theory is a powerful tool to describe the nonlinear phenomenon. In recent years, simulation model of traffic flow is more and more used in the large scale traffic flow based on cellular automata theory.CA model is the most simple description of unidirectional single lane highway traffic flow on the 184th rules of CA model named Wolfram. Model considering single lane road vehicle speed distribution and stochastic acceleration, deceleration, the simulation results show the traffic gradually by the free movement of low density to the movement process of the congested, image expressing movement like the waves in the team passed on scene .then,NagelandSchreck-enberg proposed Nasc model and then Fuku and Ishibashi proposed FI model. The cellular automata (Cellular Automata, CA) is a kind of discrete space-time local dynamics model, is a typical complex systems research methods, especially suitable for space-time dynamic simulation of complex systems research.

Its essence is the definition, which in a composition of cellular space with discrete, finite state , and in accordance with the local rules, dynamic system evolution in the dimension of time discrete. In this paper, with the largest number of two lane high way as an example, the American and Chinese currently more common on the right side of the road under the rules established a cellular automata model, through the simulation results under this rule to identify the relationship between the traffic density and traffic capacity. And the trade-off relationship between safety, vehicle speed, traffic density of the three. Through researching the literature, we established a CA model under the new rules of highway in recent years, which the vehicle change lane independently, from the theoretical evidence of the superiority of rules, proposing a new approach to solve the traffic problems. And cellular automata model has good adaptability, can according to different conditions to make appropriate corrections can be applied. Model of the mechanism is simple, easy to use, and the results of this model is established in this paper provide excellent reference solution on the traffic capacity problem.

II. THE IMPROVEMENT OF THE MODEL

In real traffic, the road generally consists of multiple lanes, travel by vehicle performance or mixed different type, and at present, many CA models, only consider one factor. Large passenger car is one of the great influence of expressway vehicle, because it has the characteristics of large, low running speed of vehicle. Its effect on the high speed stream is very obvious, the rational organization of large passenger car flow is the key to solve the problem of expressway, these existing traffic flow model gives little thought to the large passenger car. In this paper, although two lane model with the impact of freight vehicles in traffic flow are studied, but because of its setting cellular length, operating speed, lane changing rules, they don’t match the reality of highway operation rules well and can’t correctly reflect the impact of freight vehicles on freeway traffic flow. This paper fully studies on the freeway traffic flow, re calibration of the cellular length,operating speed, random slow mechanism and lane changing and overtaking rule, on the basis of the above study proposed two lane multi speed mixed vehicles traffic flow CA model under periodic boundary conditions and the impact of the large car.

III. THE ESTABLISHMENT OF OVERTAKING SYSTEM MODEL

Overtaking on the highway is in the same direction of the overtaking lane. We can don't consider the oncoming traffic. Therefore, overtaking consideration relates to the lane on the front vehicle and the vehicle overtaking lane. The driveway in front of the vehicle and the overtaking lane of the rear of the vehicle are the main factors that influence the safety of overtaking. The simplified model is shown in Figure. 1

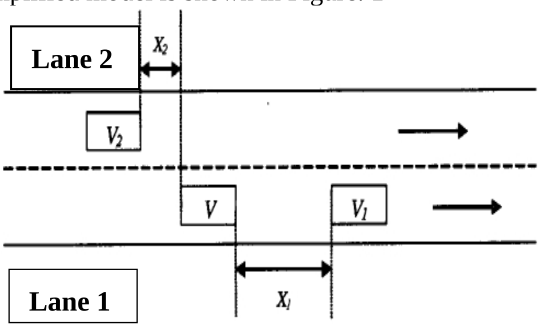

Figure.1.Vehicle location and parameter

A. The principle of the carriage way

The safety conditions of 1 Lane to 2 lane change must meet :

$$\begin{aligned}&(D_k^{1\text{-}2}(t)+V_{k+1}^2(t))\geq\\&4*V_k^1(t)\,\&\,\&(B_k^{1\text{-}2}(t)+V_k^1(t))\geq\\&4*V_{k-1}^2(t)\,\&\,\&x_k^2(t)=0\end{aligned}\tag{1}$$

The shortest travel time principle, the minimum number of deceleration of the vehicle, run the fastest, travel time shortest for the optimal target, once the vehicle meets the following conditions :

Lane 1 changing conditions:

$$\begin{aligned}&(D_k^{2\text{-}1}(t)+V_{k+1}^2(t))\geq\\&4*V_k^1(t)\,\&\,\&(B_k^{1\text{-}2}(t)+V_k^1(t))\geq 4*\\&V_{k-1}^2(t)\,\&\,\&x_k^2(t)=0\,\&\,\&(V_k^1(t)\leq\\&V_{\max}^1\,\&\,\&V_k^1(t)\geq\\&V_{k+1}^1(t))\|V_k^1(t)\leq V_{\max}\,\&\,\&V_k^1(t)\geq\\&0)\,\&\,\&D_k^{1\text{-}1}(t)\leq V_k^1(t)(2)\end{aligned}$$

B. The principle of the overtaking road

The safety conditions of 2 Lane large passenger cars to 1 Lane overtaking and lane changing conditions must be satisfied for:

$$\begin{aligned}&(D_k^{2\text{-}1}(t)+V_{k+1}^1(t))\geq\\&3.6*V_k^2(t)\,\&\,\&(B_k^{2\text{-}1}(t)+V_k^2(t))\geq\\&3.6*V_{k-1}^1(t)\,\&\,\&x_k^2(t)=0\end{aligned}\tag{3}$$

Lane changing conditions that the car of lane 2 moving to lane 1:

$$\begin{aligned}&(D_k^{2\text{-}1}(t)+V_{k+1}^1(t))\geq\\&3.6*V_k^2(t)\,\&\,\&(V_k^2(t)\geq\\&V_{k+1}^2(t)\,\&\,\&(B_k^{2-1}(t)+V_k^2(t)\geq\\&3.6*V_{k-1}^1(t)\,\&\,\&x_k^2(t)=0\end{aligned}\tag{4}$$

If it meet the lane changing conditions, then start changing lane

changing rules of lane 1:

$$\begin{aligned}&V_{change}^2(t+1)=V_k^1(t),\\&V_{change}^2(t+1)=V_k^1(t)+V_k^1(t)\end{aligned}\tag{5}$$

changing rules of lane 2:

$$\begin{aligned}&V_{change}^1(t+1)=V_k^2(t),\\&V_{change}^1(t+1)=V_k^2(t)+V_k^2(t)\end{aligned}\tag{6}$$

IV. VEHICLEEVOLUTION RULES

Here changing lane mechanism and operating mechanism are integrated. First determine whether the car to meet changing conditions, if meet the changing lanes, if not,then according to the evolution rules of velocity and position update transformation.

Update rules for vehicle state evolution is :

(1) Deterministic acceleration process

If

$$\begin{aligned}&(D_k^{1\text{-}1}(t)\geq 3.6*V_{k-1}^1(t)\|(D_k^{2\text{-}2}(t)\geq 4*\\&V_k^2(t)\|(D_k^{1\text{-}1}(t)<3.6*V_k^1(t)\,\&\,\&V_k^1(t)\leq\\&V_{\min})\|(D_k^{2\text{-}2}(t)<4*V_k^2(t)\,\&\,\&V_k^2(t)\leq V_{\min}\end{aligned}$$

then:

$$V_k^j(t+1)=\min(V_k^j(t)+2,V_{\max}^1)\tag{7}$$

(2) General acceleration process

If

$$
\begin{aligned}
&(D_k^{1\text{-}1}(t) < 3.6 * V_k^1(t) \,\&\&\, D_k^{1\text{-}1}(t) \geq \\
&V_k^1(t) \,\&\&\, V_k^1(t) \leq V_{\max}^1 \,\&\&\, V_k^1(t) > \\
&V_{\min} \| (D_k^{2\text{-}2}(t) < 4 * V_k^2(t) \,\&\&\, D_k^{2\text{-}2}(t) \geq \\
&V_k^2(t) \,\&\&\, V_k^2(t) \leq V_{\max}^1 \,\&\&\, V_k^2(t) > V_{\min}
\end{aligned}
$$

Then:

$$V_k^j(t+1) = \min(V_k^j(t) + 1, V_{\max}^1) \qquad (8)$$

(3) Deterministic deceleration process

If

$$(D_k^{j-j}(t) > V_k^j(t))$$

then

$$V_k^j(t+1) = \max(D_k^{j-i}(t) - 1, 0) \qquad (9)$$

(4) The random deceleration with probability p

If

$$(V_k^j(t) > V_{\min})$$

then

$$V_k^j(t+1) = \max(V_k^j(t) - 1, V_{\min}, p) \qquad (10)$$

(5) update position

$$X_k^j(t+1) = X_k^j(t) + V_k^j(t+1) \qquad (11)$$

V.NUMERICAL SIMULATION

The basic parameters of the model are as follows:

For the analysis of dynamic properties of traffic flow system, defining the total density of vehicle on two lanes are .The density of large car is .The average velocity at time tis .lane occupancy rate , is the length of the i car on the lane 1. is the number of 1 lane changing into 2 lane. is the number of 2 lane changing into 1 lane. is conversion coefficient. is the randomization deceleration probability of large car. is the randomization deceleration probability of small car.

This paper simulated when the lane is composed of 3650 lattice, the actual road length of about 11 km, with periodic boundary conditions, the initial time of two vehicles, according to a certain proportion of mixture distribution in the 1 Lane, from left to right. No. 0, 1,... (N-1), begins to run from the initial state of the model, the evolution time step is 1 s, a total of 4800 step, taking the 1000~3600 as the simulation results (to exclude the influence of the initial state)

Figure.2~Figure.4 is given in the condition , in different passenger car ratio case,the relationship among two lane traffic density and traffic flow, speed, the number of vehicle changing lane.

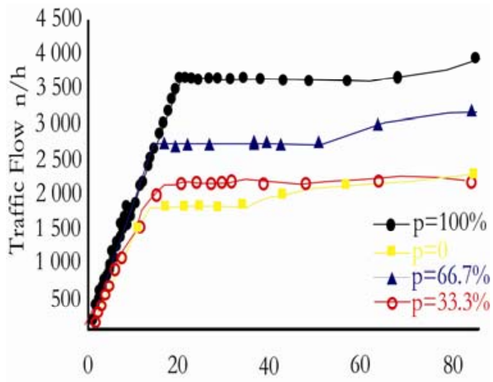

Figure.2 Relationship between density and traffic flow diagram

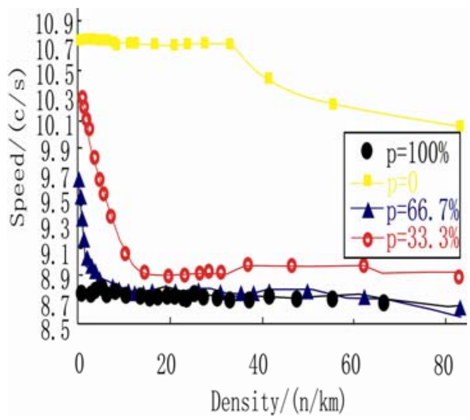

Figure.3 Relationship between density and velocity

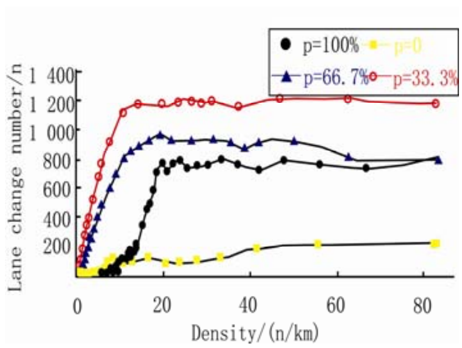

Figure.4 Relationship between Density and lane changing number diagram

Seen from the Figure.2, with the increase of the density of vehicles on the expressway, traffic flow increases, and finally tends to saturation, because of large bus length is 2 times the car, then converted into the standard vehicle conversion coefficients are 2, 1, so when all vehicles for passenger cars, the maximum traffic volume can reach about 2 times as much as the small car, and the small car has higher speed, when all the vehicles are small cars, in the relatively smaller density, can achieve the largest traffic flow. When the bus was 0% ~ 100%, the data is also in the ratio between 100% and no bus.

From the Figure.3 can be seen, in the absence of passenger cars and passenger ratio is 100%, with the increase of the density of vehicles on the roadway, the average speed of traffic flow firstly to gentle and then slowly declined, that’s when the density is small , the distance headway between vehicles is longer, vehicle free driving space is large, the mutual influence is small, the vehicle can be free driving, but when the density increased to a certain extent, the space becomes small, the vehicle free driving also become smaller. When the passenger car ratio was 33.7%, 66.7%, the decline faster, more obvious, and with the increase of the proportion of large passenger cars, cars can’t free driving, the image is closer to the full image for large passenger cars.

From the Figure.4 can be seen, in the absence of passenger cars and passenger ratio is 100%, with the increase of the density of vehicles on the roadway, the average number of vehicle changing lane increased in the same way basically, and image compared with the passenger car ratio in 0% ~ 100% the average number is much smaller, and the lane changing rules of bus in specified, passenger car ratio image amplitude 100% basic 4 times without bus. And in proportion to the number 33.7% bus to change number significantly more than the 66.7%’s, this is due to the increase with the proportion of large buses, causing the traffic lane “changing bottleneck”, the vehicle can’t change lanes.

In order to solve the balanced problem of flow and road safety, as well as speed affected, we have to find the relationship between the three parties. The traffic safety problem includes many aspects, such as whether two cars in the safe distance, whether overtaking meet traffic safety rule and so on, these are all safety issues which need to be considered In the process of the vehicle. We use AHP to analyze the relationship between traffic flow and safety and speed, using the theory of fuzzy mathematics. Find out the trade-off relationship between traffic flow and safety issues.

VI. CONCLUSION

Cellular automata traffic flow model considering the impact of passenger car, compared with the existing freeway traffic flow cellular automata model closer to the actual traffic flow.

Through the simulation of freeway traffic flow under different conditions, we found that with the increase of vehicle density double driveway, traffic flow increases, and finally tends to saturation, the average speed of traffic decline, increasing the average change number of traffic flow, and when the passenger ratio is not same, the corresponding increase or decrease the amplitude of each parameter is different It can be obtained by the simulation results, in the context of assumptions, low density of traffic flow and vehicle density linearly relationship. In high density traffic flow is difficult to increase or even decline that caused the capacity drop road congestion situation.

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