2021 China Automation Congress (CAC) | 978-1-6654-2647-3/21/$31.00 ©2021 IEEE | DOI: 10.1109/CAC53003.2021.9728156

An improved cellular automata model of traffic flow with look-ahead potential[1]

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***Abstract*-This paper presents an improved automata model for traffic flow based upon models for cellular automata and traffic flow. The proposed model is concerned with the headway and multiple velocities. The proposed model enforces the stochastic rules for moving a car on the basis of traffic in front of it. Rules for updating the velocity of car relies upon the location of the car as well as front traffic and their velocities. In particular, by using numerical simulations, the model proposed in this study can reach the steady-state more quickly for random perturbations.**

Keywords: look-ahead potential, traffic flow, cellular automata

I. Introduction

The growth of the economy as well as the increase in population and vehicles, vehicular traffic jam have become one of the critical issues in metro cities [1,2].The existing transportation system has become a bottleneck restricting sustainable development. The existing traffic models are unable to provide a better description of the complex traffic phenomenon by virtue of their nonlinear, multi-behavior subject features of traffic flow, dynamic, and stochastic. Traffic flow is affected by a variety of random factors, including external factors such as weather, as well as internal factors such as road facilities, vehicle characteristics, and driving behavior. Random evolutionary mechanisms and stochastic behaviors of traffic flow contributes a significant part in better formulation of the intrinsic evolutionary patterns of the traffic flow system.

Several models have been developed by following theoretical systems for handling real traffic. The existing models are categorized into a variety of traffic flow models, namely, [4] (1) macroscopic, (2) mesoscopic and (3) microscopic. Microscopic models apply the Lagrangian method for analyzing traffic flow dynamics and provides a description of the interaction a single trajectory of the vehicle or trajectories of multiple vehicles[5]. Whereas, microscopic models simply apply cellular automata (CA) model that is capable of representing complex the traffic flow. These models are also employed to specify the motion of a particle. The advantage of using CA to simulate a traffic flow process is that it eliminates the use of differential equations as a transition and directly sculpts rules to simulate nonlinear traffic phenomena.Unlike the general dynamic model, the CA model does not have a definite equation form, but instead contains a series of model construction rules for the grid dynamics model. It is theoretically equivalent to the modern digital computer's logical model of the " turing" machine, in principle, the CA model Can perform any computable task and is especially suitable for parallel processing

Therefore, evolution of computers makes the CA models as a research focus for its usage in traffic flow models[6]. In the year 1986, Cremer and Ludwig[7] introduced the first CA model. In spite of proposal of NS model by Nagel and Schreckenberg[8] as a minimized model of CA vehicles, the NS model is widely used till date. Afterwards, several research efforts have been put in for development of CA models for representing real traffic flow. Chowdhury and Schadschneider[9] studied the interactions of vehicles and their control signals for urban area traffic. In references[10,11], the acceleration process was improved. The authors of studies [12,13,14] proposed to reduce the randomization probability to a velocity function. The impact of brake lights has been analyzed in [15]. These improvements promoted the further development of the CA model. K. Bentaleb et al. [16] suggested a model for analysis of vehicles having slow and high speeds. The authors of the study [17] proposed a CA model for safe conditions of driving by analyzing the creating and destroying clusters or platoons of the vehicles. Chmura T, et al. [18] investigated the stable states for flow that is synchronized by using CA model. In references [19], establishing a cellular automaton model for highway traffic flow under lane control when an accident occurs. Interested readers can further explore on this topic in the studies [20,21,22].

In the actual transportation system, the traffic behavior is affected by many uncertain factors. The influence of random factors on the traffic flow can't be ignored. CA model is considered as a significant model for analysis of the random impact of traffic flow considering randomization slowdown probability. However, for the CA models, the randomization slowdown probability is assumed to be stationary. Because of the stationary slowdown probability, it is difficult to assess the impact of the random behavior higher than the critical value of the density [21]. To illustrate the random nature of traffic flow having high density, some models based on statistical physics method have been proposed. Chowdhury D et al.[23], presented a review using analytical approaches and numerical approaches from statistics physics called AM Model for studying particle hop models. These models help to understand different physical features of traffic of the vehicles. Katsoulakis [24] suggested a stochastic model for analyzing traffic flow on the basis of Arrhenius dynamic approach. The proposed model presents the state of traffic on the basis of the results of the particle hop model. Vehicles move forwards on the basis of the look-ahead potential of traffic conditions. The

[1] This paper is supported by the Fundamental Research Funds of the Central University, NO. A0920502052101-88

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AM model enables the reproduction of highly dense traffic behavior using numerical simulations. It was employable to a multi lane system for traffic [25] and was further extended to a non lattice system [26]. Using AM model, a new CA model with interactional potential was proposed by Cory Hauck et al. in Ref. [27-28]. Here, the authors analyzed significant statistical characteristics of the AM model. By incorporating the look ahead potential of vehicles into the randomization slowdown probability, a new cellular automata model was suggested in the Ref.[29] (VP model).There are few improvements directly on the fixed deceleration probability in existing CA models. Moreover, the randomization slowdown probability is not a fixed value in actual traffic situations and changes along with the variation of the status of vehicles and external factors. Hence, in an actual driving sense, the randomization slowdown probability is changed continuously with the variation of different traffic situations which are affected by the uncertain stochastic factors. However, similar to AM model, the use of look-ahead potential in the form of a constant that is not related to distance and velocity in the VP model is still a draw. In a real system for traffic, distance and velocity impacts differently acceleration and deceleration process of the driver. When the velocity of a vehicle ahead at the same position is slower than the velocity of the following vehicle, the following vehicle is more likely to slow down, vice versa. We need to build a new mechanism to consider this difference. To describe these differences and improve the limitations of AM and VP models, based on the look-ahead potential function associated with the head way and multiple velocity, an improved model of traffic flow based on CA model (HM model) with interactional potential is suggested in this paper. The modeling process simulates the driver's random decision. Finally, through numerical simulations, abundant fundamental traffic diagrams are achieved, and the complex highly dense traffic nature is again produced.

The rest of the paper is arranged as follows. Section presents the modeling process. Section 3 highlights the effects of various look ahead potential parameters on flow of traffic using numerical simulation. Finally, the paper is concluded in Section 4.

II. Modeling process

This section presents HM model and its process. It generally happens that in real situations, a car driver considers car traffic near him. The decisions of a car driver are affected in a variety of ways like head ways and velocities of surrounding vehicles. A function for head way and more than one velocities is presented for look ahead rule in the proposed model on the basis of the way for describing randomization slowdown probability in VP. We adopted a refined form of randomization for dynamic transition change rate. The process of modeling is described as below.

We proposed the division of 1 dimensional high way road into N cells denoted as $L=\{1,2,...,N\}$, $N>1$ as suggested for modeling of AM and VP model [23] for describing the state of one lane traffic system. For each individual cell sites denoted as $x \in L$, the state is computed using an order parameter $\sigma = \left\{\sigma(x) : x \in L\right\}$, as per Eq 1.

$$\sigma(x)=\begin{cases}1, & \text{When cell } x \text{ is occupied ;}\\ 0, & \text{When cell } x \text{ is not occupied(no car).}\end{cases} \qquad (1)$$

It is assumed that no backward movement of vehicles is allowed in traffic and each vehicle occupies only one cell at a particular time. As per real world traffic of vehicles, it is observed that car drivers access the position and velocity of the leading car as well as other cars in front of the leading car. So, the interactional vehicles' potential (local behavior) is presented in Eq 2 that is same as Arrhenius dynamics for Ising systems.

$$U(x,\sigma)=\sum_{\substack{y\in L\\ y>x}} J(x,y)\sigma(y) \qquad (2)$$

where J represents the interaction potential among vehicles (named interaction strength).

In references [30], Evans and Rothery reveal the decisions of a car driver are affected in a variety of ways like head ways and velocities of surrounding vehicles. Therefore, we also consider that interaction strength is given by

$$J(x,y)=J_0\left(\frac{y-x}{l}\right)^2(V_x-V_y) \qquad (3)$$

In this function, l denotes the potential radius; V_x gives the vehicles' velocity at cell site denoted by x and V_y vehicles' velocity at cell site denoted by y; J_0 represents interactional potential strength parameter on the basis of its sign described attractive repulsive or non interaction. This function reflects the effects of the headway and velocity difference on the target vehicle.

Thus, the potential function is described as per eq. 4:

$$U(x,\sigma)=\sum_{\substack{y\in L\\ y>x}} J(x,y)\sigma(y)=J_0\sum_{i=1}^{Q}\left(\frac{i}{l}\right)^2(V_x-V_{x+i})\sigma_{x+i}(t) \quad (4)$$

Here, Q is the vehicle count on the right cell denoted by x; $U(x,\sigma)>0$ reflects the exclusion, $U(x,\sigma)<0$ reflects the attraction.

As described in AM and VP models, randomization slowdown process of vehicles in look-ahead length during the time interval $[t,t+\Delta t]$ occurs with probability P, which can be expressed as:

$$p=c_0\exp(-\left|U(x,\sigma)\right|)\Delta t=c_0\exp\left(-\left|J_0\sum_{i=1}^{Q}\left(\frac{i}{l}\right)^2(V_x-V_{x+i})\sigma_{x+i}(t)\right|\right)\Delta t$$

(5)

where the prefactor $c_0=1/\tau_0$ maps to the car movement frequency and τ_0 is the feature or time for relaxation. The term $\exp[-|U(x,\sigma)|]$ represents a slow down factor dense forward vehicle. On the basis of probability, car driver makes his movement decisions accordingly. Based on this process, the slowdown probability in randomization step of CA model could be improved by this dynamically changed probability.

So, the improved CA traffic flow model in along with look ahead rule is derived. It comprises of four steps as described below.

Make x_n and v_n represents position and speed of the n-th vehicle and make $V_{\max}$ gives peak speed of vehicle, and $d_i(t)=x_{i+1}(t)-x_i(t)-1$ the separation between the i-th and its front vehicle.

Step 1 Acceleration phase: If $V_i(t) < V_{\max}$ speed of the n[th] vehicle is incremented by one unit. The rule is given as $V_i(t+1) = \min(V_i(t)+1, V_{\max})$.

Step 2 Deceleration phase: If $V_i(t) < V_{\max}$ the speed of the n-th vehicle is decreased to $d_i(t)-1$. The rule is given as $V_i(t+1) = \min(V_i(t), d_i(t)-1)$.

Step3 Randomization slowdown process with variable probability:

(1) If $x_{i+1}(t) = 0$, $U(x,\sigma) \geq 0$ and

$$p >= c_0 \exp\left(-\left|J_0 \sum_{i=1}^{Q} \left(\frac{i}{l}\right)^2 (V_x - V_{x+i})\sigma_{x+i}(t)\right|\right)\Delta t \text{ , then}$$

$V_i(t+1) = \max(V_i(t)-1, 0)$.

(1) If $x_{i+1}(t) = 0$, $U(x,\sigma) < 0$ and

$$p < c_0 \exp\left(-\left|J_0 \sum_{i=1}^{Q} \left(\frac{i}{l}\right)^2 (V_x - V_{x+i})\sigma_{x+i}(t)\right|\right)\Delta t \text{ , then}$$

$V_i(t+1) = \max(V_i(t)-1, 0)$.

Where, p is a random number between [0,1].

Step 4 Vehicle position update process: Each vehicle is moving forward according to its new velocity determined in Steps 1-3. The rule is given as $x_i(t+1) \rightarrow x_i(t) + v_i(t+1)$.

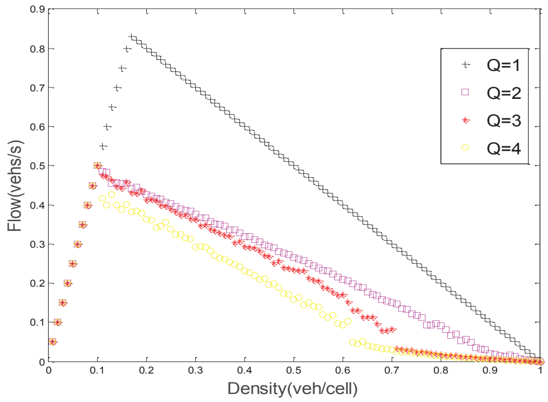
III. Numerical simulation and discussion

In this section, numerical simulation experiments are presented according to cellular evolution rules on the basis of traffic flow, and the corresponding reporting results are discussed. The system for 1 lane traffic flow is simulated by using Matlab. In the simulation, the one-lane road is divided into one thousand cells with each cell being 7.5m long. Then, the highway is $1000 \times 7.5 = 7500m$ long. The peak expected safe speed is 135 km/h, i.e., $V_{\max} = 5cell/s$. The vehicles are allowed to move in a forward direction or they stop. The speed is assumed to be non-negative for each vehicle.

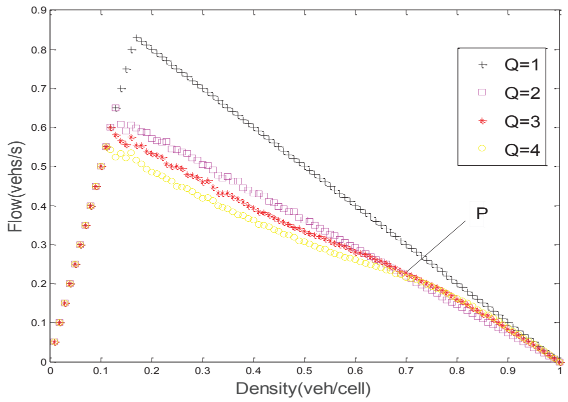
We considered the periodic conditions for boundary. The starting distribution of vehicles and the random starting speed are set initially, and then vehicles are made to move for a given time period. As per initial vehicle distribution, the speed as well as density is computed by the average of space and time for the entire circular road. Following section describes the results and discussion.

A. Basic diagram variation with interactional potential length

With fixed look-ahead strength, various the interactional potential length values have been set. The look ahead potential length Q takes the values of 1, 2, 3, 4 and $J_0 = 4$ for this set of simulations. The other parameters are $c_0 = 1$, $V_{\max} = 5$, $\Delta t = 1s$, and the total duration of run time is 5000s. The reporting results for the flow density of HM model as well as VP models are depicted in Fig.1.



(a) VP model



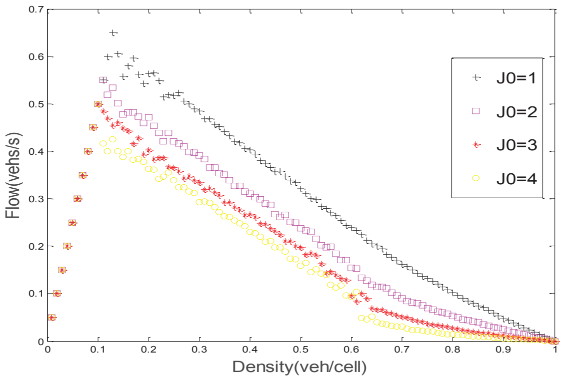
(b) HM model

Fig.1. Basic diagrams of (a) non-weighted VP model (b) HM model with different values of Q

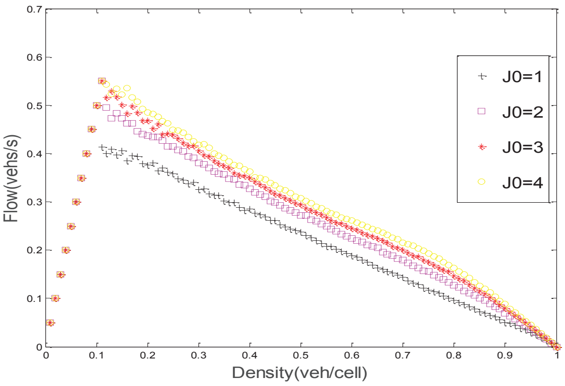
It can be observed from Fig 1 that flow density diagrams indicate similar regular patterns of HM model as well as non weighted VP model. It can be also be noted that maximum flux and critical density gradually reduce as parameter Q increases. Fig 1 also shows that the curves corresponding to VP model presents a concave tendency for high density area. However, the curves of HM model show non-convexity and non-concavity. In the whole process, the HM model' density-flow curves have a cross point in the density of 0.7 (named P), which also indicate that flux is approximately equal in high density area. The consistent results of the LWP and AM models are considered as exception for $M = 1$.

B. Basic diagram variations with interactional potential strength

Here, the interactional potential strength values are initialized as per fixed look ahead length. In this set of experiments, the values of 1, 2, 3, 4 are set for the look-ahead potential strength J_0 separately. The look ahead length is fixed as $Q = 4$. We assumed the same values of other parameters as described in Subsection 3.1. Fig 2 depicts the the experimental results for the flow–density.



（a）VP model



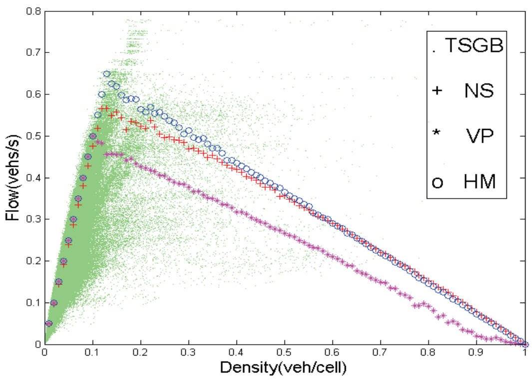
（b）HM model

Fig.2. Basic diagramsof (a) non-weighted VP model and(b) HMmodel with differentvalues of J_0

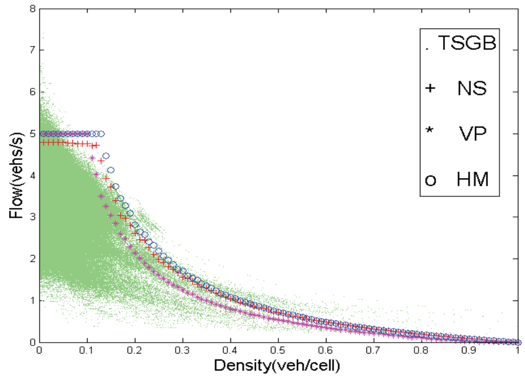
It can be observed from the Fig.2 that for fixed Q, peak value of flux and critical density is reducing with rising look ahead potential strength parameter J_0 for VP model. The result is in the opposite direction of HM model. It is also noted that traffic flux has reported improved values in case higher density traffic of VP model in comparison to HM model,.

C. Comparative analysis of VP, HM and NS models

For a comprehensive comparison analysis, the reporting results are graphically represented in Fig. 3. Here, it is assumed to follow the parameters as $Q=2, J_0=4, V_{\max}=5$, $\Delta t=1s$,time=5000s and probability of randomization deceleration for NS model is taken as $p=0.18$



（a）flow-density



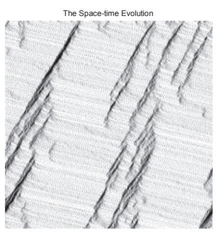
（b）velocity-density

Fig.3.Comparative analysis VP, HM and NS models in terms of (a) flow-density (b) velocity-density . Measured traffic flow data are statistical data for the whole year 2014 at Station LM160(green dots in the picture), which are measured by TSGB（Transport Statistics Great Britain[31])

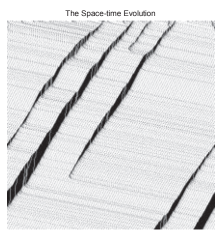
Fig. 3(a) proves that the HM model can result maximum average flow as 0.58, and maximum flow rate as 0.65. These values are found to be more than the corresponding NS model. It can also be noted that the VP model reported lower values of vehicle flux than that of HM model. This maintains a good agreement with the results of the measured data. The maximum flux of the HM model is 0.66, which is closer to the actual observation value of 0.65[10] than the NS and VP models. It is also further explained that the HM model can reflect the real traffic behavior, which is conducive to making a high traffic flux. Fig. 3(b) indicates that the HM model reported higher speed than that of NS, VP models.

D. Comparative analysis of VP, HM and NS models in terms of space and time

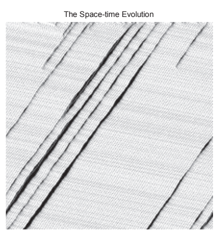
We assumed the initial distribution value for parameters as $\rho=0.2$, $Q=2,\ J_0=4,\ V_{\max}=5,\ \Delta t=1s$,and time=5000s in this set of experiments. The probability values for randomization deceleration for NS model is considered as $p=0.2$. The reporting results for three models in terms of space and time diagrams are depicted in Fig. 4.



(a)



(b)

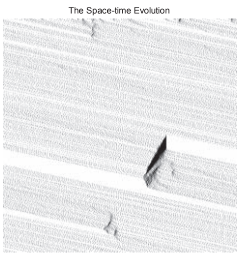


(c)

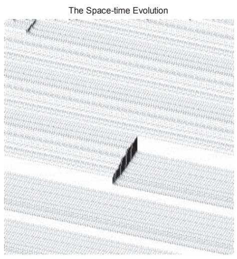
Fig.4. comparative analysis of (a)NS model, (b)VP model, and (c) HM model in terms of Space-time diagrams.

It can be observed from Fig. 4 that the phenomena of stop and go is found in all the models. The values for maintenance time and duration of jamming traffic is lower in the case HM model than the corresponding values of the NS and VP model.

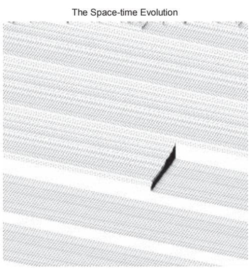
Cars are prevented to pass for a period of 30 times steps at a particular location. It is represented as a black triangle in the results. However, the shape of the triangle is formed on the basis of average density and the rules for acceleration. In this set of experiments, the starting distribution values of density is taken as $\rho = 0.1$ and corresponding results are shown in Fig.5.



(a)



(b)



(c)

Fig. 5.A shock in the traffic using (a) NS model, (b) VP model, and (d) HM model.

From Fig.5, we note that the jammed areas in case of HM model are easy to dissipate comparatively. In the HM model, the black triangle area is minimal and reaches a steady state faster.

IV.Conclusions

This paper presents a new model for cellular automata traffic flow on the basis of headway and multiple velocity. The rules for updating the car velocity are based on the positions of the car, ahead cars, and their velocities. This process of traffic modeling is desirable in taking random decisions by the car drivers on the basis of environmental traffic situations.

Afterwards, a comparative analysis of the experimental results of the proposed model and existing model, namey, NS, VP and HM models is presented. We obtained the basic diagram and density speed graphs for display of a variety of observed traffic phenomena. The phenomena include stop-and-go. In addition to this, we also analyzed the impact of various parameters on traffic flow. The results also compared in terms of shocks in the traffic space time diagrams of NS, VP, and HM models for their corresponding steady state attainment.

However, more interactive potential function may be formulated for describing stochastic behavior of traffic flow as an extension of this work in future.

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