A study on the effects of the transit parking time on traffic flow based on cellular automata theory*

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(Received 4 June 2009; revised manuscript received 18 August 2009)

This paper mainly deals with the effects of transit stops on vehicle speeds and conversion lane numbers in a mixed traffic lane. Based on thorough research of traffic flow and cellular automata theory, it calibrates the cellular length and the running speed. Also, a cellular automata model for mixed traffic flow on a two-lane system under a periodic boundary condition is presented herewith, which also takes into consideration the harbour-shaped transit stop as well. By means of computer simulation, the article also studies the effects of bus parking time on the traffic volume, the transit speed and the fast lane speed at the same time. The results demonstrate that, with the increase of the bus parking time, the traffic volume of the transit stop and the transit speed decrease while the fast lane speed increases. This result could help calculate the transit delay correctly and make arrangements for transit routes reasonably and scientifically.

Keywords: two-lane cellular automata, mixed traffic flow model, harbour-shaped transit stop, parking time

PACC: 8220F

1. Introduction

The cellular automaton (CA) model is one of the grid dynamics models in which time and space are all discrete. Its comprehensive features, such as powerful complicated calculating function, inherent parallel computing capacity, high dynamic and high flexibility, and so on, enable it to have the strongest capacity in the simulation of the complicated traffic transportation system on dynamical evolution of space and time. The CA model, which was named by Wolfram, is the initial CA model of traffic flow.[1] Later, as an extension to Wolfram's No. 184 CA, the one-dimensional (1D) expressway CA model of traffic flow (also called the "NS model") was put forward by German scholars Nagel and Schreckenberg in 1992.[2] In the same year, Biham and his team presented the two-dimensional traffic flow CA model (also called the "BML model") of the urban transport network, which established the foundation for traffic simulation research based on the CA model.[3] Since then, many researchers have performed various extensive work to the NS model and the BLM model by means of different traffic situations, and have obtained a lot of gratifying results for it.[4−15]

In Ref. [4], a new vehicle running model was proposed which considered the actual traffic situations of our country. It consists of the car-following model, the impact neighbourhood-car model and the changing-lane model, which could reflect the actual traffic conditions of China. Based on the analysis of measured data, reference [5] established the functional relationship between the speed and its influencing factors. Reference [6] only took into consideration the impact of non-harbour-shaped transit stops. Reference [7] studied the fact that bus way stations (not totally distinguishing between non-harbour and harbour) had an influence on the traffic flow and the capacity of the road with the assistance of the investigating method and statistic data. The numbers of the investigated samples had a certain influence on the results of the study. It is obvious that the existing traffic flow models often select a road section with non-harbour-shaped stops in a certain scope so as to dispel the influence of the buses' passing in and out against other vehicles.

Based on the previous research,[16−21] this paper uses mainly CA simulation theory and focuses on

*Project supported by the Science and Technology Support Program of Gansu Province, China (Grant No. 0804GKCA038).
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the impact of bus parking time on the traffic flow at harbour-shaped transit stops. In this paper, the cellular length and the running speed are calibrated in a new way and a CA model for mixed traffic flow on a two-lane system under periodic boundary condition is proposed herewith, which considers the harbour-shaped transit stop. Through further computerized simulation study, this article researches the effects of the average bus parking time on the traffic flow.

2. Analysis of bus parking time

According to the U.S. "Highway Capacity Manual", the calculation formula of bus parking time in the bus station is as follows:

$$D=\begin{cases} aA & \text{only consider the get-off traffic flow,}\\ bB & \text{only consider the get-on traffic flow,}\\ (aA+bB)y & \text{get-on and get-off through a door,}\end{cases} \tag{1}$$

where D is the bus parking time, a is the rate of getting off, A is the number of passengers who get off, b is the rate of getting on, B is the number of passengers who get on, y is 1.2 when the stop is the main point of transfer, and 1 in other situations.

By formula (1), the main factors which affect the bus parking time are the set of the door, passing through rules, the speed of getting on and getting off, and the position of the bus station, etc.

Apparently, the bus parking time in a harbour-shaped stop should have a certain effect on the traffic flow, mainly in the traffic flow, the speed of bus and the speed in the fast lane.[8] Hereby the relationship between the parking time, flow and speed in two-way 4 lanes on a harbour is demonstrated by using computerized simulation techniques.

3. Establishment of the two-lane traffic flow CA model by considering a harbour-shaped bus stop

3.1. Definition for model symbols

Assume the urban road to be two 1D separate grid point chains where the lanes on the left and right are parallel and the length is L; each grid point is empty at every moment or is occupied by a vehicle; the lane on the right side is defined as the 1st lane (bus lane) while the lane on the left side is defined as the 2nd lane (fast lane). Suppose that there are only buses and cars on the road; the cellular length is 3.75 m, a car will take 2 cellulars, a bus takes 4 cellulars, and a non-harbour type bus stop takes 4 cellulars, too. Suppose that the buses and cars have the same slowdown probability.

The speed of a vehicle k at the moment t is represented by $V_k(t), V_k(t)\in[0,V_{\max}], V_{\max}$ is the upper limit of the vehicle, $V_{\max,\text{bus}}=3$, the practical speed corresponding to it is 40.5 km/h, $V_{\max,\text{car}}=5$, the practical speed corresponding to it is 67.5 km/h. We use $X_k^1(t)$ to express the position of the k-th vehicle at the moment t on the 1st lane, $V_k^1(t)$ represents the speed of the k-th vehicle at the moment t on the 1st lane. We use $X_k^2(t)$ to express the position of the k-th vehicle at the moment t on the 2nd lane, and $V_k^2(t)$ represents the speed of the k-th vehicle at the moment t on the 2nd lane, then at the moment t the distance between the k-th vehicle and the closely neighbouring vehicles in front of it on the 1st lane is: $D_k^{1-1}(t)$ and $D_k^{1-1}(t)=X_{k+1}^1(t)-X_k^1(t)-1$. The distance between the k-th vehicle and the closely neighbouring vehicles in front of it on the 2nd lane is $D_k^{2-2}(t)$ and $D_k^{2-2}(t)=X_{k+1}^1(t)-X_k^1(t)-1$, at the moment t the distance between the k-th vehicle on the 1st lane and the closely neighbouring vehicles in front on 2nd lane is $D_k^{1-2}(t)$, the distance between the closely neighbouring vehicles behind is $B_k^{1-2}(t)$, the distance between the k-th vehicle on the 2nd lane and the closely neighbouring vehicles in front of it on the 1st lane is $D_k^{2-1}(t)$, the distance between the closely neighbouring vehicles behind is $B_k^{2-1}(t)$.

3.2. The bus running rules in a harbour-shaped transit stop[9]

Suppose that passengers on a bus should get on or get off in the harbour and every bus must stop in the harbour. When the bus enters a station, it should be at a low speed; the distance between the k-th bus and the closely neighbouring stop in front of it at the moment t is $d(t)$, if $d(t)<V_{\max,\text{bus}}$, then $V_k(t+1)=\min\{d(t),V_k(t+1)\}$. It must be certain that a bus can reach the entry position of a harbour after a certain time. When vehicles arrive at the entrance position of the harbour, the first thing to do is to judge whether there are any cars in the harbour.

If there are vehicles in the harbour, the bus has to wait at the entrance position; if not, the bus can enter the harbour directly. When the bus intends to leave the station, it must send out a signal to contact the vehicle first. If the condition is satisfied, the bus may leave the station at the speed $V_k(t) = 1$.

3.3. Car operation rules in a harbour-shaped transit stop

When a vehicle arrives at the entrance of a harbour, it must judge first whether there are any signals for departure from a bus in the harbour. If not, it runs normally; otherwise, the vehicle should slow down to stop and await the bus getting off, or change the lane to run.

3.4. The conditions and rules of a car changing lane

For a car k in lane 1, the condition of changing lane is

$V_k^1(t) > D_k^{1-1}(t)\&\&B_k^{1-2}(t) + V_k^1(t) > V_{\max}\&\& D_k^{1-2}(t) > V_k^1(t)$

For the car k in lane 2, the condition of changing lane is

$V_k^2(t) > D_k^{2-2}(t)\&\&B_k^{2-1}(t) + V_k^2(t) > V_{\max}\&\& D_k^{2-1}(t) > V_k^2(t)$

If the vehicles meet the condition of changing lane, then they change it. The rule of changing lane on the 1st lane is

$$V_k^2(t+1) = V_k^1(t), \quad X_k^2(t+1) = X_k^1(t) + V_k^1(t).$$

The rule of changing lane on the 2nd lane is

$$V_k^1(t+1) = V_k^2(t), \quad X_k^1(t+1) = X_k^2(t) + V_k^2(t).$$

3.5. The renewable rule of the evolution of a vehicle's state

For each vehicle outside the station, the speed and position can be updated according to the evolution rules of the NS model, while for the vehicles at the station, the speed and position can be upgraded according to the evolution rules of the NS model at first and then be revised according to the running rules of the stand.

(i) Accelerator: if $V(t) \leq D_k(t)$ then $V(t+1) = V_{\max}$.

(ii) Deterministic deceleration process: if $V(t) > D_k(t)$ then $V(t+1) = D_k(t)$.

(iii) Stochastic deceleration process by the probability p:

if $V(t) = V_{\max}$ then $V(t+1) = V_{\max} - 1$, by the probability p.

(iv) The renewal of the position: $X(t+1) = X(t) + V(t+1)$.

4. Numerical simulations and results of the discussion

To make a concrete analysis of the kinetic property of the traffic flow system, we define the vehicle density on the 1st lane (bus lane) as $\rho_1 = (N_{\rm c}^1 + N_{\rm b})/L$, on the 2nd lane (fast lane) as $\rho_2 = N_{\rm c}^2/L$, the average velocity of the car at the moment as $\overline{V_{\rm c}}(t) = (\sum_{k=1}^{N_{\rm c}^1} V_k(t) + \sum_{k=1}^{N_{\rm c}^2} V_k(t))/(N_{\rm c}^1 + N_{\rm c}^2)$, the average velocity of the bus as $\overline{V_{\rm b}}(t) = (\sum_{k=1}^{N_{\rm b}'} V_k(t))/N_{\rm b}$. In this formula, $N_{\rm c}^1$ is the total number of the cars in the 1st lane, and $N_{\rm c}^2$ is the total number of the cars in the 2nd lane, $N_{\rm b}$ is the total number of buses, $N_{\rm b}'$ is the number of buses in the lane, excluding those staying in the harbour-stop. $V_{\rm c}(t)$ is the velocity of the k-th car at moment t, $V_{\rm b}(t)$ is the velocity of the k-th bus at moment t. Calculating traffic flow Q (called flow) is the number of vehicles that are passing across the cellular at the same moment. In order to consider the vehicles' mixed level occupying rate of buses, the possession ratio coefficient of a bus is introduced: $f = N_{\rm b}/(N_{\rm b} + N_{\rm c}),\ 0 \leq f \leq 1,\ N_{\rm c} = N_{\rm c}^1 + N_{\rm c}^2$.

In order to study the effects of the distance between bus stations on city traffic flow, we introduce the distance between bus stations and the average parking time $t_{\rm bs}$.

In this article, we use the periodic boundary in the simulation. $L = 2000$, at the initial moment, two hybrid vehicles uniformly mixingly distributed in the lane according to a certain fixed ratio coefficient f, the time step for each evolution of the model is 1000, the velocity $V_k(t)$ in each step ranging from 6000 to 9000 is recorded, and an average velocity in each step will be worked out. Then we find the average time using the velocity statistics with the number of 3600, and get an average velocity for each step.

Figures 1 and 2 present separately the relationship between the flow and the parking time, between bus average speed and parking time when $s = 200$, $t_{\rm bs} = 20$ s, $f = 0.15$, $p = 0.2$, $\rho = 95$, 80, 65, 50. We can find out from Fig. 1 that the influence of the bus parking time on traffic flow is more obvious: the longer

the average parking time is, the lower the traffic flow is; when parking time rises from 15 s to 30 s, the flow will reduce about 150/h correspondingly; when parking time rises from 30 s to 45 s, the flow will reduce about 50/h correspondingly.

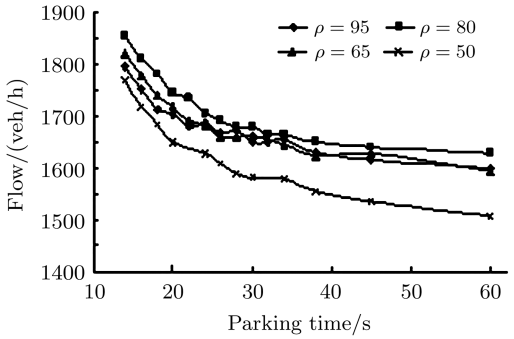


Fig. 1. The relationship between bus parking time and flow.

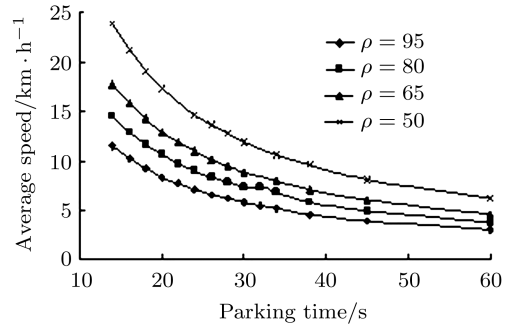


Fig. 2. The relationship between bus parking time and its average speed.

In addition, when a bus stops at the harbour-shaped transit stop, it will influence the following access vehicles and the following buses have to stop and wait outside the harbour, which leads to the fact that the vehicles passing in the highway section finally reduce in the unit time.

We can find out from Fig. 2 that the smaller ρ is, the higher the bus average speed is; and the longer the bus parking time is, the lower the bus average speed is. This is because on the road the smaller ρ is, the fewer vehicles there are, and the smaller the interference between them is. As f in the unchanged value indicates, the smallerρ is, the smaller the total number of buses on the road will be; the number of harbours will increase the satisfaction degree to the buses. This phenomenon shows that bus numbers waiting outside will be improved and the average speed will increase too. But with the increase of parking time, the number of buses waiting outside the harbour will increase, which will make the average speed of buses decreases. The concrete situation can be shown by a space-time evolution spot figure of the bus lane from Fig. 3.

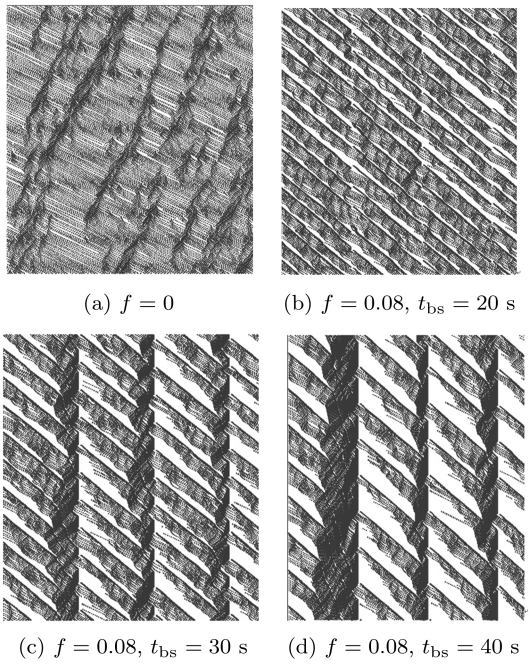


Fig. 3. Space-time evolution spot figure of the bus lane.

Figure 3 is the NS model under the conditions of $f = 0.0$, $\rho = 63$, $p = 0.2$. Figures 3(b), 3(c) and 3(d) represent the separate hybrid vehicle model at the moment of $t_{\rm bs}$ with 20 s, 30 s and 40 s under the conditions of $s = 200$, $\rho = 63$, $p = 0.20$, $f = 0.08$. The space-time evolution spot figure of the bus lane shows the situation when L is from 0 to 1000, t between 9000 to 9400, the vehicle moves from left to right, the cross axle expresses the position of the vehicle, the axis of ordinates expresses time, the black point expresses the position of the vehicle and the white point expresses the empty lattice point.

From Fig. 3(a), we can find out the blocking areas randomly with $f = 0$, the result is the same as the NS model. By comparing with Figs. 3(b), 3(c) and 3(d), we can see that when ρ and f are under a certain situation, the bigger $t_{\rm bs}$ is, the more obvious the blocking areas are, the bigger the road blank areas are and the lower the utilization ratio will be. As the harbour-shaped transit stop can only meet a few vehicles stopping at the same time, the vehicle which arrives later has to wait at the entrance position of the harbour, which may prevent the following cars from running normally. So the latter will have to change lane to overtake, or stop and wait. This could result in the blockage of the area around the bus station. but there would be some blank area of the region in

front of the bus, which, in turn, causes the waste of the utilization ratio of the road.

Figure 4 indicates that the average parking time of a bus has an influence on the car average speed under the condition of $s = 200$, $t_{\rm bs} = 20$ s, $f = 0.2$, $p = 0.2$, $\rho = 95$, 80, 65, 50. We can find out that ρ has the greatest impact on cars running in the fast lane from Fig. 4. The smaller ρ is, the bigger the average car speed is. When ρ is under a certain situation, with the increase of average bus parking time, the average car speed will thereupon increase in the fast lane.

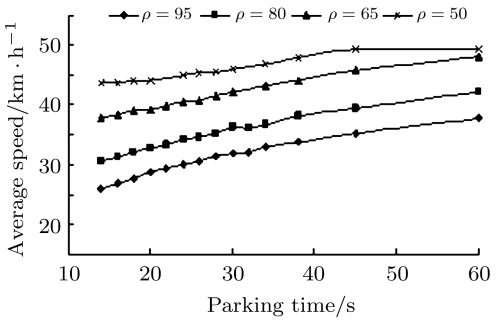


Fig. 4. The relationship between parking time and speed in the fast lane.

5. Conclusion

The interaction of buses and other vehicles has an important impact on urban traffic. Bus parking time is an important indicator. From it we can observe the micro-state of the buses by changing the bus parking time respectively, then analyse the degree of the buses' effects on other kind of vehicles and on the extent of the road under different parking times. In this paper, we have presented a model for mixed traffic flow on a two-lane system under a periodic boundary condition and computerized simulation. A systematic analysis was made in this paper. First, it shows that the influence of the bus parking time on traffic flow is more obvious: the longer the average parking time is, the lower the traffic flow is. Second, we can find out that the smaller ρ is, the higher the average bus speed is; and the longer the bus parking time is, the lower the average bus speed is. Moreover, with the increase of parking time, the number of buses waiting outside the harbour increases, which makes the bus average speed decrease. As a consequence of the numerical simulations, it is clear that this has an important reference value and practical value on the actual work of the reasonable positioning of bus stops, clever arrangement of bus routes, precise calculations of bus delays in running state and the capacity of bus stops.

Acknowledgments

We would like to thank Gao Zi-You, Liu Mu-Ren, Huang Hai-Jun and other professors in this study area. It is on the basis of their study that we are able to get this research result.

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