Research for Urban Traffic Simulation Model of Cross-street Pedestrian Influence

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Abstract. To study the influence of cross-street pedestrian on the urban traffic flow, traffic characteristic of vehicle and pedestrian are investigated under horizontal interference conditions. With resetting the rules of vehicle operation behaviour such as deceleration, acceleration, lane change, etc, a new simulation model of two-lane urban traffic flow is established, which is also called cellular automata model. To simulate the traffic conditions of signal control road sections and non-signal control road sections and generate the space-time diagram, the softwares MATLAB and ORIGIN is used for acquiring numerical simulating results and relational graphs of the traffic flow parameters. Comparative analysis is carried on between traffic state with horizontal interference and traffic state without horizontal interference. Finally, simulation results show that pedestrian crossing street has less obvious impact on traffic flow in larger density (higher than 0.22), signal control and acceptable crossing gaps for pedestrian have certain influence on traffic flow and lane change of vehicle. The proposed simulation model is in better consistence with actual situation and has some practical and theoretical significance for traffic flow research.

1. Introduction
The simulation model involved in this paper is called Cellular Automata model which is suitable for simulation of microscopic traffic flow phenomena. Since the most original classic NS model was proposed in 1992, lots of improved models from it were established. Existing research results can be summarized as two types of CA model: freeway and urban road. Freeway traffic flow is continuous and there is less interference from both sides of the road, actually its CA models come to maturity. Recent research[1-2] interests focus primarily on the impact of traffic bottlenecks section, as well as mixed traffic flow. However, urban road traffic characteristics is complex, including multiple modes of transportation, various types of vehicles, a variety of different acts and coming in and going out frequently. Urban road traffic flow CA model still needs to be improved. Existing research[3-7] results include CA models built by taking into account mixed traffic flow, driver psychology and longitudinal interference or other factors.

Road intersections and road section crosswalks are two important urban road cross-sectional elements, which directly impact on the continuity of traffic flow. Some scholars have respectively conducted a number of studies[8-10]. Traffic survey shows that, if there are pedestrians crossing a road, vehicles decelerate or stop to give way. If no pedestrian waiting at both ends of crosswalk or vehicle keeps smaller spacing with front vehicle, current vehicle will maintain its speed to go ahead. If there are pedestrians waiting at both ends of crosswalk and vehicle keeping larger spacing with front vehicle, current vehicle will pass through slowing down by certain probability based on their observation. Pedestrians can cross street using gap between vehicles. If vehicles stop to give way,
pedestrians will flock to move on, and subsequent pedestrians will accelerate to catch up to achieve the centralized passage.

Considering the psychological characteristics and self-organizing behavior of pedestrians and vehicle drivers, this paper tries to establish an urban road traffic flow cellular automaton model with taking into account pedestrian crossing street. Then, the relationship between density, vehicle speed, acceptable crossing gaps for pedestrian, number of pedestrians and other parameters are researched, besides, impact of crosswalk and signal control on traffic flow are comparatively analyzed.

The following section of this paper establishes the models of vehicles movement and pedestrian movement. Then, section three provides a numerical simulation to demonstrate the proposed model. The final section then concludes the paper and recommends the follow-up.

2. Models

2.1. Lane change rules
In road sections without horizontal interference, such as vehicle green light period in signal control sections, as well as sections away from the crosswalk location without signal control, the goal of lane change is to improve vehicle speed under premise of ensuring security.

During vehicle red light period in signal control sections, if not considering the needs for front steering, vehicle slows down into queued state. Survey shows that if neighboring lane has one cellular for parking, current vehicle will change lane with probability of value $p_2$. If neighboring lane has two or more cells for parking, current vehicle is bound to change lane under premise of ensuring security.

For road sections without signal control, vehicle behavior is more complex when approaching crosswalk, which is subject to the degree of pedestrian occupying the road space. If pedestrians observe rules, vehicles will follow driving and not change lane. If pedestrians attempt to enter driveway or invade small lane space, vehicles tend to transform track and laterally offset from pedestrians, causing many line ball travel, and reply to original lane after passing crosswalk. If pedestrians invade majority of lane space, vehicle has to stop to or forced to change lane.

2.2. Vehicles movement model
In existing research results, two-lane traffic flow CA models without considering horizontal interference have matured. Rules for lane change need to take into account traffic conditions, road conditions, drivers’ psychological factor and other factors. The model uses two-stage method in each discrete unit time length of stride to reappear position and speed renewal. The first step is lane change, the second step is vehicle-following driving. Combined with the basis of previous studies, considering different horizontal interference factors, the rules of vehicle changing lane, acceleration and deceleration, Randomization and position update are formulated as follows:

First step: lane changing

Parameter $gap_{\text{present}}^i(t)$ is defined as the distance between current vehicle $i$ and front vehicle in current lane at $t$ moment. Parameter $gap_{\text{target}}^i(t)$ is the distance between current vehicle $i$ and front vehicle in target lane at $t$ moment. Parameter $gap_{\text{back}}^i(t)$ is the distance between current vehicle $i$ and back vehicle in target lane at $t$ moment. Parameter $v^i(t)$ and parameter $x^i(t)$ are the speed and location of current vehicle. Vehicle $i$ will change lane when it meets following conditions:

1. Signal control sections during vehicle green periods or sections without horizontal interference.
   
   $b^i(t) = 0$  
   
   $gap_{\text{present}}^i(t) < \min(v^i(t) + 1, v_{\text{max}})$  
   
   $v^i(t) < gap_{\text{target}}^i(t)$,  
   
   $v^i(t) < gap_{\text{back}}^i(t)$  
   
   $\text{rand}() < p_1$
Where, (1a) shows that brake lights is in off state, which is the premise of current car for lane change. (1b) shows that current vehicle is subject to the gap between the front vehicle and itself, and it is difficult to travel to the expect speed. (1c) indicates that adjacent lane can provide secure space requirements. In formula (1d), function \( \text{rand}(\cdot) \) is a random number ranging from 0 to 1, indicating that when above conditions are met, vehicle will change lane with a certain probability.

(2) Signal control sections during vehicle red periods

\[
\begin{align*}
 b^{i+1}(t) & = 1, \quad b^i(t) = 0 \quad (2a) \\
 \text{gap}^i_{\text{target}}(t) & = 1, \quad \text{rand}(\cdot) < p_2 \quad (2b) \\
 \text{gap}^i_{\text{target}}(t) & \geq 2 \quad (2c) \\
 v^i(t) & < \text{gap}^i_{\text{back}}(t) \quad (2d)
\end{align*}
\]

Where, (2a) shows that current vehicle brake lights is off and front vehicle brake lights is on, meanwhile current vehicle is about to enter the queue. (2b) and (2c) indicate that vehicles change to adjacent lane by certain probability according to parking space. (2d) is security conditions.

(3) Sections without signal control but setting crosswalk

\[
\begin{align*}
 b^i(t) & = 0 \quad (3a) \\
 \text{ped}^i(t) & = 1, \quad \text{ped}^i_{\text{target}}(t) = 0 \quad (3b) \\
 v^i(t) & < \text{gap}^i_{\text{target}}(t), \quad v^i(t) < \text{gap}^i_{\text{back}}(t) \quad (3c) \\
 \text{gap}^i_{\text{vp}}(t) & < D \quad (3d)
\end{align*}
\]

Where, formula (3a) shows that current vehicle brake light is in off state. (3b) indicates that there are pedestrians passing through or standing on crosswalk at current lane, while there are no pedestrians at adjacent lanes. (3c) is security conditions. (3d) is the supplement for security conditions, if parameter \( \text{gap}^i_{\text{vp}}(t) \) exceeds \( D \) value, pedestrians are bound to use the lane in next step, current vehicle lost significance for lane change. In which \( D \) is the acceptable crossing gaps for pedestrian, parameter \( \text{gap}^i_{\text{vp}}(t) \) denotes actual gap of adjacent lane for pedestrian crossing.

Second step: Speed and location update

(1) Accelerate

Signal control sections during vehicle green periods or sections without horizontal interference, vehicles travel to desired speed as high as possible when conditions permit.

\[
\begin{align*}
 b^{i+1}(t) & = 0, \quad b^i(t) = 0 \\
 v^i(t + 1) & = \min(v^i(t) + 1, v_{\text{max}})
\end{align*}
\]

(2) Decelerate

\[
\begin{align*}
 v^i(t + 1) & = \min(v^i(t), \quad d^i_{\text{off}}) \\
 \text{If} \quad v^i(t + 1) < v^i(t) \quad \text{then} \quad b^i(t + 1) = 1
\end{align*}
\]

(3) Randomization and brake status updating

\[
\begin{align*}
 \text{If} \quad \text{rand}(\cdot) < p_0, \quad \text{then} \quad v^i(t + 1) & = \max(v^i(t + 1) - 1, 0) \\
 \text{If} \quad p_0 = p_b, \quad \text{then} \quad b^i(t + 1) = 1
\end{align*}
\]

(4) Location updating

\[
\begin{align*}
 x^i(t + 1) & = x^i(t) + v^i(t + 1)
\end{align*}
\]

2.3. Pedestrian movement model

The cocurrent pedestrians tend to cluster through crosswalk. Pedestrians will give way to left or right sides by certain probability when they encounter to pedestrian. In addition, pedestrian numbers, age
and gender have a greater impact on pace. Thus, relative to vehicle, pedestrian walk behavior is more complicated. From the perspective of vehicle, pedestrian crosswalk occupied or not determines whether the lanes can pass. To simplify problem, pedestrian impact is summed up as two parameters: (1) $D$: Threshold of acceptable crossing gaps for pedestrian. When distance from the closest vehicle to crosswalk exceeds this value, pedestrians will occupy lanes. When distance below this value, pedestrians will occupy lane by certain probability according to pedestrian quantity and the judgment of vehicles speed. (2) Pedestrian quantity: The more the number of pedestrian waiting on both sides of crosswalk, the greater the probability of vehicles decelerating and giving way to pedestrian, which increases risk of pedestrian adventure through the lane.

3. Numerical simulation analysis

3.1. The basic parameters of numerical simulation

The NS model sets cellular grid length of 7.5 meters. Many following revision models take this as basis. Investigations of vehicles queued during a red light show that urban road space occupied by a standard vehicle is about 6.0 meters. So, the cellular grid length is set with 6 meters in this model.

Periodic boundary condition is used for numerical simulation, that is, total number of vehicles is constant. Density of lane $j$ at time $t$ is defined as $\rho_j(t) = N_j(t)/L$, average speed $\overline{V}_i = \frac{1}{T} \sum_{t=0}^{T-1} \overline{V}_i$, average flow $Q = \rho \times V$. Where $N$ is the total number of vehicles, $L$ is the cellular total number of single lane. $N_j(t)$ is the vehicle number of lane $j$ at time $t$, $\overline{V}_i$ is the average speed of vehicle on a per lane at time $t$, $T$ is simulation time.

In simulation program, each lane is composed by 1000 cells with cellular length of 6.0m, corresponding to actual road length is about 6.0km.

Assuming that the maximum speed of two types of vehicles on road are 2 and 3 (unit: cells per second), randomization probability is valued 0.3. Model is run 20000 time steps (time step length sets 1s) in each test. The position and speed of all vehicles are record in each time step. In order to eliminate pseudo-randomness in start time of simulation, the documental values of last 1000 time steps are used to calculate average speed.

3.2. Numerical simulation analysis

Figure 1 to 9 are vehicle space-time state evolution spots figures for single lane with different vehicle density, including three states: sections without interference, signal control sections, sections without signal control but setting crosswalk. In these figures, horizontal axis represents the left-right movement of vehicle in space, and vertical axis represents the top-down movement of vehicle in time. However, the black dot indicates the vehicle position while white point indicates blank.

Figure 1 to 3 are space-time diagrams of sections without interference. Observation can be found in the lower density, for example $\rho = 0.04$ (unit: vehicle / cell / lane), that vehicles travel in free flow state and are more evenly distributed. What’s more, dense but not crowded phenomenon will appear at some time due to randomness. In moderate density, for example $\rho = 0.20$, vehicles travel in synchronize flow state, periodic blocking will automatically dissipate within a short time. In higher density, for example $\rho = 0.40$, vehicles travel in very crowded state, and take too long to dissipate after a blockage. The above phenomenon is consistent with existing research conclusions.

Figure 4 to 6 are space-time diagrams of signal control sections. In lower density, for example $\rho = 0.04$, vehicles travel in free flow state and are more evenly distributed. What’s more, dense but not crowded phenomenon will appear at light control department. But queue length is very small and blockage is quickly dissipated when signal light is changed. In moderate density, for example $\rho = 0.20$, intensive vehicles cause cyclical long queues at position of traffic lights. In higher density, for example $\rho =
0.40, vehicles are driving in a very crowded state, queue is appearing periodically at traffic lights position and queue length is longer.

Figure 7 to 9 are space-time diagrams of sections without signal control but setting crosswalks. In lower density ($\rho = 0.04$), driving vehicles are evenly distributed, cyclical stagnation vehicles emerge at crosswalk, but queuing vehicles are rare and obstruction is not obvious, the impact of vehicle stagnation is a very short time, because road is not wide and pedestrian crossing takes very little time. In moderate density ($\rho = 0.20$), vehicles are more intensive and vehicles stagnation queuing phenomenon appear periodically at crosswalk, but obstruction is not particularly obvious. In higher density ($\rho = 0.40$), vehicles are traveling in a very crowded state, and crosswalk is substantially no effect on traffic, because that these very intensive vehicles causing pedestrians are almost no suitable neutral to cross street.
Fig 7. Space-time diagram of sections without signal control in lower density ($\rho = 0.04$)

Fig 8. Space-time diagram of sections without signal control in moderate density ($\rho = 0.20$)

Fig 9. Space-time diagram of sections without signal control in moderate density ($\rho = 0.40$)

Figure 10 to 11 are average speed and average flow diagrams with different vehicle density, still including three kinds of section state. The two figures show that, in lower density (less than 0.12), curves of average speed and average flow change the same under three types of road conditions. As density increases, average velocity and average flow of signal control sections are significantly lower than the other two scenarios. When density is greater than 0.22, influence of sections without signal control but setting crosswalk begins to emerge.

Fig 10. Density vs. average speed

Fig 11. Density vs. average flow

Figure 12 is the number of lane change with density changes under three kinds of section state. The figure shows that sections without signal control but setting crosswalk has almost no additional impact on lane change. And the impact of signal control on lane change number is evident when density is less than 0.2. This is because, when traffic flow encounters a red traffic light, the front vehicle decelerates, and the latter vehicle changes lane for the opportunity to seek way forward. Therefore, at
this stage, an increase in number of lane change is more obvious.

Figure 12. Density vs. number of lane change

Figure 13 to 14 are average speed and average flow diagrams with different vehicle density under different green light time. The diagrams show that all curves are consistent with increasing density. The simulation assumes that red light time and green light time are equal, so it will have a little effect on speed and flow when it changes for.

Figure 15 is the number of lane change diagram with different vehicle density under different green light time. Due to the influence of signal control, vehicles change lanes more frequently in case of relatively low density. The number of lane change per time step reaches its maximum when density is about 0.12. When vehicle density increases to a certain extent (density is 0.2), the number of lane change is in a low level and reduces rapidly until no vehicle to change lane. The spacing between successive cars is very small in case of high density, so the principles of safe overtaking are difficult to meet, therefore vehicle can not change lane.
Figure 16 to 18 are average speed, average flow and lane change number diagrams with different vehicle density under different acceptable crossing gaps for pedestrian. Simulation road condition is section without signal control but setting crosswalk. Diagrams indicate that when density is low (less than 0.24), different acceptable crossing gaps for pedestrian have little effect on vehicle flow and speed. As densities continue to increase, the crossing gap smaller, the vehicle speed and volume lower. Figure 18 shows that lane change number is hardly affected by crossing gaps for pedestrian.

![Graph 1: Density vs. average speed](image1)

**Fig16. Density vs. average speed**

![Graph 2: Density vs. average flow](image2)

**Fig17. Density vs. average flow**

![Graph 3: Density vs. number of lane change](image3)

**Fig18. Density vs. number of lane change**

4. Conclusions

(1) Taking into account pedestrians crossing street, urban road two-lane traffic flow cellular automaton model is established. Space-time diagram is used to reproduce vehicle congestion, queuing and dissipation phenomena under different road conditions.

(2) Numerical simulation results indicate that, when vehicle density is lower than 0.12, pedestrian crossing street has less impact on traffic flow. When vehicle density is higher than 0.22, traffic speed and volume will decrease significantly on sections without signal control but setting crosswalk.

(3) Signal control increases lane change number in low density (less than 0.2), while other parameter adjustments have no significant effect to lane change.

(4) When density exceeds 0.24, different values of acceptable crossing gaps for pedestrian have a certain impact on traffic flow. The smaller the values are, the smaller the traffic speed and flow will be.

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