Simulation of non-motor vehicle and pedestrian mixed crossing behavior

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Abstract. In order to study the mixed traffic of non-motor vehicles and pedestrians at urban intersections, a two-dimensional cellular automata model was established by analyzing the movement characteristics of non-motor vehicles and pedestrians, which included the field, cellular space, attributes, and forward decision-making of pedestrians and non-motor vehicles. This model can reflect the interweaving and interference behavior of non-motor vehicles and pedestrians in the time window of the intersection, and describe the behavior characteristics of non-motor vehicles and pedestrians in different stages of crossing the intersection.

Key words: Non-motor vehicle; Pedestrian simulation; Crosswalk; Cellular automata.

1. Introduction
Convenience, speed and low cost have led to an increasing number of e-bikes due to the pressure of commuting and the growth of new jobs such as riding and agent driving. Therefore, the mixed traffic flow formed by pedestrians and non-motor vehicles during the signal phase at the intersection mainly includes three kinds of traffic participants: walkers, traditional bicycle riders and electric bicycle riders. In view of non-motor vehicle and pedestrian traffic characteristics, many scholars have carried out various researches. Yang Xiaofang [1] established a cellular automata model, which considered the existence of higher speed vehicles in the hybrid non-motor vehicle system and studied the running state of the mixed traffic flow under different parameters. Zhang Jin [2] et al. established a unidirectional two-dimensional non-motor vehicle cellular automata model and simulated the influence of lane number. Gangren et al. [3] introduced non-lane-based cycling behavior, clarified the boundary between dispersion and contraction, and modeled the traffic characteristics of the straight hybrid bicycle flow at the intersection after the green light. Based on the NS model, Wei Liying [4] considered the lane changing behavior of bicycles and added the rule of path selection. Hui [5] introduced the no-traffic rules to study the management and control of electric bicycles at signalized intersections.

There are many achievements in studies on pedestrians and non-motor vehicles at intersections. These studies mostly describe individual pedestrian movements from a micro perspective, such as social force model [6] and lattice gas model [7]. However, most studies take one of the two as the research subject, or study the mutual interference with motor vehicles, while the mutual interference between non-motor vehicles and pedestrians is relatively less. At the same time, in the process of using micro model research, attention is paid to the discrete description of the behavior of traffic individuals, without considering the pairing of individuals. For example, the traffic behavior of pedestrians is often...
accompanied by the phenomenon of "walking in pairs", and group synchronized traffic behavior appears in twos and in twos. Especially in signal intersection, green light and bright, after the stop line waiting for pedestrians and non-motor vehicles movement at the same time, the empty roads for resources at the same time, further interference phenomenon, should not be neglected, compared to the pedestrian in phenomenon, significantly greater than the pedestrian non-motor vehicles speed, based on the rapid demand across the street, crossing the intersection during the companion phenomenon is not obvious. In view of the above factors, this paper aims at the situation of non-motor vehicles and pedestrians crossing the street at the signalized intersection and considers the phenomenon of pedestrian pairing. Based on the cellular automata, the mixed traffic flow is modeled to analyze the mixed traffic behavior mechanism under the pairing situation.

2. Model establishment

2.1. Basic assumptions of traffic individuals are as follows:

(1) Pedestrians move in both directions. The movement range takes the crosswalk as the main area, and it is allowed to go beyond the crosswalk area. The side near the non-motorized lane is allowed to spread to the width of a traveling space, and the side near the stop line is allowed to spread to the boundary area.

(2) the rider is a one-way movement, movement range for non-motor vehicle lanes, left and right sides of the travel can spread a rider's width, the right part is used for simulating the overtaking or controlling behavior of extra time takes up the situation, namely the side beyond the interference of lane area into the pedestrian crossing, on the left side of the diffusion area occupied non-motor vehicle lanes and roads of horizontal interval. For the pertinence of the study, short-term occupancy during non-motor vehicle travel is allowed, which is represented in the model as the horizontal width of a cyclist.

(3) Some pairing behaviors are added in the pedestrian group, and two or three people are side by side. After the obstacle is divided into two situations, three people temporarily separated, to the people through, and then reconsidered side by side; The same as above or change the form of two people, from side by side to side by side.

(4) There are two types of individual states. When the signal light is red, both pedestrians and non-motor vehicles are waiting at the stop line. When the signal light is green, both pedestrians and non-motor vehicles start to cross the street.

2.2. Two-dimensional cellular automata model

Non-motor vehicle model

The length of a non-motor vehicle is generally 1.6~1.9 meters, the width is 0.5~0.6 meters, and the swing range from side to side is about 0.2 meters during the driving process. Therefore, in this model, the space length of a non-motor vehicle is defined as 2 meters and the width is 0.8 meters, occupying a range of 2 widths and 4 lengths, namely, 8 cellular Spaces.

Non-motor vehicles include human-powered bicycles and electric bicycles. In the process of driving at the intersection area, the maximum speed of human-powered bicycles is 4m/s and the average speed is 3.08m/s. The maximum speed of electric bicycles is 6m/s and the average speed is 4.1m/s. Considering universality, the maximum cell velocity in this model is taken the corresponding average value respectively, which is corresponding to $V_{max}=10cell/s$ and $V_{cmax}=7cell/s$.

The grid of two-dimensional cells is designed according to the non-motor vehicle access area at the intersection, and the dispersion effect, the surplus width on one side of the adjacent motor vehicle lane and the interference area mixed with pedestrians are also taken into account. The total driving width corresponds to 8 cell widths, that is, the width required by 4 non-motor vehicles driving side by side.

The position of each cell in the grid is represented by two-dimensional coordinates, so the current state of each cell can be represented by a matrix. Cellular states can be divided into the following categories: empty, occupied by non-motor vehicles and with a forward speed of $V$, $V_e$ is 0~10, and $V_e$ is 0~7.
The pedestrian model

Similar to non-motor vehicles, the space occupied by a single pedestrian is a cell, and the walking speed is about 0.6m/s. Considering that the pedestrian walking speed at the intersection is slightly faster, the maximum speed in this model is 0.8m/s, that is, $V_h = 2c_{cell}/s$. The moving space of the pedestrian cell in the grid is the crosswalk area, the diffusion area and the mixed disturbance area. The state of the cell is empty, occupied and the velocity is $V_h$, and the value of $V_h$ is 0–2.

![Fig. 1 Distribution of non-motor vehicles and pedestrians in cellular space](image)

2.3. Decision rules for non-motor vehicles and pedestrians

At the initial moment, pedestrians and non-motor vehicles wait outside the stop line. When the signal light turns on, they start to move forward until the street crossing behavior is completed, and the first simulation is completed. In order to realize the behavior of non-motor vehicles and pedestrians advancing in separate lanes, the concept of "field" is introduced. The field is divided into three types: non-motor vehicle field, pedestrian field and overlapping field: Non-motor vehicle yard domain is in the process of the vehicle forward, pedestrians field driving lane area are pedestrians walking forward in the process of lane area, overlapping field is in the process of motor vehicles and pedestrians in advance because beyond or avoidance behavior needs to occupy the other lane's Shared area, based on the field the category of the assignment on each cell Spaces.

$$E_{xy} = \begin{cases} 
1, & \text{The cell card is located in the non-motor vehicle field} \\
1.5, & \text{The cellular card is located in an overlapping field} \\
-1, & \text{The cellular card is located in the pedestrian field}
\end{cases}$$

The cellular attraction parameter $A_{ij}$ of pedestrians and non-motorized vehicles reflects the attraction of the surrounding cellular space to non-motorized and non-motorized pedestrians.

$$A_{ij} = \begin{cases} 
1, & \text{Adjacent cells are empty} \\
0, & \text{Otherwise}
\end{cases}$$

Consider field category and location parameters can be calculated a return, according to the size of the profit value, can get the possibility of non-motor vehicles and pedestrians to move next size, so as to realize the two crossing behavior, among them, the $p$ for forward probability, value is 0.99, for a right turn probability, value of 0.5, as the discriminant factor, non-motor vehicle area value is 1, The value of pedestrian area is -1, and the value of overlapping area is 0.5.

$$S_{ij} = \begin{cases} 
E_{xy} \cdot A_{ij} \cdot p & i + 1 = 0, \ j + 1 = 0 \\
E_{xy} \cdot A_{ij} \cdot \omega & i + 1 \neq 0, \ j + 1 \neq 0
\end{cases}$$

2.4. Algorithm Steps

Step 1: Initialize the space environment, given the length and width of the simulation area, generate non-motor vehicles and motor vehicles.

Step 2: Assign values to the Spaces in the environment as described above.

Step 3: According to the field category and position attraction parameters, calculate and get the profit value of non-motor vehicles and pedestrians. Non-motor vehicles and pedestrians select the grid they want to move at the next moment according to the profit value.

Step 4: Judge whether non-motor vehicles and pedestrians have reached the stop line on the other side. If they have already crossed the stop line, the number of non-motor vehicles or pedestrians $n=n-1$. 

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Step 5: Determine whether there are any non-motor vehicles or pedestrians in the intersection area. If there are still non-motor vehicles or pedestrians, return to Step 3. Otherwise, complete the simulation.

3. Model Simulation

3.1. Scene and traffic characteristics
The crosswalk and non-motor vehicle lane areas at intersections are spatially pulled out, including the extension areas on the left and right sides. The motor vehicles outside the stop line on the right side are regarded as fixed obstacles, and the boundary area between non-motor vehicles and motor vehicle lane on the left side is regarded as the boundary. The traffic window during the green light period is pulled out from the signal cycle. Pedestrians and non-motor vehicles wait at the stop line during the red light period and start to cross the street after the green light turns on.

![Fig. 2 Lane division and non-motor vehicles and pedestrians are in a holding state](image)

The traveling space is divided into uniform squares, the size of each grid is 0.4m×0.4m, and the whole model space is a grid of LXW, the length L is 16m, and the width W is 5.6m. As shown in the figure above, the driving direction is from left to right. Different colors distinguish different areas. The blue area is the extended area, which means that pedestrians and non-motor vehicles take up part of the space on both sides due to the demand of lateral space. The left side of non-motor vehicles can reach lane 1 as far as the right side of pedestrians can reach lane 14. The yellow part is the non-motor vehicle driving area, that is, the lane corresponding to the number 2-6 in the two-dimensional grid; the green part is the crosswalk area, namely the lane corresponding to the number 7-13 in the two-dimensional grid. The model in this paper includes the mutual interference between non-motor vehicles and pedestrians: ① Non-motor vehicles can occupy the pedestrian area. Considering the actual situation, it can occupy up to two sub-lanes, that is, the width space required for a non-motor vehicle to drive, corresponding to the two sub-lanes 7 and 8 in the figure. ② Pedestrians can occupy the non-motorized lane area, which is also the transverse space of a pedestrian, corresponding to sub-lane 6 in the figure. Under the interference rule, the sub-lanes of 6, 7 and 8 are mixed lanes.

3.2. Model running results
The figure shows the distribution of non-motor vehicles and pedestrians with asynchronous length. It can be found that the process of non-motor vehicles and pedestrians crossing the intersection can be roughly divided into four stages.

Phase 1: The waiting phase. At this time, non-motor vehicles and pedestrians are waiting outside the road test stop line.

Stage 2: Straight forward. At this stage, non-motor vehicles and pedestrians cross the stop line and start to move forward to the opposite direction. There is no obstruction in the front area either in the same direction or in the opposite direction of traffic individuals. Non-motor vehicles and pedestrians almost keep moving forward in a straight line.

Stage 3: The avoidance stage. The stage on both sides of the pedestrian encounters in the forward process, due to different direction and speed difference and space constraints, the other pedestrians around pedestrians will take the initiative to give way, at the same time, some pedestrians cross the pedestrian area, use the space of the non-motor vehicle lanes, non-motor vehicles will exceed the original lane area, use pedestrian space, Namely, non-motor vehicles and pedestrians interweave and interfere with each other in this area.
Stage 4: Final Pass Stage. In this stage, pedestrians on both sides have completed the process of avoiding the opposite direction and moving forward, and have also completed the interweaving interference process with non-motor vehicles. The non-motor vehicle has left the intersection due to its faster speed, while the pedestrian is still in the crosswalk at the intersection due to its slower speed. At this time, the pedestrian will move forward steadily until all the pedestrians leave the crosswalk and complete the crossing of the intersection.

Fig. 3 Simulation results under different time steps

4. Conclusion
In the intersection area, considering the factors of pedestrian pairing behavior, the traveling space is divided based on the field discrimination condition, the traveling behavior of pedestrians is depicted, and the moving decision rules of non-motor vehicles and pedestrians are formulated, so as to realize the mutual avoidance and sharing of traveling space between pedestrians and non-motor vehicles. It reproduces various phenomena that pedestrians and non-motor vehicles may show in the process of advancing in the intersection area.

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