

The Research on the Interaction between Mopeds and Bicycles Using Cellular Automata Method

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Abstract: In this paper, dynamic behaviors of mopeds and bicycles are described using cellular automata method. Traffic flow model under the interaction between mopeds and bicycles is established, and its rationality is proved by the measured data. Experimental and numerical results reveal that interference endured by mopeds is mainly determined by the density rate of the two kinds of traffic flows. Bicycle flows have inhibiting effect on low-density moped flows. *Copyright © 2013 IFSA.*

Keywords: Mopeds, Bicycles, Cellular automata, Density rate.

1. Introduction

In developing countries, mixed traffic flow of motorized vehicles and non-motorized vehicles or multiple vehicles with great disparity in performance is a common phenomenon in road traffics, which is significantly different from that of the developed countries with car-dominated traffic condition. In a sense, car traffic flow is a special case of mixed traffic flow. Overtaking traffic flow exists under mixed traffic flow conditions. Research on mixed traffic flow has attracted widespread attention at home and abroad.

Bicycle is one of the major trip means for Chinese people. Existing bike-related researches have proposed a number of microscopic models, but it is still difficult to express the characteristics of lateral swings [1]. Therefore, bicycle traffic flows are generally simulated by the application of motorized vehicle models (such as the related models of PTV VISSIM software) through adjusting the parameters. A variety of corresponding traffic flow models have been proposed, such as hydrodynamic model, kinetic

model, car following model, cellular automata model and so on. Among these models, cellular automata (CA) model can effectively describe the microscopic motion state and the interaction mechanism between vehicles; therefore, it has been widely used and developed in traffic flow study. For mixed traffic, the number of ongoing research works is limited. Literature [2] proposed a 1D CA model for mixed traffic flow to study the characteristics of multi-speed hybrid traffic flows, revealing that the flow and speed of single lane are determined by vehicles with lower speed.

The moped is actually a transport tool that is ranged between bicycle and motorized vehicle. Compared to bicycles, the particularities of mopeds lie in higher speed and weight. The mixed traffic flow of bicycles and mopeds has significant differences to traditional non-motorized transport flows in both individual and group characteristics.

At present, researches on mixed traffic flow of motorized vehicles with different natures using cellular automata model have achieved fruitful results [3]. As for researches on mixed traffic flows of

bicycles and mopeds, the number is limited; besides, these works are only extensions based on existing hybrid traffic flow models. Namely bicycles in these works are treated as motorized vehicles with small dimension and speed. In the existing models, non-motorized vehicles and motorized vehicles occupy the same length, and the interaction between vehicles is in the form of “block interference”, i.e., the following vehicle must decelerate due to the obstruction of the front vehicle. This is suitable for dealing with mixed flow on narrow roads, but it cannot fully reflect the mixed traffic flow of non-motorized vehicles on actual roads under general state [4]. Empirical analysis shows that: in addition to block interference, the influence of bicycles on moped traffic flow is also expressed as “friction interference” due to the lateral swings of bicycles and mopeds in running process [5]. For the modeling of mixed traffic flows of bicycles and mopeds, it is difficult to describe using a unified model due to the essentially different behaviors of the two traffic flows [6].

In this paper, a cellular automaton model is proposed to examine mixed traffic flow of bicycles and mopeds. Using this model, the “block interference” and “friction interference” of bicycles on moped flow are discussed. And, the results of the simulation are compared to that of the experiments.

2. Cellular Automata Model and Evolution Rules

2.1. Cellular Automata Models

2.1.1. Cellular Automata Model for Mopeds

NS model is one of the most classic one-dimensional cellular automaton models with simple rules, which is able to reflect the basic natures of the traffic flow [7, 8]. The lane of this model is composed by a total of L (set $L=7000$ in this work) cells, and the length of each cell is 1 m, i.e. the actual length of the lane in the model is 7 km. In the initial moment, vehicles are equally spaced on the lane. The length of each vehicle is L_{car} ; vehicle speed on the bend is V_{safe} ; the maximum velocity for the vehicles $V_{max}=35$ cells/s=126 km/h. The bend is set at the intermediate position of the lane, the vehicle deceleration is b , the friction coefficient of the lane is μ , the gravity acceleration is g . Periodic boundary condition is adopted in this model, that is, when a vehicle running out of the L^{th} cell, it will enter the system again from the first cell.

Before the enactment of the model operating rules, the following assumptions are made in this article:

1) The external environment is good, without interference of pedestrians or horizontal traffic, and the effect of weather and other factors is ignored;

2) On the straight-line section, the vehicles are running at the desired speed as possible, and vehicle speed will not increase after the maximum speed is reached;

3) Vehicle speed is decelerated on the transition section before entering the bend;

4) There has significant difference in vehicle performance is considered in this work.

2.1.2. Cellular Automata Model for Bicycles

With characteristics of small dimension, slow velocity and large lateral swing, overtaking behavior of bicycles is very flexible and free, which is not suitable for being described using some fixed rules. Besides, there are no obvious lane signs for bike lane at actual roads. If the modeling of bicycle flows adopts methods similar to multi-lane motorized traffic flows, it is necessary to develop very complex overtaking rules. Therefore, Multi-value CA model with randomization can be used for simulation non bicycle traffic flow.

2.2. Evolution Rules

2.2.1. Evolution Rules for Mopeds

Considering the characteristics of driving behavior on the bend, the effect of road bend conditions (curve radius r , curve arc length s , and road surface friction coefficient μ) and vehicle types on the vehicle speed and latency probability is summarized based on the classic NaSch model. The evolution rules of normal sections, transition sections and bend sections are detailed as below.

1) Evolution rules of normal sections.

Step1: acceleration $Vn(t) = \min(Vn(t)+1, V_{max})$

Step2: deceleration $Vn(t) = \min(Vn(t), gap_n(t))$

Step3: randomization deceleration with probability $P10$ $Vn(t) = \max(Vn(t)-1, 0)$

Step4: location update $Xn(t) = Xn(t) + Vn(t)$

2) Evolution rules of transition sections.

Step1: (acceleration) if $Vn(t) < V_{expect}$, then vehicle will be accelerated with probability $P2$ $Vn(t) = Vn(t) + D1$

Step2: (deceleration) if $Vn(t) > V_{expect}$, then vehicle will be decelerated with probability $P3$ $Vn(t) = Vn(t) - D2$.

Here $V_{expect} = (Vn^2 - V_{safe}^2) / 2b$ is the desired running speed on the transition section, which is considered as reference to reduce the sharp shift of vehicle speed. When the vehicle speed is smaller than V_{expect} , the vehicle will be accelerated (the acceleration is $D1$) with probability $P2$; when the

vehicle speed is larger than V_{expect} , the vehicle will be decelerated (the acceleration is $D2$) with probability $P3$.

Step3: (safe deceleration)
 $Vn(t) = \min(Vn(t), gap_n(t))$

Step4: deceleration with probability $P11$;
 $Vn(t) = \max(Vn(t) - 1, 0)$

Step5: location update $Xn(t) = Xn(t) + Vn(t)$

3) Evolution rules of bend sections.

Step1: (acceleration) if $Vn(t) < V_{safe}$, then vehicle will be accelerated with probability $P4$ $Vn(t) = \min(Vn(t) + 1, V_{safe})$. Here means that the vehicle will be accelerated with probability $P4$ when the vehicle speed is less than the safe speed.

Step2: (forced deceleration) if $Vn(t) > V_{safe}$, then the vehicle must be decelerated $Vn(t) = V_{safe}$. When the vehicle entering the bend with speed larger than the safety speed, the vehicle speed must be decelerated to the safe speed to ensure driving safety; otherwise the vehicle may be skidded off the lane because of the excessive centrifugal force.

Step3: (safe deceleration)
 $Vn(t) = \min(Vn(t), gap_n(t))$

Step4: randomization deceleration with probability $P12$; $Vn(t) = \max(Vn(t) - 1, 0)$

Step5: location update $Xn(t) = Xn(t) + Vn(t)$

Here $Vn(t)$ is the speed of vehicle n at time t ; $Xn(t)$ is the location of vehicle n at time t ; $gap_n(t) = Xn(t+1) - Xn(t) - L_{car}$ is the distance between vehicle n and the front vehicle at time t ; V_{safe} is the safety speed (also the maximum speed) on the bend; $P10$, $P11$ and $P12$ are the randomization deceleration probability for normal sections, transition sections and bend sections respectively; $P2$ is the deceleration probability when the vehicle speed larger than the desired speed on the transition section; $P3$ is the acceleration probability when the vehicle speed less than the desired speed on the transition section; $P4$ is the acceleration probability when the vehicle speed less than the maximum speed on the bend section.

2.2.2. Evolution Rules for Bicycles

In the modeling of bicycle traffic flows, randomization rules are introduced into EBCA (Equivalent Bit Conversion Algorithm), where the update process of the vehicles can be expressed as:

a. If the cell in front is empty, the vehicle will occupy this cell;

b. If the cell in front of the vehicle in step a is empty, the vehicle will move forward again.

Evolution equation can be expressed as:

$$U_j(t+1) = U_j(t) + b_{j-1}(t) - b_j(t) + c_{j-2}(t) - c_{j-1}(t), \quad (1)$$

where $U_j(t)$ indicates the number of vehicles in cell j at time t ; $b_j(t) = \min(U_j(t), M - U_{j+1}(t))$ indicates the number of vehicles moving according to step a in cell j at time t ; $c_j(t) = \min(b_j(t), M - U_{j+2}(t) - b_{j+1}(t) + b_{j+2}(t))$ indicates the number of vehicles moving according to step b.

Thus, the EBCA rule can be summarized as:

1. For each cell, calculate and
 $b_j(t) = \min(U_j(t), M - U_{j+1}(t))$
 $c_j(t) = \min(b_j(t), M - U_{j+2}(t) - b_{j+1}(t) + b_{j+2}(t))$;
2. Deceleration with randomization probability P , $c_j(t) = \max(c_j(t) - 1, 0)$;
3. Update $U_j(t)$ according to formula (1).

In this article, bicycle traffic flow is simulated using EBCA model; moped traffic flow is simulated using NS model and EBCA model; and the combination of the two is the mixed bicycle and moped flow in actual road traffic.

2.2.3. Evolution Rules for Mixed Bicycle and Moped Flow

In the simulation of hybrid bicycle and moped flow, a bicycle occupies one unit space, and a moped occupies two unit space. The traffic flow consists of the following three types (?) of vehicles: bicycles with the maximum speed of 1; moped with the maximum speed of 1. The capacity of each cell is M unit spaces; A unit road length contains L cells; the total number of bicycles in this system is N_1 , containing N_1^s slow bicycles, N_1^t rapid bicycles; the total number of mopeds in this system is N_2 . Then the occupancy rate o of the cellular space can be expressed as

$$o = \frac{N_1 + 2N_2}{LM} \quad (2)$$

The proportion r of mopeds is defined as:

$$r = \frac{2N_2}{N_1 + 2N_2} \quad (3)$$

From formulas (2) and (3), we get:

$$N_1 = OLM(1-r) \quad (4)$$

$$N_2 = OLMr / 2 \quad (5)$$

Flux generated from cell j is:

$$q_j = b_{j-1,1}(t) + c_{j-2,1}(t) + 2b_{j-1,2}(t) \quad (6)$$

Because a moped occupies 2 unit spaces, the statistical moped traffic flow Q should be multiplied by 2:

$$Q = \frac{1}{LM} \sum_{j=1}^t q_j \quad (7)$$

The average velocity of the bicycles is:

$$\bar{v}_1 = \frac{\sum (b_{j,1}(t) + c_{j,1}(t))}{N_1} \quad (8)$$

The average velocity of the mopeds is:

$$\bar{v}_2 = \frac{\sum b_{j,2}(t)}{N_2} \quad (9)$$

The average velocity of the system is:

$$\bar{v} = \bar{v}_1 + (\bar{v}_2 - \bar{v}_1)r \quad (10)$$

Therefore, the flux of the system can be expressed as:

$$Q = \frac{1}{LM} (N_1 \bar{v}_1 + 2N_2 \bar{v}_2) \quad (11)$$

3. Simulation Results and Experimental Analysis

3.1. Experimental Arrangement and Selection of Data Points

Traffic flow is videoed using cameras fixed on dominant positions of the road. In this way, the whole process is unfolded in the form of pictures, giving investigators intuitive judgments. To ensure the representativeness of the sample data, the videos were taken in sunny days to eliminate the effect of severe weather on traffic behavior and traffic psychology of bicycle riders. Data acquisition time takes the morning rush hours of the observation sites, when the traffic flow is density, and continuous flow non-saturated non-motorized and saturated non-motorized traffic flows can be observed. Before the

actual filming, some markers on the sites should be selected and measured for data analysis.

Typical road sections in Shanghai were selected for data collection. Wu Ning Road is an important transport corridor for Shanghai city, which is located in the core area of this city. The width of non-maneuverable lane is 3.5 m, as shown in Fig. 1. The data of this work was collected from 7:00 to 8:30 on 2013.3.14, and the shooting location was the footbridge. Each site is videoed twice; the length of each video is 1.5 h. Extract the data of speed, density and flow every 5 s; extract overtaking number and eigenvalues every 30 s; and a total of 1000 valid samples were collected. Non-motorized vehicles are not affected by vehicles and pedestrians. In addition, non-motorized traffic flows are not affected by intersections.



Fig. 1. Data acquisition location.

Since the interaction between bicycles and mopeds is the focus of this work, the following rules must be complied in the process of data screening: a) mopeds and bicycles must be mixed travelling on the same road space, otherwise deleted; b) distance headway in front of the mopeds must be large enough, otherwise deleted.

The unbiasedness of samples is ensured by the means of random sampling, and the size of the samples selected is depended on accuracy requirements. Considering the requirement of the average speed, the minimum sample size n can be determined according to the following formula:

$$n = \left[\frac{t\sigma}{E} \right]^2$$

Road sections in this work are urban roads. When confidence level is 95 %, E is 2 km/h, $t = 1.96$ and $\sigma = 8.0 \text{ km/h}$, the minimum sample size is 60. Statistics methods are as follows:

1) Acquisition methods for traffic flow.

Select a transect, and count the number of bicycles n_1 and mopeds n_2 that get across the transect during a certain time interval (in this work, the length of an interval is 5 seconds). Then the flow is:

$$Q = \frac{n_1 + n_2}{5 \times W_0}, \quad (12)$$

where Q is the flow of non-motorized vehicles; n_1 is the number of bicycles getting across the transect during a certain time interval; n_2 is the number of mopeds getting across the transect during a certain time interval; W_0 is the effective width of the lane.

2) Acquisition methods for vehicle speed.

Set the number of frames for a vehicle traveling $L = 10$ m is n , and a frame takes $1/25$ seconds, then the speed of the vehicle can be determined as follows:

$$V_s = \frac{L \times 25}{n}, \quad (13)$$

where V_s is the speed of the vehicle, m/s; L is the length of the observation interval (10m); n is the number of frames for a vehicle traveling 10 m.

3) Acquisition methods for density.

Count the number of bicycles and mopeds in the observation interval every 5 seconds. Taking into account the variation of vehicle density in the interval, in this study the average of the vehicle numbers k_i at three moments was adopted, and the vehicle density is the number of vehicles per square meter:

$$k = \frac{\sum_{i=1}^3 k_i}{3} \times \frac{1}{LW_0}, \quad (14)$$

where k is the density of non-motorized traffic flow; k_i is the number of vehicles in the i th image; L is the length of the observation interval (30 m); W_0 is the effective width of the lane.

4) Acquisition methods for overtaking.

Record the number of overtaking per 30s.

3.2. Analysis on the Speed and Traffic Flow of Mixed Traffic System

The mixed traffic flow model mentioned above is simulated numerically, to examine the dependence of speed and flow on different vehicle densities. The cellular automata model is simulated using Matlab.

Fig. 2 shows that mopeds can overtake freely, namely there are free moving phase and approximate free moving phase. With the increase of moped density, overtaking is inhibited, namely mopeds enter congestion phase; and that, following bicycles are in the state of stop-and-go, indicating the system enters the mixed traffic congestion phase. With the increase of bicycle density, the speed of mopeds will be reduced. When bicycle density reaches a certain level, the free moving phase of mopeds will be degenerated into mixed traffic congestion phase, i.e. the increase of bicycles will destroy the free traveling of mopeds. In Fig. 2 the solid lines are simulation results; the dots are the results of experimental observation. It can infer that the model adopted in this work can describe the actual situation of mixed traffic flows correctly.

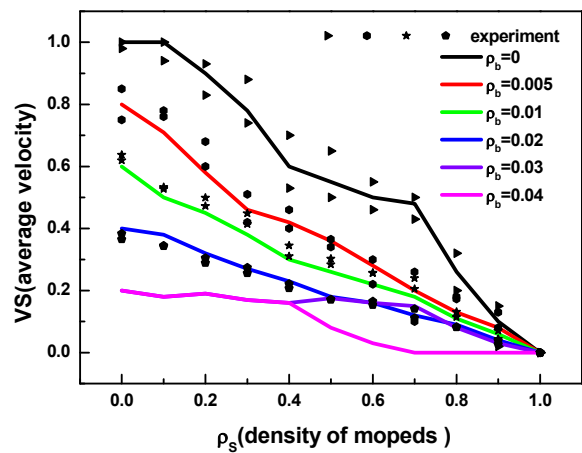


Fig. 2. Scaling of average velocity with density of mopeds under different density of bicycle.

Fig. 3 shows the scaling law of average velocity of mopeds on density of bicycle for different density of mopeds.

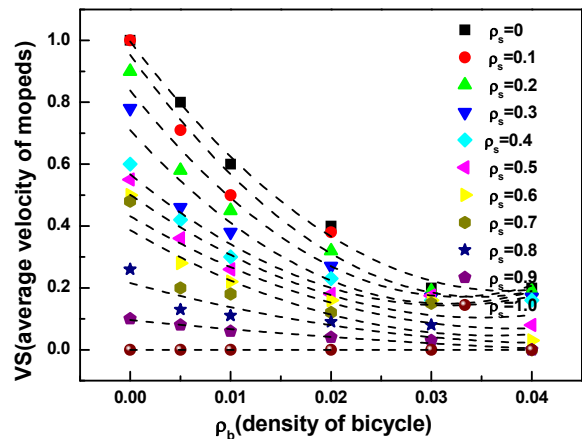


Fig. 3. The dependence of average velocity of mopeds on density of bicycle.

Here the dot with different shapes represents different density of mopeds, and the black dash lines indicate the fitting line about the scaling law. It can be found that the average velocity of mopeds decrease with the density of mopeds. The important thing that the average velocity of mopeds, which is averaged over all different simulation points, all decrease square with the density of bicycle for all the density of mopeds. Therefore, the interactions between mopeds and bicycles have some nonlinearity in the same lane. When the density of bicycles reached to the maximum, the velocities of mopeds are nonzero except for the density of mopeds get to the saturation value. This is due to the bike with small dimension, and the lanes always have some space to left for the mopeds even if the density of bicycles reached to the maximum.

Fig. 4 shows the dependence of average flux on density of mopeds for different density of bicycles. Here the dot represents the result of experiment, and all kinds of color lines indicate the simulation results. The shapes of dot mean different density of bicycles.

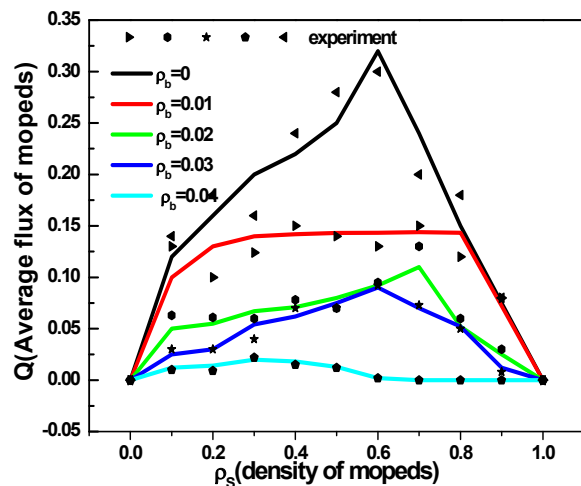


Fig. 4. Scaling of average flux with density of mopeds under different density of bicycle.

It can be seen that when the bicycle density is smaller, the mopeds are free driving. With the density of mopeds increasing, the flow is increased at first and then decreased. When the density is appropriate, mopeds can travel freely; inhibitions between mopeds reduce the traffic flow after the density reaching a certain value. For large bicycle density, the dependence of moped flow on moped density still follows the above rules. Thus, the increase of bicycles has inhibition effect on mopeds.

Fig. 5 shows the scaling law of average flux of mopeds on density of bicycle for different density of mopeds. Here the dot with different shapes represents different density of mopeds, and the black dash lines indicate the fitting line about the scaling law.

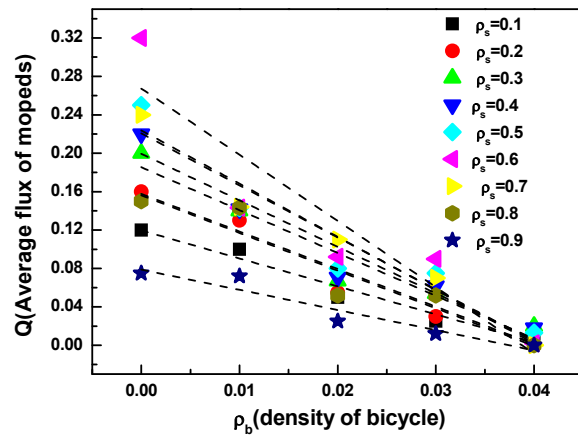


Fig. 5. The dependence of average flux of mopeds on density of bicycle.

It can be seen that, the average flux of mopeds, which is averaged over all different simulation points, all decrease approximately linearly with the density of bicycle for all the density of mopeds. Meanwhile, this trend is becoming weakened with the increasing density of mopeds, which means the slope of the line decreases with the decreasing density of mopeds. Therefore, when the density of mopeds is much greater, the influence of bicycles on mopeds can be neglected. The comparison between the results of simulation, the simulation model predictions are well consistence with the experiment results. Thus a unified description of the mixing traffic flow between bicycles and mopeds is achieved.

4. Conclusions

This paper established traffic flow model under the interaction between mopeds and bicycles based on cellular automata method. Using cellular automata method, the dynamic behaviors of mopeds and bicycles are described, and the mixed line traffic flow model is presented. In addition, its rationality is proved by the measured data. Experimental and numerical results reveal that interference endured by mopeds is mainly determined by the density rate of the two kinds of traffic flows; bicycle flows have effect on low-density moped flows by inhibiting flux and speed of the mopeds. Meanwhile, the average velocity and flows of mopeds are proportional to the square and linear to the density of bicycle flows respectively.

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