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Mixed Traffic Flow Simulation at Urban Intersections and Its Application

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Abstract: After a detailed analysis of the characteristics of mixed traffic flow, the methods of Cellular Automata theory and rule description are used to build the pedestrian model, motor vehicle model and non-motor vehicle model. And then, the avoidance strategy is provided for motor vehicle as well as non-motor vehicle to avoid pedestrian. Finally, the simulation experiment prototype system of the mixed traffic flow is achieved by the means of system integration. The simulation results show that the system can better describe the complexity and uncertainty of the mixed traffic flow which provides decision-making basis for improving traffic flow at the intersections.

Key words: Mixed traffic flow, microcosmic model, conflict avoidance model, system simulation

INTRODUCTION

At present, traffic congestion in China's big cities is increasingly serious. Traffic chaos and traffic jam at intersections have been severe urban problems. Researchers of the western developed countries have made considerable progress in the field of traffic simulation since 1980s. They developed a large number of traffic simulation models and software, some of which have been commercialized and possess practical applications successfully.

However, the Western traffic simulation software is difficult to be applied directly in China for the reason that the traffic systems in most cities of China have a distinct characteristic of mixed traffic which is obviously different from the Western developed countries. Figure 1 is the photo of an intersection with typical mixed traffic. This kind of mixed traffic scene is very common in most Chinese cities. Therefore, it is one of the key technologies of promoting the development of intelligent traffic system to study the characteristics of mixed traffic adequately and establish a set of applicable traffic flow models (Blue and Adler, 2001; Wu and Wu, 2010).

Fig. 1: Mixed traffic flow at urban intersection

For the system simulation of mixed traffic flow, three kinds of objects: motor vehicle, non-motor vehicle and pedestrian need to be considered. In mixed traffic model, motor vehicle has relatively mature model already, but due to the complexity and uncertainty of the pedestrian's behavior, there is no mature pedestrian model at present. In this study, the pedestrian model is established by the use of Cellular Automata (CA). Besides, the pedestrian and motor vehicle avoidance strategies are given on theoretical level based on the Cellular Automata theory. Finally, a set of mixed traffic flow simulation system is developed by the means of system integration and a decision scheme to improve the traffic capacity is given on this basis.

PEDESTRIAN MODEL BASED ON CA

Basic principles of CA: Cellular Automata (CA) is used to describe real systems that can be represented as a cell space. A cellular automaton is an infinite regular n-dimensional lattice whose cells can take one finite

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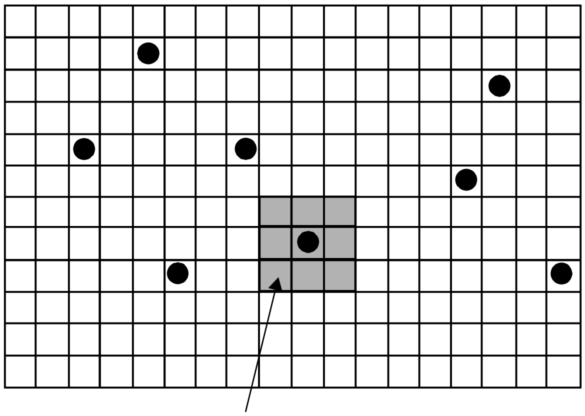

Fig. 2: Sketch of a cellular automation

value. The states in the lattice are updated according to a local rule in a simultaneous and synchronous way (Hossain and McDonald, 1998). The cell states change in discrete time steps as dictated by a local transition function using the present cell state and a finite set of nearby cells (called the neighborhood of the cell). The sketch of CA is shown in Fig. 2.

The CA possesses the characteristic of homogeneous, discreteness, synchronization, certainty and so on. Homogeneous means the distribution way of cellular is the same and follows the same rules; Synchronization means that all the cellular update synchronously in the discrete time space; certainty means that all the update rules are deterministic in space and time and are the same (Yang *et al*., 2002). In the CA, sometime the state of a cellular has relation only with its state of previous time and the state of the adjacent cellular of previous time.

The study objects such as vehicle and pedestrian in traffic problems are not continuous and the pedestrian movement has great randomness and uncertainty, so it is an innovation of traffic research method to use non-linear discrete model to describe the traffic phenomenon. The basic idea of simulation is the road grid. Each grid is regarded as the small cells with independent thinking and several small cells correspond to one or several pedestrians. Then the pedestrian movement on the pavement is seen as the evolution of grid field. The cells can determine the motion state of the next step by observing the change of the surrounding environment just as the pedestrians. All the traffic rules that pedestrian should comply with are presented as cells' evolution rules, thus the variation rules of pedestrian traffic flow are changed into the evolution rules of the cells to be studied. This is very different from the previous traffic simulation ideas. It doesn't have to find out the function form of the equation of motion, but to describe the movement with a variety of discrete rules directly.

Analysis of pedestrian traffic characteristics: Relative to the motor vehicle flow, study of the pedestrian traffic flow model is more challenging. In many ways, the pedestrian movement is more complex and random, mainly because the pedestrian is more intelligent and flexible than vehicle in speed variation and steering so that they can choose reasonable speed and direction according to the surrounding environment.

In this study, we use girds of 0.5×0.5 m^2 size to represent pedestrians. The speed of the pedestrians is 1.3 m sec^{-1}, the ideal distance is 2.0 m, the view of the pedestrians is twice as the speed and the pedestrians move on a transparent grid road. When the flow of people crossing the street is less than or equal 1,000 h^{-1}, the distribution can be generally considered as Poisson distribution (such as type 2.1 below) while more than 1000 h^{-1}, it generally obeys the negative binomial distribution (such as type 2 below):

$$p_k = \frac{(\lambda t)^k}{k} e^{-\lambda t} \tag{1}$$

$$p_k = c_n^k \left(\frac{\lambda t}{n}\right)^{n-k} \left(1-\frac{\lambda t}{n}\right)^k \quad (k = 0, 1, 2n) \tag{2}$$

In the above equations, p_k represents the probability that k pedestrians arrive in time interval t, λ denotes the average arrival rate of pedestrians, t denotes the length of a time interval and n is a positive integer (Wu and Wu, 2010).

Pedestrian avoidance model: First, investigate the situation that pedestrian passes through the traffic across the crosswalk. Due to the general pedestrian signal lights or traffic lights placed at the crosswalks, pedestrian encounters fewer vehicles when crossing the road. In addition, pedestrian has a priority at crosswalks, so the horizon of pedestrian is very small. At the same time, because of the pedestrian crowd effect, the pedestrian will consciously view whether there are pedestrian groups exist and join them if any. In the place without crosswalks, the risk of pedestrian crossing the road will increase (Qian *et al*., 2008; Jia *et al*., 2009; Tian *et al*., 2010). Thus, the walking strategy and vision of pedestrian will be significantly changed. According to the previous pedestrian model, the pedestrian will choose to cross a road section (that is, all the identical lane) successively every time when crossing the road. Then he will cross the road if he judge there is sufficient clearance between the vehicles. And the clearance should be $s \geq 13.5+v \times t$ under normal circumstance. Therefore, the width of pedestrian's vision must be larger than $13.5+v_{av} \times t$ (v_{av} is the average speed of vehicle).

MOTOR VEHICLE AVOIDANCE MODEL

Motor vehicle generally travels along the lane strictly in a given direction. A lane can accommodate only one car and does not allow two or even more vehicles to travel side by side. As for the overtaking behavior, the vehicle can be transferred from the current lane to an adjacent lane and then from the adjacent lane reversed, experiencing two lane changing process (Yang *et al*., 2011; Li *et al*., 2009). Thus, the driving operation of the motor vehicle in a particular lane can be regarded as one-dimensional that is, the velocity and displacement of the motor vehicle can be represented by only one algebraic parameter. This is the characteristic of motor vehicle driving. For the micro-modeling of motor vehicle, it is possible to adopt the typical car-following model due to the above characteristic that is, what the vehicle needs to consider is only the impact of the front vehicle on this one. Then the acceleration of the vehicle next step is decided based on the current and maximum speed of the two vehicles as well as the distance between them. Therefrom, the improved vehicle-following model is obtained:

$$a_{0(t)} = \partial \times \left(\left(1 - \frac{v_{0(t-T)}}{v_{0free}}\right) - \left(\frac{d_{desire(t-T)}}{d_{01(t-T)}}\right)^m \left(1 - \frac{v_{1(t-T)}}{v_{0free}}\right) \right) = \partial \times \left(f_{(t-T)} - g_{(t-T)}\right) \quad (3)$$

V_0 is current speed; V_1 is the speed of front vehicle; V_{free} is free speed; d_{01} is current vehicle gap; d_{desire} is expectative vehicle gap; m is index parameter:

$$\partial = \frac{c'}{d_{01(t-T)}}$$

is sensitive coefficient after correction; c' is sensitive coefficient in classic vehicle-following model, relating to the front vehicle quality. Motor vehicle avoidance strategy is shown as Fig. 3 (Wu and Wu, 2010).

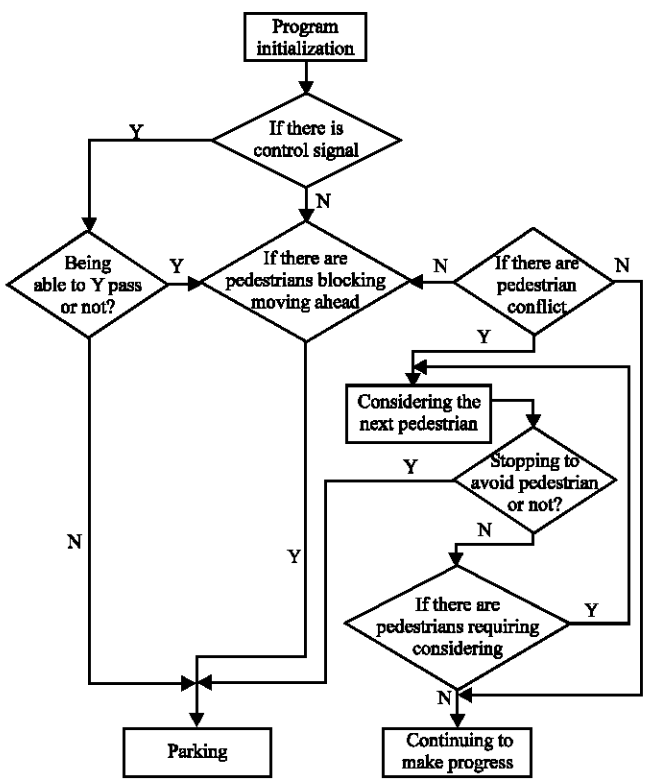

Fig. 3: Vehicle avoiding model

NON-MOTOR VEHICLE MODEL

The driving pattern of non-motor vehicle in the lane is different from motor vehicle. First, there are lots of non-motor vehicles driving side by side. Then, non-motor vehicle oblique shift and pull over frequently. Finally, the lateral movement of non-motor vehicle leads to some impact of the lane edge on non-motor vehicle. In this case, the biggest difference between non-motor vehicle and motor vehicle is that the movement of non-motor vehicle must be viewed as two-dimensional motion (Wu and Su, 2009; Wang, 2003). The speed and displacement need to be represented by two algebras. Wang (2003) proposed a vector field model:

$$a_{0(t)} = \frac{c'}{d_{0c}} \times \left(f_{(t-T)} - \sum_{i=1}^{N} k_i \times g_{i(t-T)}' - \sum_{i=N+1}^{N+2} g_{i(t-T)}' \right) = \partial \times \left(f_{(t-T)} - g_{(t-T)}' \right) \tag{4}$$

Under the function of many factors such as the surrounding vehicles and roads, non-motor vehicle move in the direction of minimum hindrance and maximum space. The vector field model can also be used as a unified microscopic model of the mixed traffic of motor vehicle and non-motor vehicle.

DESIGN AND EXPERIMENTAL ANALYSIS OF SIMULATION SYSTEM

Simulation system design: This study adopts the way of system integration to establish a mixed traffic flow simulation prototype system. The system is suitable for mixed traffic flow with Chinese characteristics, meets the real-time requirements and provides a simulation platform for a variety of new traffic elements of intelligent traffic (Tang *et al*., 2009). The whole system is divided into five sub-modules: the simulation environment module, mixed traffic element module, core simulation computing engine module, the running results display module and data storage module. The system framework is shown as Fig. 4:

- Simulation environment module is mainly responsible for creating the traffic network and controlling signal lights
- Mixed traffic element module is mainly responsible for generating traffic elements-motor vehicle, non-motor vehicle and pedestrian model
- Simulation computing module is mainly responsible for receiving the control parameters, operating the simulation calculation of system integration and outputting operation results

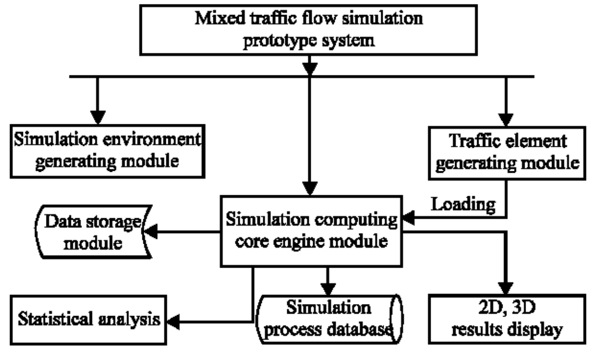

Fig. 4: Hybrid traffic simulation system

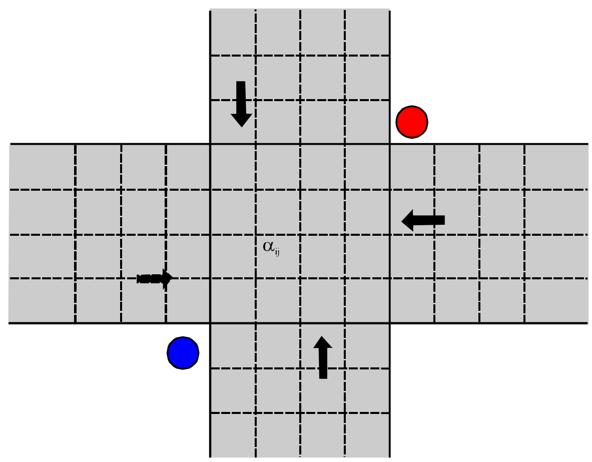

Fig. 5: Single intersection model

- Results display module is mainly responsible for two-dimensional or three-dimensional dynamic presentation of the simulation results and providing data basis for statistical analysis
- Data storage module is mainly responsible for the storage of simulation environment data and simulation process data

Simulation experimental analysis: The system development platform is Windows XP, using Microsoft visual programming language Visual C^{++} as the software development tool. In the realization of pedestrian CA model, the characteristics of traditional CA model that pedestrians move strictly in accordance with the grid is abandoned and the transparent grid on the crosswalk is refined to the smallest unit of measurement (0.1 M). Each pedestrian is seen as a cellular, occupying a small grid. Pedestrian can move freely under the guidance of the rules which not only reflects the pedestrian traffic rules, but also fully demonstrates the arbitrariness of pedestrian traffic at the same time. Single intersection model is shown as Fig. 5.

Figure 6 shows a simulation model of a single intersection. Among them, small rectangular squares represent motor vehicles; different colors represent different movement directions; small triangles represent pedestrian crowds and the pedestrian density can be set. Figure 6a is the simulation situation without pedestrian model while Fig. 6b is that with pedestrian model added.

Figure 7 shows the simulation scenarios of a complex combination intersection.

As can be seen from the simulation process in Fig. 6 and 7, pedestrian model based on CA can better simulate the traffic characteristics of pedestrian at intersections. The motor vehicle and non-motor vehicle avoidance for pedestrian better reflect the characteristics of the mixed traffic flow at intersections. After pedestrian traffic module is loaded in the simulation environment, the residence time of vehicles on the road and traffic intersection increases obviously; traffic flow at traffic

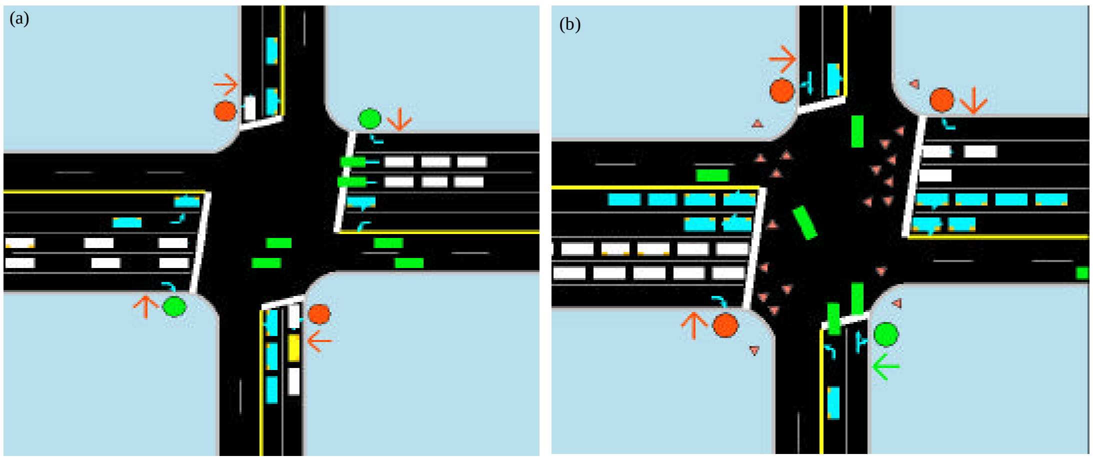

Fig. 6(a-b): Simulation scenarios of single intersection (a) Without pedestrian model and (b) With pedestrian model

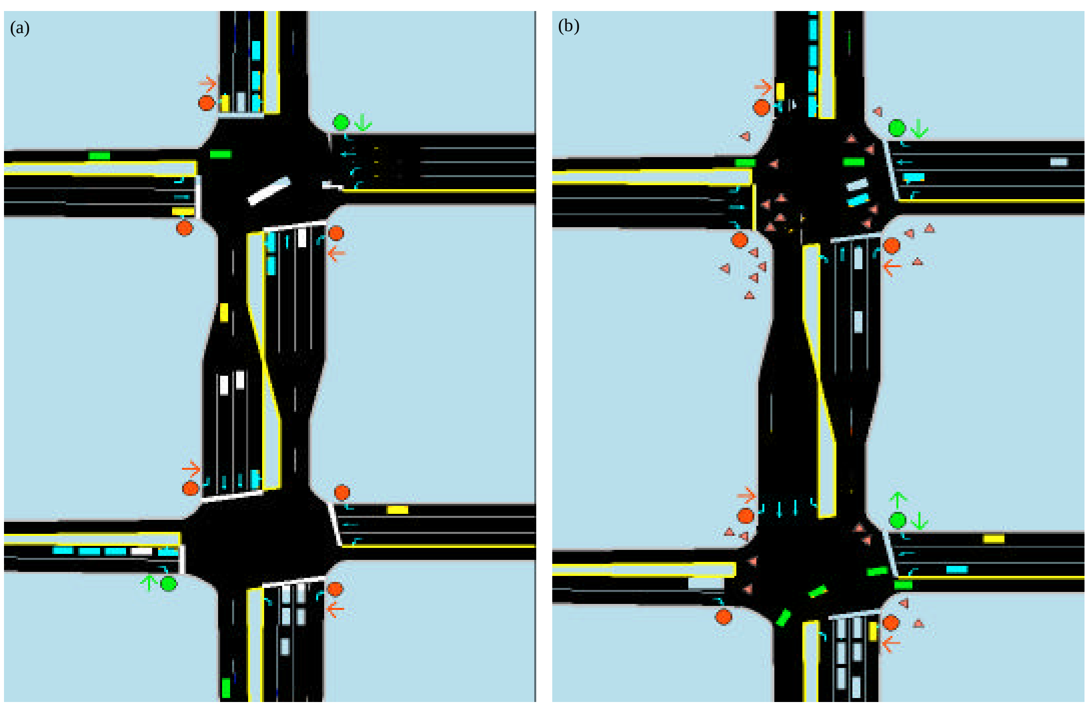

Fig. 7(a-b): Simulation scenarios of complex combination intersection (a) Without pedestrian model and (b) With pedestrian model

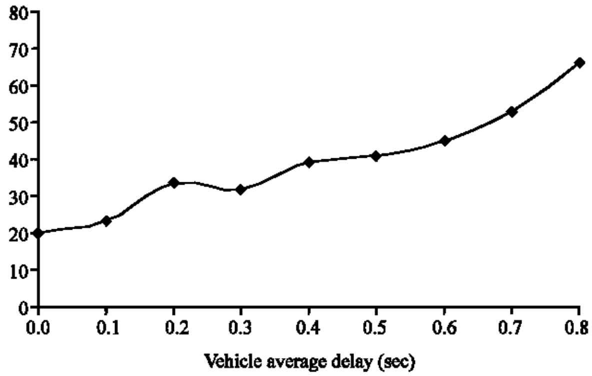

Fig. 8: Statistical relationships between pedestrian density and average vehicle waiting time

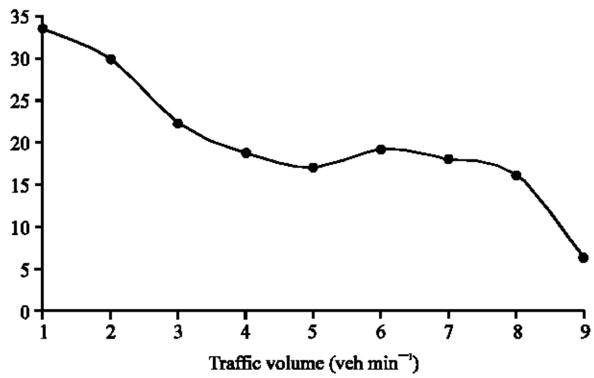

Fig. 9: Statistical relationships between pedestrian density and traffic volume

intersection correspondingly decreases. Figure 8 and 9 show the statistical relationship between the pedestrian density and traffic volume and the average vehicle waiting time at the traffic intersection.

CONCLUSION

This study adopts rule description and Cellular Automata theory to create the mixed traffic flow simulation model and give the motor vehicle as well as non-motor vehicle avoidance model for pedestrian. It analyzes the relationship between the pedestrian density and traffic volume and the average vehicle delay. Through the simulation, we can analyze current traffic situation at intersection clearly which provides decision-making basis for improving traffic capacity. This makes the result more generalized so as to enhance the practical guiding significance.

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