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Analysis of urban road intersection model based on cellular automaton

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Abstract: In the urban road network, urban road intersection is the main bottleneck of traffic capacity. It is very important to ensure the orderly operation of urban road intersection for the improvement of urban traffic. In this paper, it is started with urban road intersection. The relationship of vehicle speed, vehicle changing lanes, vehicle running red light, and pedestrian running red light is introduced into cellular automaton model, and established the cellular automaton model of urban road intersection. After traffic situation is highly simulated by cellular automaton model of urban road intersection, it is found that complex traffic rules make vehicles detained in the intersection, which deteriorates the traffic conditions of intersection; pedestrians and vehicles running red light will make the intersection disorder, and vehicles running red light influences more on the traffic situation of the intersection than pedestrians do.

Keywords: Cellular automaton, urban traffic, Intersection, Orderliness

1. Introduction

As an important part of urban road, urban road intersection plays an important role in urban road network as well as the key control points of all kinds of organization, management of road traffic. Whether urban roads are blocked or not, largely depends on the intersection of the traffic situation. Therefore, the

urban road intersections become a major research field for the experts and scholars home and abroad.

Cellular automaton model of urban road intersections originated from the BML model (Biham et al., 1992) raised by Biham, Middleton and Levine in 1992. In order to research and simulate the actual traffic conditions of the urban road intersection, domestic and foreign scholars made a variety of improvements and expansion on urban road intersection model. Foreign scholars such as Chowdhury (1999), Schadschneider (1999), Fukui (1996), Chung and Freund (1995) made a variety of improvements and expansion based on the BML model. For the domestic situation of mixed traffic flow in urban road intersection, domestic scholars established urban road intersection cellular automaton model mainly from single point of pedestrian, driver, traffic light (Neng & Li, 2009; Xiong & Huang, 2009).Throughout the urban road intersections cellular automaton model, it is found that cellular automaton model is a far cry from the traffic situation. These differences mainly are: (1) from simulation scope of view, the existing intersection model did not treat the city traffic as a network, just simulated an intersection; (2) from the simulation content of view, the existing model didn't simulate many objects of urban road intersection, but simulated individual elements.

It is found the disadvantages of the existing urban road cellular automaton model on the hardware and rules of traffic rules simply simulating traffic system. Traffic characteristics of people are rarely reflected in existing cellular automaton model, especially the different traffic characteristics of "social man". In order to simulate the reality of urban road intersections better, this paper, based on the study of domestic and foreign scholars, is committed to design and implementation of urban road intersection cellular automaton model and to describe and mirror the complicated traffic characteristics of intersection through simulating the whole intersection including transport infrastructure, traffic rules, and traffic principal. Simultaneously, it is reflected psychological qualities of pedestrians and drivers by setting the probability of pedestrian and vehicles running red light, and analyzed the influence degree that intersection is affected by pedestrians and vehicles.

2. Analysis on Model Objects of Urban Road Intersection

The structure of urban intersection system is complex (Chen & Zhang, 2009) and owns the feature of multilevel, dependence between subsystems, variables' dynamics of internal system, as well as the interaction and feedback relationship of traffic subjects which are difficult to describe. In this paper it is mainly analyzed the modelling object of urban intersection from the following three aspects: static characteristics, dynamic characteristics and social features of the intersection.

Analyze of intersection static characteristics. In order to simplify the simulation, it is chosen two-way six lanes which have the same width 3.5m not only ensuring the accuracy but enabling to simulate various types of traffic flow to the influence of the traffic in this paper. In the middle of lane, motor vehicle isolation belt is set to separate operational vehicles. The width of sidewalk is 3m, and it is more or less 1m away from the stop line. Traffic lights for vehicles not for pedestrians are set in this model. Pedestrians walk down in terms of the lights for vehicles.

Analyze of intersection dynamic characteristics. Traffic subjects in the intersection are so complicated, including motor vehicles and non-motor vehicles as well as pedestrians. So as to effectively simulate and simplify the model, motorcycle and bicycle are not taken into account, buses and cars are treated as the same kind of motor vehicle in this paper. The basic movements of vehicles are going straight, turning left and turning right, turning around, overtaking and changing lanes (Wu & Su, 2009).

Analyze of intersection social features. The social and economic characteristics as well as psychological factors of human are so complex that it is so difficult to consider this problem comprehensively and scientifically (Qi & He, 2010). In this model, acceleration and deceleration of motor vehicle, running a red light of drivers and pedestrians are the major expansion elements.

3. Cellular Automaton Model Designs of Urban Road Intersections

In this model, cellular attributes includes road type of cellular region, road direction, occupied state, holding time, movement direction of cell, motion state of cell, neighbor and traffic signal.

Cellular space: There are three kinds of cellular space. They are forthright cellular space, cellular space of intersection area and cellular space of non-road. Cellular Evolution Rule: The rule is tantamount to state transfer function of cellular automaton, that is to say, the change of cellular state is determined by the rule. In this paper we define that v_t is the speed of time t, v_{max} is the maximum speed of cellular, gap is the distance between current vehicle and front one, gap_{ahead} is the distance between current vehicle and the front vehicle of adjacent road, gap_{back} is the distance between current vehicle and back vehicle, gap_{safety} is the safe distance ($gap_{safety}=max(V_t+1,\ V_{max})$), p_{slow} is deceleration probability.

Speed rules. Acceleration, deceleration and speed transformation with the probability p are carried on because vehicles and pedestrians are affected by various social and psychological factors in society.

Acceleration rules: if $v_t \le v_{max}$, and then $v_{max} = min(v_{max},\ v_{t+1})$;

Deceleration rules: if $v_t \ge gap$, and then $v_{t+1} = gap$

Random rules: In the probability p, $v_{t+1} = max(v_{t+1}-1,0)$.

Location up dating rules, $x_{t+1} = x_t + v_{t+1}$,

Change lane rules. In a lane change, there are two basic rules to follow, one is overtaking rules, and the other is safety rules (Huang & Huang, 2003).

Overtaking rules: $gap < min(v_t+1,\ v_{max})$,

Safety rules: $gap_{back} > gap_{safty},\ gap_{ahead} > gap,\ Rand() < P_{slow}$.

Cellular Boundary: In order to reflect the reality of road traffic situation, open boundary can be used. In this paper, vehicles drive into and drive out of the system with certain probability. Vehicles with speed v_t ($v_{t+1} \in (0,\ v_{max})$) are

brought forth with probability p (every road not the same) on each road starting line.

Cellular Neighbors: Moore neighbors, namely, cellular of 8 directions, are used by this paper.

4. Realizations and Simulation of Cellular Automation Model of Urban Road Intersection

As is shown in Figure 4-1, Figure 4-2, Figure 4-3, Figure 4-4, Figure 4-5, Figure 4-6, the interface of simulation and the result of simulation can be acquired after urban road intersection cellular automaton model was operated in the version of MATLAB7.10.0. The operation and results will be mainly discussed as follows.

Simulate the Traffic Situation of Intersection. As is shown in Figure 4-1, intersections are represented by yellow area, blue area of dotted line stands for road boundary. So as to control exhibition, traffic lights in the center of the intersection instruct vehicles running on the horizontal direction in Figure 4-1. Besides, traffic isolation belts can be indicated by black dotted line sit in the center of road. Furthermore, motor vehicles are expressed by arrows; however, the green arrows represent vehicles running on the horizontal direction, and the red arrows stand for vehicles running on the vertical direction. Moreover, the blue area on the horizontal border of intersection marked 1 expresses that sidewalk is occupied by pedestrians. Lastly, vehicles operate in the light of the state of traffic light and traffic rules. This paper designs a kind of function that can track move locus of single vehicle so that the operation characteristic of single vehicle can be studied. As is depicted in Figure 4-1, blue lines mark the locus of vehicle.

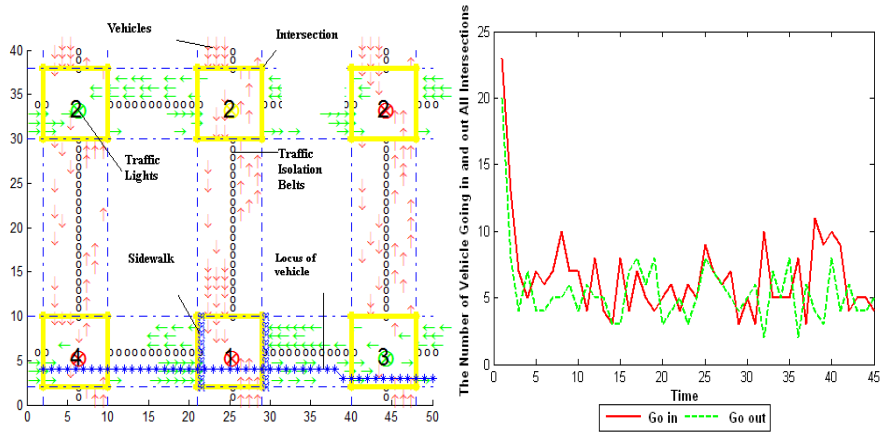

Figure 4-1 Diagram of Traffic simulation of several vehicles and pedestrians in the intersection

Figure 4-2 The number of cars in the intersection. Straight line represents the number of vehicles going into intersection, and the dotted line represents the number of vehicles going out intersection.

Statistically analyze on Vehicle Flow Rate. In order to illustrate the number of motor vehicles that drive into and out the interactions, it is figured out all the vehicles that drive as well as drive into and out each interaction. In this paper, vehicle flow rate of driving into and out the intersection refers to the sum of the number of vehicles which drive in and out the same intersection in per unit time. It's obvious that vehicles going into intersection are expressed by red curve; vehicles going out the intersection are indicated by green curve in Figure 4-2. In Figure 4-3 it appears a specific number on the top left corner of each small chart, which expresses that the interaction is operated the traffic rule that is shown by the number. From Figure 4-3, we can found that the number of going in the intersection is in step with the number of going out the intersection and the traffic operates well, when the intersection revolves rule No. 1 and rule No.2. Additionally, it is apparent that the number of going in the intersection is more than the number of going out the intersection and the traffic goes worse, when the intersection runs rule No.3 and rule No.4 in Figure 4-3. Compared the traffic situation of the intersection, it's found that, in a sense, complicated traffic rules delay the time of the vehicle driving out the intersection and deteriorate the traffic situation of urban road intersection.

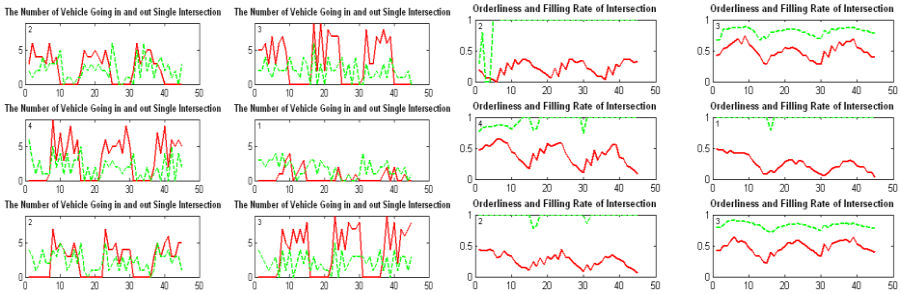

Fig 4-3 The number of cars in the single intersection. Straight line represents the number of vehicles going into intersection, and the dotted line represents the number of vehicles going out intersection.

Figure 4-4 Orderliness that pedestrians run the red light and vehicles don't run the light. Dotted line represents filling rate, and the straight line represents orderliness.

Analyze on the Orderliness of Urban Road Intersection. In this paper, two indexes including orderliness and filling rate are set so as to demonstrate the traffic situation in the intersection. Filling rate refers to the proportion that the real number of vehicles takes up the whole capacity in the interaction. When it needs to show a special moment, filling rate means the proportion that the number of vehicles takes up the whole capacity in the special interaction. As quantitative indicators in this model, filling rate is used to measure space utilization level, which also works well in illustrating congestion to a degree. Traffic orderliness refers to the order level of vehicles operation at the special moment in the whole interaction. In this paper orderliness means the consistence proportion that the moving direction of vehicles and pedestrians in the interaction, and the moving direction of the rule under the condition of traffic lights in theory.

Figure 4-4 reveals filling rate and orderliness on condition that pedestrians run the red light with probability of 0.3, vehicles don't run the red light. Filling rate and orderliness are displayed in which pedestrians don't run the red light and vehicles run the red light with probability of 0.3 in Figure 4-5. As is shown in Figure 4-6, it expresses filling rate and orderliness are caused by pedestrians and vehicles that they run the light with probability of 0.3. From Figure 4-6, it is evident that there is a relationship of negative correlation between filling rate and orderliness. The relationship implies that orderliness may decrease and

traffic situation may turn for the worse if vehicles in the interactions get more and more. Making a comparison between Figure 4-4 and Figure 4-5, we can find that orderliness that pedestrians run the red light and vehicles don't run the red light is higher than that pedestrians don't run the light and vehicles run the red light. For this reason, we can make a conclusion that vehicles may bring about a greater impact on intersection traffic than pedestrians. Traffic situation is deteriorated by pedestrians and vehicles that both of them run the red light by making a comparison between Figure 4-4, Figure 4-5 and Figure 4-6.

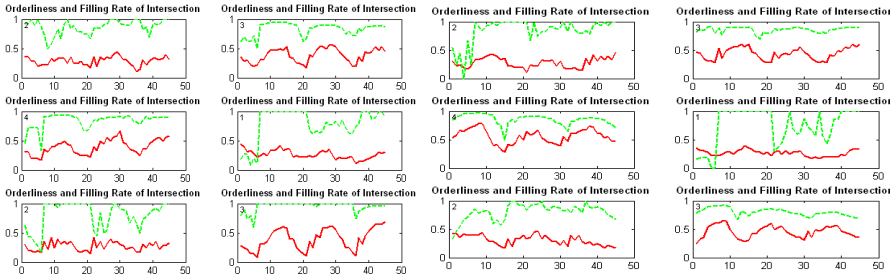

Figure 4-5 Orderliness that pedestrians don't run the red light and vehicles run the light. Dotted line represents filling rate, and the straight line represents orderliness.

Figure 4-6 Orderliness that pedestrians and vehicles run the red light. Dotted line represents filling rate, and the straight line represents orderliness.

5. Conclusions

As an important part of urban transportation, the research of urban road intersections has an important theoretical and realistic significance. This paper establishes a dynamic simulation system which could simulates the whole traffic of crossing by the model of cellular automaton, referring to the present microscopic simulation method. Compared with the existing cellular automaton model of urban road intersection, the model in this paper has the ability to reflect dynamic transport features of the intersection intuitively, simulate urban road intersections comprehensively, imitate the psychology of pedestrians and drivers authentically, which makes up for a deficiency of the existing model's simplicity. Therefore, cellular automaton model in this paper is possessed of integrity and completeness. However, compared with the reality, many defects indwell in this model, such as the reasonableness of cellular and parameter

design. Much effort must be made in the design of cellular rules and investigation of traffic behavior so as to improve the insufficiency and perfect the model.

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