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Cellular automata model for urban road traffic flow considering pedestrian crossing street

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HIGHLIGHTS

- Two traffic flow cellular automaton models considering pedestrians are proposed.
- Arrival rate of pedestrians (less than 6 peds/(h m)) has slight impact on traffic flow.
- The relation between vehicle density and impact on traffic flow is studied.
- Vehicle flow with intruders' random interruption is of availability.

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ABSTRACT

In order to analyze the effect of pedestrians' crossing street on vehicle flows, we investigated traffic characteristics of vehicles and pedestrians. Based on that, rules of lane changing, acceleration, deceleration, randomization and update are modified. Then we established two urban two-lane cellular automata models of traffic flow, one of which is about sections with non-signalized crosswalk and the other is on uncontrolled sections with pedestrians crossing street at random. MATLAB is used for numerical simulation of the different traffic conditions; meanwhile space–time diagram and relational graphs of traffic flow parameters are generated and then comparatively analyzed. Simulation results indicate that when vehicle density is lower than around 25 vehs/(km lane), pedestrians have modest impact on traffic flow, whereas when vehicle density is higher than about 60 vehs/(km lane), traffic speed and volume will decrease significantly especially on sections with non-signal-controlled crosswalk. The results illustrate that the proposed models reconstruct the traffic flow's characteristic with the situation where there are pedestrians crossing and can provide some practical reference for urban traffic management.

1. Introduction

Cellular Automata model (referred to as CA model) is a mathematical model with discrete time and space units, which can be well applied to simulation of microscopic traffic flow phenomena. Since the classic one-dimensional CA traffic flow model—NS model [1] was proposed by Nagel and Schreckenberg in 1992, many scholars had established some CA models considering different road and traffic conditions by improving individual vehicle acceleration, deceleration and lane-changing rules. Improvements have been made to the N-S model to meet more feasibility condition, including the additional slow-to-start rule and the extension from single lane to multilane models [2–5]. Some scholars have used CA models to

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simulate pedestrian flow. Blue et al. proposed a pedestrian movement model for large scale open areas. Maramatsu et al. proposed a pedestrian movement model based on stochastic processes [6,7]. Existing research can be summarized into two types of CA models: on freeways and on urban roads. Freeway traffic flow is continuous and there is less interference from both sides of road, and actually its CA models reaching to maturity. Recent research [8–11] in this field focuses primarily on the impact of traffic bottleneck sections, as well as mixed traffic flow. However, urban road traffic characteristics are quite complex, relating to multiple modes of transportation, various types of vehicles, relevant acts concerning frequently going into and out of road sections. Urban road CA model still needs improvement. Existing research [12–18] results involve in CA models in terms of mixed traffic flow, driver psychology, longitudinal interference or other factors.

Pedestrian–vehicle mixed traffic flows account for a very big proportion in urban traffic flows in present China, where considerable pedestrians crossing street on urban segments becomes a typical feature nowadays and has a direct impact on the continuity of traffic flow. Obviously, to use the non-signal-controlled crosswalk or to cross road randomly from uncontrolled road sides has different influence on vehicle flows. While characteristics of pedestrians crossing on uncontrolled low-grade roads or branch roads without separating barriers in cities have received little attention for now, some scholars have respectively conducted several studies [19–32] concerning section crosswalks. It is suggested by a traffic survey that if there are pedestrians crossing a road, vehicles will decelerate or stop to give way. If there is no pedestrian waiting at either end of crosswalk or if a vehicle keeps a close distance from its front vehicle, the vehicle will maintain its speed going forward. If there are pedestrians waiting at both ends of crosswalk and vehicles keeping a long distance from their front ones, drivers tend to slow down and pass through by a certain probability based on their observation. Pedestrians generally cross streets by gap acceptance 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.

In view of the self-organizing behaviors of pedestrians and vehicles at crosswalk, considering psychological characteristics of pedestrians and motor vehicle drivers, in this paper we established a cellular automaton model about low-grade urban road traffic flow with non-signalized crosswalk. We also investigated uncontrolled urban streets without separating barriers where pedestrians may cross randomly at any location on both sides of the streets and proposed another model to simulate the interaction of vehicle flows and crossing pedestrians in this situation. MATLAB is used to realize the two proposed models (One focuses on characteristics of vehicles under lateral interference of pedestrians around non-signal-controlled crosswalk, while the other is about pedestrians crossing streets randomly on uncontrolled sections without relevant crossing facilities.) and carry on numerical simulation. Based on the simulation data, relationships between vehicle speed, traffic density, traffic flux, arrival rate of pedestrians and other relative parameters are respectively researched by us. Besides, we comparatively analyzed impacts of crosswalk and pedestrians' randomly crossing streets on traffic flow.

This paper is organized as follows. In Section 2, we describe our models in detail both at crosswalks and sections without crossing street facilities. We present a numerical simulation to demonstrate the proposed models in Section 3. Finally, we summarize and conclude the paper in Section 4.

2. Traffic flow models considering crossing pedestrians

We established two models considering crossing pedestrians at crosswalks without signal control and uncontrolled sections without relevant crossing street facilities. The two models have much in common, and some differences. The differences of the two models are that at crosswalks without signal control or on sections without relevant crossing facilities, vehicle's behaviors are related to how pedestrians occupy road space and that drivers usually do not change lanes on crosswalks, whereas on sections without specific crossing facilities this habit does not apply. Besides, in the first model vehicles will not accelerate but reduce their speed on the non-signalized crosswalks to avoid conflicts with pedestrians while in another model vehicles may accelerate rather than slow down. The two models can be illustrated from views of vehicle movement, pedestrian movement and vehicle–pedestrian conflict.

2.1. Vehicle movement

According to existing research results, two-lane traffic flow CA models without lateral pedestrian interference have been rather advanced. Lane changing rules are supposed to involve in road conditions, traffic conditions as well as drivers' psychological property and other related factors. These models [22] apply a two-step method within each discrete time unit to renew vehicles' position and speed condition. The first step is to change lanes, and the second step is vehicle-following driving. The lane changing between lanes is symmetric.

On the basis of previous studies, the road in our models is a one-way, two-lane street. The other relevant parameters as well as other parameters involved in the paper and their meanings are shown in Table 1.

Considering different pedestrian interference factors, the rules of lane-changing, acceleration, deceleration, randomization and location update are formulated as follows:

First step: lane changing on non-signal-controlled sections with crosswalk and uncontrolled sections without crossing street facilities.

If the conditions (1) or (2) are met, vehicles may change lane with a specific probability (p_{change}). $rand(\ )$ is a random number ranging from 0 to 1, indicating that when following conditions are met, vehicle will change lane with a certain

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