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Power-law in pedestrian crossing flow under the interference of vehicles at an un-signalized midblock crosswalk

Xiuying Xin [a], Ning Jia [a,*], Liang Zheng [b], Shoufeng Ma [a]

[a] Institute of Systems Engineering, Tianjin University, Tianjin 300072, China

[b] School of Traffic and Transportation Engineering, Central South University, Changsha 410075, China

HIGHLIGHTS

- Pedestrian–vehicle interferences at un-signalized midblock crosswalk are studied.
- The mixed traffic flow experiences four phases.
- Cluster sizes of pedestrian group crossing obey power law distribution.
- The heterogeneity of pedestrians acts an important role in the mixed traffic.

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ABSTRACT

Mixed traffic without signal control is complicated. This paper proposes a pedestrian–vehicle cellular automata (CA) model to study the characteristics of the mixed traffic. The model includes two sub models. One is the pedestrian model, in which the heterogeneity is taken into consideration. The other is the vehicle model, in which a safely running mode and a normally running mode are introduced. Simulation results show that (1) the traffic flow experiences four phases, that is, free flow, pedestrians-free flow, vehicles-free flow and jams, (2) pedestrians cross the crosswalk in groups and the sizes of the groups obey power law distribution, and (3) the heterogeneity of pedestrians acts an important role in the system. If the pedestrians are simultaneously homogeneous, the mixed traffic flow shows a "polarization" and these power-laws disappear under high arrival rates of vehicles and pedestrians.

1. Introduction

Mixed traffic consisting of motorized vehicles (*m*-vehicles) and pedestrians widely exists in urban traffic, especially at crosswalks. If the *m*-vehicle flow and the pedestrian flow have conflicts, the interferences between them will make bad disturbances to the traffic flow and reduce the efficiency of the road.

Numbers of researches focused on problems of mixed traffic at signalized crosswalks. Although the traffic is supposed to be well-organized with traffic lights, it becomes out-of-order due to red runners, violation followers, unreasonable signal cycle etc. [1–3]. Pedestrians' law-disobeying behavior in crossing the street can be easily observed in our daily life [2]. These risky behaviors induce traffic safety problems and seriously affect traffic capacity [4]. Despite of pedestrians' law-disobeying, reasonable design of signal cycle is needed to ensure pedestrians cross the street effectively. It also helps to reduce risky behaviors because the aggressiveness is time dependent [5].

* Corresponding author. Tel.: +86 13821155325.
E-mail address: jia_ning@tju.edu.cn (N. Jia).

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Fig. 1. Pedestrians go across the vehicle flow by lane, a snapshot of an intersection in Beijing.

Many studies have investigated the vehicle–pedestrian mixed traffic at un-signalized crosswalks. There are two factors that mainly affect the traffic flow. One of them is the traffic volume [4,6–8]. R. Jiang et al. found that if the traffic flow rate is small, the traffic flow is unaffected by pedestrians, but if the flow rate exceeds a critical value, traffic jams appear [6]. The other is the behavior of motorists and pedestrians. Motorists are supposed to stop or yield appropriately for pedestrians at un-signalized crosswalks. If they do, the traffic is well-organized, but if they do not, interferences between pedestrians and vehicles occur. The fact is that motorists in some developing countries, such as China, are less willing to stop or yield for pedestrians (Fig. 1) [9]. Thus, in this study, we consider that both of motorists and pedestrians want to cross the street as soon as possible. Moreover, pedestrians influence the traffic through their crossing decision. For example, pedestrians' different criteria of acceptance gap produce slower-is-faster effect [6], and the threshold of pedestrian's acceptable waiting time influences the traffic flux [4].

Considering the important role of pedestrian crossing behavior in traffic systems, we analyzed the features of pedestrians. The main feature is that they behave heterogeneously when they cross the road [10]. Pedestrians have heterogeneous criteria of acceptable gap and make different decisions facing the same situation. They are also heterogeneous in their walking speeds [11,12].

Under the inspiration above, we constructed a model of pedestrian–vehicle mixed traffic at an un-signalized crosswalk, in which the heterogeneity of pedestrians is taken into account. Experimental results show that the traffic experiences four phases. Cluster sizes of pedestrians' group crossing obey power law distribution. Although researchers have found obvious heterogeneity in pedestrians, to our knowledge, the influence of the heterogeneity to an un-signalized traffic has seldom been studied. Thus, the impact of the heterogeneity on the traffic flow dynamics is studied.

The paper is organized as follows. In Section 2 fundamental model configurations and evolution rules are exhibited. Then we demonstrate numerical results in Section 3, including the flux, spatiotemporal diagrams and the distributions of the cluster sizes. The effect of the heterogeneity to the traffic flow is studied in Section 4. Conclusions are given in Section 5.

2. Model

Cellular Automata model simulates complex phenomena in the real world using a set of simple rules. It is easily implemented on computers and has been successfully applied to modeling vehicular flows. In the CA model, the interactions of the particles are based on understandable behavioral rules, rather than functions.

With above mentioned advantages, our model is established based on cellular automata. The model depicts a street that consists of a single-lane road and an un-signalized midblock crosswalk, which popularly exists in residential area. As illustrated in Fig. 2, the crosswalk is composed of a motorway and a non-motorway. Vehicles enter from the left boundary at an arrival rate r_v, while pedestrians enter from the bottom at an arrival rate r_p. Vehicles or pedestrians are channeled in the motorway or the crosswalk as Fig. 2 shows.

All particles are updated in parallel and the open boundary conditions are applied in this model [13].

2.1. Pedestrian model

The pedestrian model includes crossing decision rules and moving rules. The crossing decision rules describe pedestrians' behavior of perception and judgment during street crossing. The moving rules involve bi-dimensional route selection and conflict elimination.