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Impacts of group behavior on bicycle flow at a signalized intersection

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HIGHLIGHTS

- Bicycle's shoulder group behavior and following group behavior at a signalized intersection are defined.
- Some rules are proposed to describe each bicycle's motion under the two kinds of group behaviors.
- The impacts of the two group behaviors on each bicycle's motion and the operational efficiency are studied.

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ABSTRACT

Bicycle's riders widely have group behaviors due to the bicycle's features and the group behaviors may have significant impacts on bicycle flow (especially at a signalized intersection). In this paper, we propose a cellular automaton (CA) model to explore the impacts of shoulder group behavior and following group behavior of bicycles during the process that bicycles pass through a signalized intersection. In the proposed model, the acceleration/waiting phenomenon (caused by the two group behaviors at the intersection) is explicitly considered. The numerical results indicate that the proposed model can effectively reproduce the actions of group bicycles at the intersection and that the two group behaviors have prominent negative impacts on the operational efficiency of the intersection, which shows that the group behaviors should be controlled at the intersection.

1. Introduction

With the development of sharing bicycle (SB), bicycle has been a popular traffic tool in China, again. The statistics data show that SBs exist in more than 200 cities in China and that the number of SBs has exceeded 25 million [1].

However, the rapid increase of SBs has produced a great challenge (e.g., disorder traffic, safety, etc.) on the operation of urban traffic system [2,3], which has attracted many researchers to explore the effects of bicycles on traffic flow [4,5]. As for traffic flow, many models were proposed to study the traffic phenomena caused by vehicles [6–15]. However, the models [6–16] cannot directly be used to study bicycle flow. As for bicycle flow, researchers proposed many models to study the complex phenomena caused by bicycles [17–28]. Roughly speaking, the models [17–28] can be divided into three groups, i.e.,

(1) The first group explores the traffic characteristic of bicycle flow. For example, Gould Karner [17] designed some lane-changing rules and proposed a CA (cellular automaton) model to the traffic phenomena of bicycle flow. Zhao et al. [18] developed an extended CA model to explore the mixed traffic flow that consists of conventional bicycle and electric bicycle.

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Fig. 1. Bicycle's shoulder group behavior and following group behavior.

Jiang et al. [19] proposed a CA model to explore the mixed flow consisting of bicycle and vehicle. Xue et al. [20] developed another CA model to depict the bicycle motion and used experimental data to calibrate the main parameters of the proposed model.

(2) The second group studies the bicyclist's travel behavior when bicycle is used as a traffic tool [21–24]. Shafizadeh and Niemeir [21] utilized the survey data to explore the relationship between the demographic attributes and spatial clusters of individuals making a weekday bicycle journey-to-work commute and the commuting travel time. Hood et al. [22] used the GPS data to propose a bicycle route choice model and studied the cyclist's decision-making behavior in California. Broach et al. [23] later extended the work [22]. Ryu et al. [24] proposed a two-stage traffic assignment model for bicycle flow.

(3) The third group investigates the interactions among pedestrians, bicycles and vehicles at an intersection, and the complex phenomena produced by the interactions [25–28]. Räsänen and Summala [25] used the 188 bicycle-car accidents collected in 4 cities to analyze the reasons that the accidents occur at the intersection where bicycles and cars are mixed. Cheng et al. [26] explored the vehicle's driving behaviors and the bicycle's riding behaviors during intrusion conflicts in vehicles-bicycles laminar flow. Vasic and Ruskin [27] proposed a CA model to simulate the phenomena caused by the mixed traffic flow consisting of cars and bicycles. Bhatia et al. [28] studied the effects of the cycle lanes on cyclist-vehicle collisions in Toronto.

The above studies can describe many complex phenomenon of bicycle flow (e.g., congestion, safety, etc.), but they did not consider the effects of group behavior on the bicycle's motion. In fact, bicycle widely has group behavior (see Fig. 1) and the group behavior may have significant effects on the bicycle's motion. In order to describe the bicycle's group behavior, Tang et al. [29] proposed a CA model to study the effects of shoulder group behavior and following group behavior on each bicycle's motion on a road with open boundary, but they did not study the effects of the two group behaviors on each bicycle's motion at a signalized intersection. In fact, group behavior has great impacts on each bicycle's motion at a signalized intersection. In this paper, we extend the work [29] to explore the effects of group behavior on each bicycle's motion during the process that it passes through a signalized intersection. This paper is organized as follows: in Section 2, two group behaviors and the rules of each bicycle's motion are formulated; in Section 3, simulations are conducted to explore the impacts of the two group behaviors on each bicycle's motion on a road with a signalized intersection; in Section 4, some conclusions are summarized.

2. Model

Bicycles have shoulder group behavior and following group behavior (see Fig. 1). In this section, we propose two CA models to respectively explore the impacts of the two group behaviors on each bicycle's motion during the process that it runs across a signalized intersection (see Fig. 2). In this paper, we set each cell size as 0.7 m and the intersection size is 50 cell*50 cell (i.e., 35 m*35 m). Before constructing the models, we should make the following basic assumptions:

(1) Bicycles and riders are homogeneous.

(2) Turning-left and turning-right bicycles do not exist at the intersection, i.e., we should only study the bicycles' motions in the shading zone (see Fig. 2).

(3) The shading zone includes right, mid and left lanes, where each lane width is 0.7 m. The shading zone is divided into three segments, where each segment length is 50 cell (i.e., 35 m).

(4) Each bicycle occupies two cells in the longitude direction and one cell in the latitude direction (i.e., the size is 1.4 m*0.7 m). Each bicycle's location is described by (X, Y), where X denotes the longitude direction and Y denotes the latitude direction. Each cell is either empty or occupied by a bicycle.

(5) As for the shoulder group behavior, the bicycle on the far left is the leader; as for the following group behavior, the first bicycle is the leader.

(6) The bicycles with group behavior have no lane-changing behavior; retrograde is prohibited.