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Simulating the impacts of on-street vehicle parking on traffic operations on urban streets using cellular automation

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HIGHLIGHTS

- The study investigates the impacts of on-street vehicle parking on urban streets.
- Cellular automation model is developed to simulate heterogeneous traffic operations.
- Frictional and blocking conflicts on street segments with various widths are studied.
- Vehicle delays are estimated for different traffic situations and parking occupations.
- Policy suggestions regarding bicycle lane design and parking permit are proposed.

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ABSTRACT

In recent years, many bicycle lanes on urban streets are replaced with vehicle parking places. Spaces for bicycle riding are reduced, resulting in changes in bicycle and vehicle operational features. The objective of this study is to estimate the impacts of on-street parking on heterogeneous traffic operation on urban streets. A cellular automaton (CA) model is developed and calibrated to simulate bicycle lane-changing on streets with on-street parking. Two types of street segments with different bicycle lane width are considered. From the simulation, two types of conflicts between bicycles and vehicles are identified which are frictional conflicts and blocking conflicts. Factors affecting the frequency of conflicts are also identified. Based on the results, vehicle delay is estimated for various traffic situations considering the range of occupancy levels for on-street parking. Later, a numerical network example is analyzed to estimate the network impact of on-street parking on traffic assignment and operation. Findings of the study are helpful to policies and design regarding on-street vehicle parking to improve the efficiency of traffic operations.

1. Introduction

Recently, the investigation of heterogeneous traffic operation has gained more attention in the field of statistical physics [1–3]. In particular, a number of studies have been focused on investigating the interactions between vehicles

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and bicycles either at intersections or on the street segments in the urban area by statistical physicists [4–6]. On urban streets, heterogeneous traffic flow often presents a chaotic scene because vehicles and bicycles share the road resource without segregation between them. Many statistical physicists have proposed several approaches to research features of heterogeneous traffic operation, such as car following model, intelligent agents, hydrodynamic models and cellular automaton [7–9]. It is commonly recognized that an appropriate model should reflect complicated interactions in the heterogeneous traffic flow, where, as for bicycle traffic, there is no strict lane discipline, since and bicycles usually move side by side along the street segment [10].

Among these proposed models, cellular automaton (CA) is a widely utilized simulation technique in addressing sophisticated traffic operations at intersection areas and road segments. Ability to accommodate different traffic movements and high computational efficiency, means that CA has becomes a prevalent tool to simulate heterogeneous traffic operation. For instance, Luo et al. [11] proposed a CA model to simulate bicycles' spill behavior in heterogeneous vehicle and bicycle flow. The occupancy rule of their proposed model considers the variable lateral distance of mixed vehicular occupation in order to capture the complex interactions between vehicles and bicycles. Ren et al. [12] developed a calibrated CA model to research on the straight-through movements of the heterogeneous bicycle traffic at a signalized intersection. In their model, the nonlane-based cycling behavior and diverse bicycle properties are considered. They show that the dispersion phenomenon significantly influences the bicycle traffic operation in terms of spilling maneuvers and overtaking maneuvers. Vasic and Ruskin [13] proposed a CA model to examine the vehicle–bicycle interaction using two scenarios including a stretch of road and an intersection causing conflict between vehicles and bicycles sharing a lane. They present fundamental diagrams for vehicular traffic as a function of bicycle density for both scenarios. Lan et al. [14] used a CA model to represent erratic motorcycle behavior in heterogeneous car and motorcycle flow. Their simulation results show that the erratic motorcycle behaviors increase interaction among different vehicles and hence impair the flow efficiency. Jia et al. [15] investigated the operation of heterogeneous bicycles traffic flow using the multi-value CA model under both deterministic and stochastic regimes. They considered two types of bicycles with different maximum speed as well as tricycles. In these CA studies, the most marked character is to divide road section into small size cells and represent various vehicle sizes and movements by multiple cell occupancy.

Regarding heterogeneous traffic, bicycles occupy less road space and produce fewer emissions as compared to motorized transport modes. Bicycles are gradually recognized as beneficial to environment and air quality, and cycling is increasingly seen as a significant mode of transportation for the sustainable development [16]. During the past decade, there has been an increasing use of bicycles in many countries. To accommodate the increased cycling demand, bicycle lanes are designed on urban streets to provide more spaces for cyclists [17,18]. One purpose of a bicycle lane is to segregate bicycle traffic from motorized traffic in order to reduce conflicts [19,20].

On urban streets with vehicle parking, the space for cycling is limited. As bicycle flow increases, some cyclists would travel closely to motorized vehicles which greatly influence regular operation of motorized vehicles. In recent years, given continuous increase in vehicle parking demand, some cycling spaces are changed into vehicle parking places [21,22]. The decreased cycling space could remarkably increase the conflicts between bicycles and vehicles, producing excessive delay to the traveling public and more exhaust and emission. Hence, it is necessary to understand heterogeneous traffic operation like vehicle–bicycle interactions on urban streets. Many authors have investigated the operational features of bicycle traffic on urban streets, such as speeds, capacities, and passing maneuvers [23–26]. Other studies have estimated the impact of on-street parking on the vehicle speed and delay [27–30]. However, those studies did not quantify the interactions between vehicles and bicycles on urban streets.

This study aims to evaluate bicycle–vehicle interactions on urban streets with limited riding space using a cellular automaton (CA) model. The CA model was modified to simulate the behavior of vehicles and bicycles on urban streets with on-street roadside vehicle parking. Considering the fact that on-street vehicle parking is commonly implemented on collector roads, this study focused on the traffic conditions on collector roads. Collector roads mainly provide lane access to higher and lower functional classes and constitute a significant proportion of the urban road network [31]. Note that the heterogeneous traffic in this study denotes bicycles and four-wheeled motorized vehicles. Motorized vehicles from hereon are abbreviated as "vehicles", which include cars and some trucks of similar size. The remainder of this paper is organized as follows. Sections 2 and 3 present data and methodology. Section 4 shows results and finally, Section 5 concludes this paper.

2. Data collection

Field data collection was performed in Nanjing, China. The following criteria were applied in the site selection for data collection: (1) site has a good view for setting video camera; (2) path width does not change within the segment; (3) no bus stop or uncontrolled access within the segment; and (4) site has flat pavement without slope. Finally, six road segments were selected.

From field observations, we found that bicycles have exerted lateral and longitudinal interferences on vehicle traffic which were then classified into two types, defined as frictional conflicts and blocking conflicts in our study (see Fig. 1). Frictional conflicts occur when bicycles run adjacently to vehicles with close lateral distances. Vehicles have to reduce traveling speed to avoid potential scrape with bicycles. Blocking conflicts occur when bicycles run ahead of vehicles