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Simulation model of speed–density characteristics for mixed bicycle flow—Comparison between cellular automata model and gas dynamics model

Shuichao Zhang [a,*], Gang Ren [b,1], Renfa Yang [a,2]

[a] School of Transportation, Ningbo University of Technology, No. 201, Fenghua Road, Ningbo, 315211, PR China

[b] School of Transportation, Southeast University, No. 2, Sipailou, Nanjing, 210096, PR China

HIGHLIGHTS

- The mixed bicycle flow refers to the bicycle flow containing electric bicycles.
- The speed–density data of mixed bicycle flow was obtained with the virtual coil method.
- Mixed bicycle flow has unique traffic characteristic compared to pure bicycle flow.
- Cellular automata model can well simulate the mixed bicycle flow in low density.
- Gas dynamics model can well simulate the mixed bicycle flow in high density.

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ABSTRACT

The mixed bicycle flow refers to the bicycle flow containing electric bicycles. The traffic characteristics data of the mixed bicycle flow was collected by the virtual coil method in Nanjing and Ningbo, China. And the speed–density characteristics of the mixed bicycle flow with different proportions of electric bicycles were obtained. The results show that the overall speed of the mixed bicycle flow containing electric bicycles is higher than that of pure bicycle flow when the density is relatively low. The speed decreases when the density is higher than 0.08 bic/m^2; the speed–density characteristics of the bicycles and the electric bicycles tend to be the same when the density is higher than 0.25 bic/m^2. And when the density reaches 0.58 bic/m^2, the mixed bicycle flow becomes blocked and the speed is zero. The cellular automata model and gas dynamics model were also adopted to simulate the speed–density characteristics of the mixed bicycle flow. The simulation results of the cellular automata model are effectively consistent with the actual survey data when the density is lower than 0.225 bic/m^2; the simulation results of the gas dynamics model are effectively consistent with the actual survey data when the density is higher than 0.300 bic/m^2; but both of the two types of simulation models are inapplicable when the density is between 0.225 and 0.300 bic/m^2. These results will be used in the management of mixed bicycles and the research of vehicle–bicycle conflict and so on.

* Corresponding author. Tel.: +86 574015867463561.
E-mail addresses: zhangsc2588509@126.com (S. Zhang), rengang@seu.edu.cn (G. Ren), yang0403@163.com (R. Yang).
1 Tel.: +86 25013851664823.
2 Tel.: +86 574013957846565.

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(a) Bicycle. (b) Electric bicycle.

Fig. 1. Appearances of bicycle and electric bicycle.

1. Introduction

Electric bicycle is a special kind of bicycle, with a storage battery, lithium battery or other electric energy as an auxiliary power source. It has two wheels and functions such as manual riding, electro motion or power-drive. The bicycle and electric bicycle are greatly different in power, speed, acceleration and deceleration and other characteristics. The appearances of a bicycle and an electric bicycle are shown in Fig. 1. Bicycle is human-driven and has a free flow speed of 14.0 km/h or so, which is depending on the degree of physical strength of the rider and other environmental reasons. The electric bicycle is power-driven and its free flow speed is about 21.0 km/h. In recent years, due to the sharp increase in the number of electric bicycles, it is almost impossible to find pure bicycle flows, and of course, impossible to find pure electric bicycle flows. In this paper, the "mixed bicycle flow" refers to the mixed flow of both electric bicycles and bicycles.

Bicycle travel is the main travel mode adopt by the Chinese urban residents. In large and medium-sized Chinese cities, the average ratio of bicycle and electric bicycle travel is about 28%. At the same time, according to the statistics, as of the end of 2012, the quantity of national bicycle is about 540 million, and the quantity of electric bicycle is about 140 million. Therefore, China is not only a big holding country of bicycles, but also a big travel country of bicycles. Therefore, it becomes essential to research the traffic characteristics related to mixed bicycle flow, especially the speed–density characteristics of the mixed bicycle flow, i.e. the overall speed change situation of mixed bicycle flow when the density changes. The characteristics data serves as an important basic theory in the planning and design of bicycle lanes as well as bicycle and electric bicycle traffic management. Current studies in this field are relatively weak.

2. Literature review

Several pieces of research have been previously undertaken. John Parkin studied the design speed and acceleration characteristics of bicycles for use in the planning and design of a bicycle traffic system [1]. Chenpeng Shi studied the status of electric bicycles traffic in China [2]. Binjie Dong briefly studied the integrated traffic characteristics of electric bicycles [3]. Hongyi Guan directly presents the speed–density characteristics of bicycle flow, but does not obtain a systematic result [4]. Chunyan Liang studied the speed–density characteristics of bicycle flow based on the motor speed–density characteristics model but the research results only conform to the survey data in a certain density scope [5]; Congkun Zhu studied the relationship between speed and density of mixed bicycle flow, and put forward a linear model and a nonlinear model, but neither reached an ideal conformity result [6]. Navin FPD made series of experimental studies to determine the operating performance of a single bicycle and the traditional traffic flow characteristics of a stream of bicycles, and compare them to survey data. It was found that under certain conditions, bicycle flow can be treated as vehicular flow [7]. Though applying the cellular automata simulation model, Sven Maerivoet systematically explained the application of the cellular automata in the simulation of motor vehicle traffic flow [13]. Xingang Li established the bi-lane traffic flow model of one vehicle overtaking another based on the cellular automata model [8]. Lawrence W. Lan simulated the mixed traffic flow of motorcycles and vehicles with the cellular automata [9]. Rui Jiang took the stochastic randomization into two different multi-value cellular automata models in order to model the bicycle flow. It is shown that with the randomization effect considered, the multiple states in the deterministic multi-value cellular automata models disappear and the unique flow–density relations (fundamental diagrams) exist [10]. B Jia investigated mixed bicycle flow using the multi-value cellular automata model. And the system of mixed bicycles was investigated under both deterministic and stochastic regimes. On this basis, space–time plots were presented to show the evolution of mixed bicycle flow [11]. Jin Zhang established a model and carried out a simulation of bicycle flow with cellular automata, the results achieved a firm conformity between the simulation result and survey data in a certain density scope [12]. With the application of the gas dynamics simulation model, Chunyan Liang studied the stop-wave theories for bicycle flow based on the gas dynamics simulation model and obtained sound data [5], but related research into the speed–density characteristics of bicycle flow was lacking.