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Dynamic characteristics of traffic flow with consideration of pedestrians' road-crossing behavior

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HIGHLIGHTS

- We propose some rules for modeling the interaction of vehicles and pedestrians.
- A modified car-following model is introduced with consideration of a waiting pedestrian effect.
- Capacity and delay are significantly affected by pedestrians' crossing behavior.
- Dynamic characteristics of traffic flow are investigated with different pedestrian parameters.

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ABSTRACT

Pedestrians' road-crossing behavior can often interrupt traffic flow and cause vehicle queueing. In this paper, we propose some moving rules for modeling the interaction of vehicles and pedestrians. The modified visual angle car-following model is presented for the movement of vehicles with consideration of the lateral effect of waiting pedestrians. The pedestrians' behavior is summarized as consisting of three steps: pedestrian arrival, gap acceptance, and pedestrian crossing. Some characteristic parameters of pedestrians are introduced to characterize pedestrians' behavior. Simulation results show that the interaction of vehicles and pedestrians lowers the traffic capacity and increases delays to both vehicles and pedestrians.

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1. Introduction

The car-following model is one of the most celebrated models for describing the evolution of traffic dynamics at the microscopic level, and is the foundation of traffic flow analysis, simulation, and control. Many car-following models have been proposed to describe traffic flow in a single lane over the last 60 years [1,2]. However, in a real-world environment, there are many external disturbances to traffic flow, such as traffic signals, slowdown areas, lane changing, lateral vehicles, and pedestrians crossing roads. Much research has focused on their influences on traffic flow, using car-following models to analyze the characteristics of traffic flow [3–5]. Sasaki and Nagatani [6] first studied traffic flow controlled by traffic lights on a single-lane roadway by using the optimal velocity car-following model. They used three different strategies of traffic light control – simple synchronized, green wave, and random switching – to analyze the dynamic characteristics of traffic flow. Jiang and Wu [7] found the first- and second-order phase transitions from free flow to synchronized flow, under speed-limit conditions, using a full velocity difference car-following model, while Hanaura et al. [8] introduced traffic jams appearing on a single-lane highway with a few slowdown sections. Naito and Nagatani [9] studied the safety–collision transition induced

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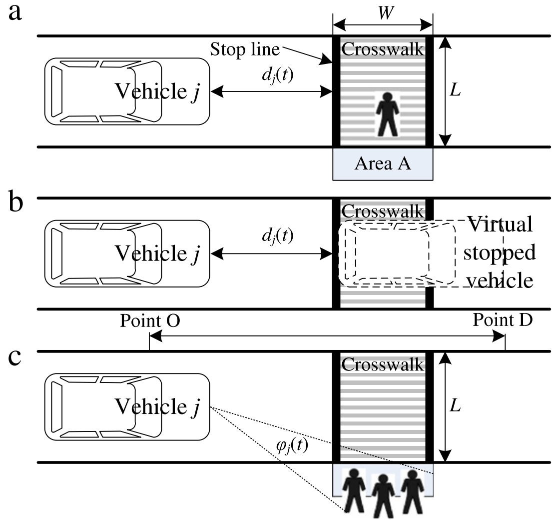

Fig. 1. Simulation of the interaction between vehicles and pedestrians: (a) the basic simulation situation, where vehicle j is the nearest upstream vehicle from the stop line, (b) when there are any pedestrians crossing, it is assumed that there is a virtual stopped vehicle on the crosswalk, and vehicle j must therefore follow this virtual stopped vehicle and stop behind the stop line, (c) the driver of vehicle j pays attention to the waiting pedestrians, and the visual angle of the waiting pedestrians is used to model lateral discomfort.

by lane changing in traffic flow. Jin et al. [10] modified the car-following model to consider lateral vehicles in neighboring lanes, and analyzed traffic stability.

To our knowledge, pedestrians' road-crossing behavior is a significant external disturbance, affecting the safety, capacity, stability, and oscillation of traffic flow. Jiang et al. [11], using a car-following model, have shown that the capacity of the road decreases in the presence of pedestrians. Helbing et al. [12] and Jiang et al. [13] also analyzed the interaction between vehicles and pedestrians, and found some interesting phenomena. None of these studies, however, considered the characteristics of pedestrians in analyzing the impacts of their crossing behavior on vehicle traffic flow. The pedestrian model they use is very simple, and does not capture the actual characteristics of pedestrians.

In this paper, we attempt to fill this gap and develop a modified car-following model and pedestrian crossing rules so as to analyze the interaction of vehicle traffic and pedestrian flow. The rest of the paper is organized as follows. In Section 2, we introduce a rule for pedestrians' crossing behavior, a modified car-following model, and an interacting rule for vehicles and pedestrians. In Section 3, we analyze the traffic capacity and delays to vehicles and pedestrians, and assess the impacts of the model parameters. Finally, some implications and extensions of this study are discussed.

2. Model

Pedestrians' road-crossing behavior affecting traffic is a very common phenomenon, and the nature of the behavior in developing countries affects traffic particularly strongly. This behavior not only greatly reduces the road capacity but can also have a serious effect on traffic safety. In this section, we give a typical single-lane situation in which we will analyze the interaction between vehicle traffic and pedestrian flow. We assume that there is a crosswalk in a single lane, and pedestrians must cross the road just at this crosswalk. Fig. 1(a) shows the specific simulation situation. A pedestrian arrives on one side of the street (area A); he/she needs to observe the traffic conditions, estimate whether it is safe to cross, and either decide to cross or wait for a safer gap to emerge at area A. Meanwhile, the driver of vehicle j, the nearest vehicle to the stop line, should observe whether there are pedestrians crossing the road or waiting to cross, and maneuver his/her vehicle accordingly so as to avoid a collision. Therefore, in this situation, vehicles and pedestrians are interacting and the moving rules of vehicles and pedestrians are affected by each other, for safety reasons. In order to describe the interacting behavior specifically, we present the following moving rules for vehicles and pedestrians.

2.1. Pedestrians' crossing rules

Pedestrians' crossing behavior is affected not only by the movement of vehicles on the road, but also by the number of pedestrians arriving at the crossing point, the characteristics of the pedestrians, the pedestrian waiting time, and so on. We now give some pedestrian parameters, to depict their crossing behavior.

Firstly, we assume that each pedestrian's arrival is independent, and that the probability of a pedestrian arriving during a simulation time interval Δt, measured in seconds, is p_{ro}. Thus, the pedestrian volume per hour equals $3600p_{ro}/\Delta t$. Next, two important parameters of crossing pedestrians' personal characteristics are proposed. One is the critical gap. The pedestrian's

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