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A model of pedestrian delay at unsignalized intersections in urban networks

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ABSTRACT

Delay is an important performance measure for pedestrian crossings considering their interactions with other road users. This study provides an improved analytical model to mathematically estimate pedestrian delay using renewal theory, which considers driver yielding and vehicle platooning. A generalized model is first provided to accommodate different traffic flow and driver behavior assumptions. Then the proposed model is developed on the basis of a mixture of free traffic and platooned traffic with consideration of driver yielding behaviors to better replicate field conditions in an urban setting. A second application using the HCM 2010 assumptions is also derived to compare it to the HCM 2010 model. Lastly, field data were collected and used for validation from two locations: Gainesville, FL and Washington, D.C. A simulation via MATLAB is performed to evaluate the model results for a variety of cases. The comparisons to the field data as well as the simulation confirm the applicability and accuracy of the proposed model. It is also found that the current HCM 2010 model overestimates the pedestrian delay compared with field data.

1. Introduction

Pedestrian street crossing leads to direct interactions with motor vehicles and other road users. Pedestrian crossing at unsignalized intersections can be simply deconstructed as follows: A pedestrian arrives at an unsignalized intersection and desires to cross the major traffic stream. If the vehicle-pedestrian gapθ_1 (i.e., the time headway between the pedestrian arrival and the vehicle arrival) is larger than the pedestrian's critical gapτ(which is equal to the minimum time to cross the road), the pedestrian crosses the street immediately; if not, the pedestrian waits, and the crossing probability depends on the driver yield behavior. A schematic of this problem is shown in Fig. 1 as a time-space diagram. Vehicle trajectories are presented (θ_i is the time headway between vehicle i and $i+1$). Pedestrians randomly arrive (at time t) at the curb and make a crossing decision immediately. The wait time at the curb (i.e., the time difference between pedestrian arrival t and departure t') is defined as the pedestrian delay for street crossing.

Pedestrian delay is often used as a performance measure for quantitatively evaluating the pedestrian-vehicle interactions, as well as estimating the facility Level of Service (HCM, 2010). It is highly dependent on vehicular traffic (Adams, 1936; Mayne, 1954; Troutbeck, 1986; Schroeder et al., 2014), road geometry (Dunn and Pretty, 1984; Troutbeck, 1986), and pedestrian behavior (Sun et al., 2003; Schroeder and Rouphail, 2010b; Schroeder et al., 2014).

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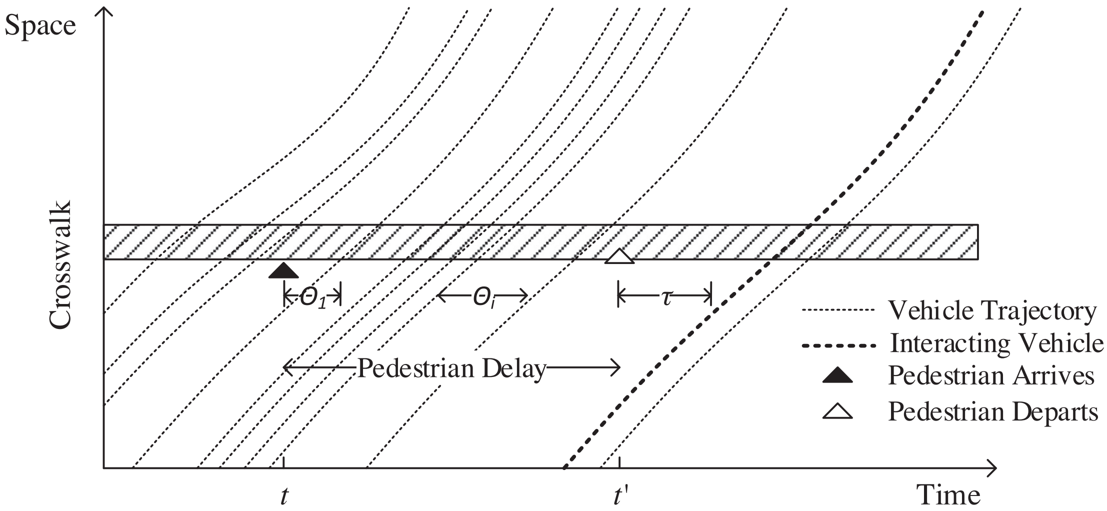

Fig. 1. Schematic of the pedestrian delay model framework.

The first pedestrian delay model was developed by William Adams in 1936 (Adams, 1936), and has been expanded/modified by various researchers (Tanner, 1951; Mayne, 1954; Underwood, 1961; Cowan, 1975; Troutbeck, 1986, etc.). The early models adopted simple vehicle headway distributions and ignored vehicle yield behaviors. A few other researchers explored this problem by considering it as a stochastic process (Weiss and Maradudin, 1962; Heidemann and Wegmann, 1997). Recent pedestrian delay studies focused on calibrating and modifying the previous models for different traffic scenarios (Guo et al., 2004; Schroeder and Rouphail, 2010b; Vasconcelos et al., 2012), such as two-stage crossing, pulsed traffic caused by signals, etc. The Highway Capacity Manual (HCM) 2010 improved Adams' model (1936) with adding the assumption of constant vehicle yield rate for estimating pedestrian delay (HCM, 2010). However, those existing models may not sufficiently capture the realistic pedestrian street crossing behavior at unsignalized intersections in urban networks. Particularly, findings from observational studies, have identified factors such as platooned traffic flow pattern (Bowman and Vecellio, 1994; Sisiopiku and Akin, 2003; Avineri et al., 2012; Schroeder et al., 2014), driver yielding behavior (Sun et al., 2003; Schroeder, 2008), and pedestrian yield recognition (Schroeder, 2008; Schroeder et al., 2014), that have great importance and should be considered in the pedestrian delay model. The existing models are missing those and may not perform well in estimating pedestrian delay in cases of high-level pedestrian activities, such as in major city CBD areas, campus areas, etc.

The objective of this study is to propose a generalized mathematical model of pedestrian delay for crossing a traffic stream at unsignalized intersections, and based on that to address driver yielding and platooned vehicular traffic conditions in urban networks. The model is developed using Renewal Theory, which solves this problem in a more direct way as a stochastic process and provides possibilities for future model expansion. Firstly, a generalized model is developed to be applied with any vehicle headway distribution or driver yield behavior assumptions (solving a G/G/1 queuing system). Then the proposed model is applied on the basis of a mixture of free traffic and platooned traffic with consideration of driver yielding behaviors to replicate field conditions. A special case adopting the HCM 2010 assumptions is also derived as a comparison with the HCM 2010 model. Next, the model was compared to field data. A total of 110 pedestrian crossing events in Gainesville, Florida, as well as 99 pedestrian crossing events in Washington, D.C., were used in the comparison. An expanded validation using simulation was also employed to evaluate the model results under a broad set of parameters.

The rest of the paper is organized as follows. Section 2 provides an overview of previous research on pedestrian delay and pedestrian street crossing behavior (with related vehicle interactions). Section 3 discusses the model assumptions and variable definitions. Section 4 discusses renewal theory and provides the model formulation and the two application cases. Section 5 presents the field data collection procedure and the model results. Section 6 provides the stochastic simulation and model validation results. Conclusions and recommendations are provided in the last section.

2. Literature review

An overview of previous research on pedestrian delay models is provided in this section. Existing studies on pedestrian street crossing behavior (with related vehicle interactions) are also reviewed to provide the basic assumptions for the proposed pedestrian delay model in this study.