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Pedestrian temporal and spatial gap acceptance at mid-block street crossing in developing world

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ABSTRACT

Introduction: Most of the midblock pedestrian crossings on urban roads in India are uncontrolled; wherein the high degree of discretion in pedestrians' behavior while crossing the traffic stream, has made the situation complex to analyze. Vehicles do not yield to pedestrians, even though the traffic laws give priority to pedestrians over motorized vehicles at unsignalized pedestrian crossings. Therefore, a pedestrian has to decide if an available gap is safe or not for crossing. *Method:* This paper aims to investigate pedestrian temporal and spatial gap acceptance for midblock street crossings. Field data were collected using video camera at two midblock pedestrian crossings. The data extraction in laboratory resulted in 1107 pedestrian gaps. Available gaps, pedestrians' decision, traffic volume, etc. were extracted from the videos. While crossing a road with multiple lanes, rolling gap acceptance behavior was observed. Using binary logit analysis, six utility models were developed, three each for temporal and spatial gaps. *Results and conclusions:* The 50th percentile temporal and spatial gaps ranged from 4.1 to 4.8 s and 67 to 79 m respectively, whereas the 85th percentile temporal and spatial gaps ranged from 5 to 5.8 s and 82 to 95 m respectively. These gap values were smaller than that reported in the studies in developed countries. The speed of conflicting vehicle was found to be significant in spatial gap but not in temporal gap acceptance. The gap acceptance decision was also found to be affected by the type of conflicting vehicles. *Practical applications:* The insights from this study can be used for the safety and performance evaluation of uncontrolled midblock street crossings in developing countries.

1. Introduction

Because of the relatively low penetration of vehicles, existence of multi-modal transit systems, high congestion levels on roads, high population density, and mixed land-use, walking is a predominant mode of transportation in Indian cities for short trips. As per the comprehensive transportation study (Transform, 2008) for Mumbai Metropolitan Region (MMR), about 52% of the total trips are walking trips. This high level presence of pedestrians results in safety concerns. In Mumbai, 57% of the persons who died in road accidents between 2008 and 2012 were pedestrians (Singh, 2013). Other cities in India also have a very high share of pedestrians in road accident fatalities. During 2006 to 2009 in Delhi, the national capital, this share was found to be 52% (PTI, 2014). A total of 858 persons died in road accidents in Bangalore in 2010, of which 400 were pedestrians (Ray, 2013). In order to propose measures to minimize pedestrian fatalities, it is important to study the behavior of pedestrians at the facilities used by pedestrians. Midblock pedestrian crossing is an important pedestrian facility, which is the focus of this study.

The traffic on Indian urban roads is heterogeneous, which is characterized by the following: (a) large variations in vehicle characteristics; (b) absence of lane-based movements; (c) aggressive driving; and (d) weak enforcement of traffic rules. Among the various pedestrian facilities, unsignalized midblock crossings are critical because hardly any vehicle yields to pedestrians there, even in the presence of proper signs. The Central Motor Vehicles Rules of 1989 (Ministry of Road Transport and Highways, 1989) gives priority to pedestrians over motorized vehicles at unsignalized pedestrian crossings. However, the enforcement of the rule is practically non-existent and it is generally assumed that pedestrians have lower priority at unsignalized crossings. Therefore, pedestrians need to wait until a suitable gap is available in the conflicting traffic stream. At a crossing on multi-lane roads, pedestrians often cross in stages, making decisions for each conflicting vehicle. Decision to accept a gap is influenced by many factors. All the above discussion emphasizes the need to understand the gap acceptance behavior of pedestrians at uncontrolled pedestrian crossings in the presence of heterogeneous traffic. For additional discussion and analysis of different aspects of heterogeneous traffic, see Arasan and Koshy (2005), Venkatesan, Gowri, and Sivanandan (2008), Tang, Huang, Zhao, and Shang (2009), Mathew and Radhakrishnan (2010), Patil and Pawar (in press), and Patil and Sangole (in press). Although there are a few more studies analyzing and modeling heterogeneous

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traffic, studies on interactions of pedestrians with heterogeneous traffic are limited. With the help of data collected at two uncontrolled pedestrian crossings, we analyzed the factors influencing the gap acceptance and developed models to estimate gap acceptance probability. We have considered both temporal and spatial gaps in this paper.

This paper is organized into six sections, including this section. Section 2 reviews the past literature related to pedestrian gap acceptance. The definitions and measurement of lag and gap at pedestrian crossings are presented in section 3. Data collection and extraction procedure is explained in Section 4. Development of gap acceptance models and their comparison are given in Section 5. We present our conclusions and limitations of the study in Section 6.

2. Literature review

Maneuvering an uncontrolled multi-lane crossing especially on an arterial with high speeds is not an easy task for pedestrians. Often pedestrians misjudge available gaps and make very unsafe decisions that sometimes result in an accident. Sandt and Zegeer (2006) analyzed the crashes at midblock and intersection pedestrian crossing using the data from Kentucky, Florida, and North Carolina. They revealed that 79% to 89% of crashes took place at selected uncontrolled midblock crossings. According to Chu (2006), crossing at midblock locations appears to be more deadly than at intersections.

A few studies that have analyzed the gap acceptance behavior of pedestrians are presented below. Using a lognormal regression model, Yannis, Papadimitriou, and Theofilatos (2013) studied the effect of various parameters on pedestrian gap acceptance. Papadimitriou, Yannis, and Golias (2009) discussed discrete choice models to enumerate pedestrian's decision while crossing a road section. According to Chu, Gittenplan, and Baltes (2002) and Sun, Ukkusuri, Benekohal, and Waller (2003), the decision of pedestrians to cross the road depends on the distance between the approaching vehicle and pedestrian (i.e., available gap). Oxley, Ihsen, Fildes, Charlton, and Days (2005) and Das, Manski, and Manuszak (2005) concluded that the distance between the vehicles and the pedestrians is an important predictor of crossing decisions. Oxley et al. (2005) studied the crossing behavior by grouping pedestrians into three age groups (30–45, 60–69, and 75–above). Brewer, Fitzpatrick, Whitacre, and Lord (2006) found speed of the pedestrians as a factor affecting pedestrian gap acceptance. A study by Abdel-Aty, Chundi, and Lee (2007) showed that the number of lanes, median type, speed limits, and speed ratio were correlated with the frequency of crashes during crossing. Hamed (2001) studied pedestrian waiting time while crossing, to understand its effect on pedestrian behavior. Zegeer, Stewart, Huang, and Lagerwey (2001) studied safety effects of marked and unmarked crosswalks at uncontrolled locations. The research done by DiPietro and King (1970) observed that pedestrians moving in group accept shorter gaps than that of segregated pedestrians.

The term critical gap is used as threshold gap value in capacity and LOS analysis of unsignalized intersection and pedestrian crossing. Highway Capacity Manual 2000 (HCM, 2000) used term critical gap, but in Highway Capacity Manual 2010 (HCM 2010) the term is replaced with critical headway. HCM-2010 defines critical headway as "the time in seconds below which a pedestrian will not attempt to begin crossing the street." If the available gap is greater than the critical gap, it is assumed that the pedestrian will cross, but if the available gap is less than the critical gap, it is assumed that the pedestrian will not cross. Brewer et al. (2006) explained in detail the different gaps encountered by the pedestrian. They classified gaps depending on characteristics of the site and time a pedestrian attempts to cross. In the former case, gaps are referred to as adequate gap and critical gap. While in the latter case gaps are referred to as available gap, accepted gap, and rejected gap. Manual on Uniform Traffic Control Devices (MUTCD) (Federal Highway Administration, 2009) uses the term 'adequate gap,' which is the same as the critical gap defined in other studies.

The literature review indicates that very few studies have been done on pedestrian crossings at uncontrolled midblock sections with heterogeneous traffic. Moreover, no study was found that analyzes spatial gaps for uncontrolled midblock pedestrian crossings in India. In this study, we analyzed and compared spatial and temporal gaps estimated by binary logit models. Required gap acceptance data were collected at two uncontrolled marked midblock crossings using video and extracted in laboratory.

3. Lag and gap at pedestrian crossings

We defined temporal gap (spatial gap) for a pedestrian waiting to cross the uncontrolled midblock section as the time (space) separating two consecutive vehicles approaching the crossing. The point of intersection of the paths of pedestrians and approaching vehicles is a conflicting point. Lag is the first gap that a crossing pedestrian faces. Temporal lag is the time passed after a pedestrian is ready to cross the road until the first approaching vehicle reaches the conflicting point. The vehicle intending to approach the uncontrolled crossing is referred to as conflicting vehicles. Spatial lag is the distance of the first conflicting vehicle from the conflict point when a pedestrian starts looking for a suitable gap.

Gap and lag are explained with the help of Fig. 1. Let t_0 be the time at which the pedestrian arrives at crossing point. Let the first conflicting vehicle at time t_0 be at position Y′–Y′ and S be the distance of the conflicting vehicle from the conflict point. The distance S is the spatial lag. The time at which the conflicting vehicle reaches the conflict point is t_1. The difference between time t_1 and t_0 is the temporal lag.

It should be noted that when a road section has multiple lanes, the first conflicting vehicles can be on any lane. In other words, in case of multi-lane roadway, conflict point is not fixed laterally, thus we need to use conflict line as a reference. The position of conflicting vehicles transverse to the road length may influence the gap acceptance behavior of the pedestrians.

Based on the geometry and traffic at crossing, pedestrians may have to accept gap considering traffic in either one direction (E–W or W–E)

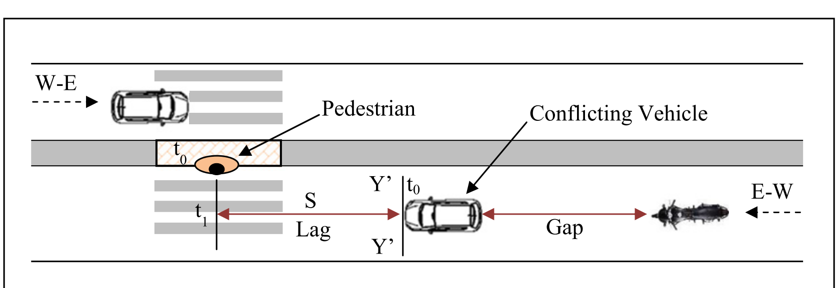

Fig. 1. Description of gap and lag (temporal and spatial).