Journal of Safety Research xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Safety Research

journal homepage: www.elsevier.com/locate/jsr

Special report from the CDC

Pedestrian crossing behaviors at uncontrolled multi-lane mid-block crosswalks in developing world

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ARTICLE INFO

Article history:
Received 24 June 2016
Received in revised form 2 October 2017
Accepted 5 December 2017
Available online xxxx

Keywords:
Pedestrians' crossing behaviors
Crossing strategy
Mid-block crosswalk
Gap acceptance model
Lane-based gap (LGAP)

ABSTRACT

Introduction: The gap acceptance theory was primarily used to study pedestrian crossing behaviors, in accordance to static gaps that are calculated in the light of the cross section of crosswalk. However, pedestrians will face a series of dynamic gaps (especially at any uncontrolled multi-lane crosswalk) when they decide to cross the street, thus, pedestrians' decisions are made based on the dynamic gaps of each lane. *Method:* Pedestrians' crossing behaviors at uncontrolled multi-lane mid-block crosswalk were investigated in this study. The lane-based gap (LGAP) was defined and five mid-block crosswalks were selected for observation in Wuhan, China. Pedestrians' behaviors and the corresponding traffic statuses were videoed as collected data, whose statistical analysis indicates that most pedestrians choose the rolling gap crossing strategy, which is different from existing research. Moreover, a logistic regression model was established to evaluate various influencing parameters (such as gender, age, waiting time and traffic volume) on the pedestrians' crossing strategy, whose accuracy is not satisfying. Therefore, the pedestrian dynamic gap acceptance (PDGA) model was put forward to describe pedestrians' crossing behaviors at any multi-lane crosswalk based on detailed analysis of the pedestrians' decision procedure. *Results:* The corresponding results show that its accuracy may be up to 88.6% to well describe pedestrians' crossing behaviors.

1. Introduction

With the rapid growth of automobiles in the developing world, pedestrian safety is a serious problem. According to the World Health Organization (WHO, 2013), about 270,000 pedestrians were killed in 2010 all over the world, and a high proportion of the casualties occurred in developing countries. Many pedestrian-vehicle crashes occurred at mid-block crosswalks (Aziz, Ukkusuri, & Hasan, 2013) because of the low yielding rate of vehicles at crosswalks in developing countries (such as China and India), even though traffic laws give priority to pedestrians over motorized vehicles at any non-signalized crosswalk. In light of the road traffic accident statistics report of China (Traffic Management Bureau of the Ministry of Public Security, 2013), 15,221 pedestrians were killed in 2012, which accounts for 25.37% of the total traffic accident fatalities. The situation was even worse in India where, for example, 57% of road fatalities from 2008 to 2012 were pedestrians in Mumbai (Pawar & Patil, 2015).

Pedestrian crossing behaviors must be understood in detail to improve their safety. Studies generally focused pedestrian crossing behaviors at mid-block crosswalks (Pawar & Patil, 2015; Rastogi, Chandra, Vamsheedhar, & Das, 2014; Sun, Ukkusuri, Benekohal, & Waller, 2003; Yannis, Papadimitriou, & Theofilatos, 2010) based on the pedestrian gap acceptance (PGA) theory. Most scholars presumed that pedestrians made decisions based on the current gaps calculated in the light of the cross section of the whole road (See Fig. 1(a)). Only the nearest vehicle, rather than other vehicles close to the crosswalk, is taken into account. On the other hand, pedestrians may actually face a series of complicated and dynamic gaps and usually observe the gaps for each lane, then adopt the appropriate gap to cross the street in developing countries (Kadali & Vedagiri, 2013). The crossing procedures are generally discontinuous or even lane by lane. The gap should be calculated for each lane called as a lane-based gap (LGAP, see Fig. 1(b)) to describe the above crossing mode accurately. However, few studies have investigated pedestrians' crossing behaviors based on LGAP so far.

Pedestrians' crossing behaviors at multi-lane mid-block crosswalks were investigated in this study. The traffic survey was carried out at five uncontrolled mid-block crosswalks in Wuhan, China. Then,

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https://doi.org/10.1016/j.jsr.2017.12.018
0022-4375/

Please cite this article as: Zhang, C., et al., Pedestrian crossing behaviors at uncontrolled multi-lane mid-block crosswalks in developing world, *Journal of Safety Research* (2017), https://doi.org/10.1016/j.jsr.2017.12.018

pedestrian crossing behaviors were analyzed and a pedestrian dynamic gap acceptance (PDGA) model was established based on LGAP to accurately depict pedestrians crossing procedures at multi-lane crosswalks.

2. Literature review

Crossing an uncontrolled multi-lane crosswalk is not easy for any pedestrian. Analysis of crashes at mid-block crosswalks and intersections revealed that 79% to 89% of crashes took place at selected uncontrolled mid-block crossings (Sandt & Zegeer, 2006). According to Chu (2006), crossing at mid-block locations is becoming more deadly than that at intersections.

Many studies were carried out to observe pedestrian crossing behaviors and safety, whose influencing factors primarily include several human and environmental factors, demography, roadway characteristics, and vehicular characteristics. Many studies focused on statistical analysis (Almodfer, Xiong, Fang, Kong, & Zheng, 2015; Sandt & Zegeer, 2006), influencing factors (Abdel-Aty, Chundi, & Lee, 2007; Das, Manski, & Manuszak, 2005; Hamed, 2001; Oxley, Ihsen, Fildes, Charlton, & Day, 2005; Sun et al., 2003; Zegeer, Stewart, Huang, & Lagerwey, 2001; Zhuang & Wu, 2013), and different models to reflect pedestrian crossing behaviors (Cherry, Donlon, Yan, Moore, & Xiong, 2012; Papadimitriou, Yannis, & Golias, 2009; Petzoldt, 2014). Hamed (2001) investigated pedestrians' waiting time to understand its effect on pedestrians' crossing behaviors. Zegeer et al. (2001) studied safety effects of marked and unmarked crosswalks at uncontrolled locations. Papadimitriou et al. (2009) discussed a discrete choice model to describe pedestrians' decision while they are crossing street. Abdel-Aty et al. (2007) pointed out that the number of lanes, median type, speed limits, and speed ratio were correlated to the frequency of crossing crashes for pedestrians. Das et al. (2005) noted that pedestrian crossing behaviors were related to their standing at roadsides or central zones. Chandra, Rastogi, and Das (2014) carried out a detailed analysis to determine various influencing parameters for pedestrians' crossing behaviors and to find that the accepted gaps vary with conflicting traffic and crossing speed of pedestrians. Cherry et al. (2012) studied illegal mid-block pedestrian crossings in China, and established a conflict model to evaluate the accident risk of pedestrians. Petzoldt (2014) found that pedestrians were apt to make their decisions based on systematically distorted time rather than physical distance to arrival estimates.

The pedestrian gap acceptance (PGA) model is popular to analyze pedestrians' crossing behaviors (Kadali & Perumal, 2012; Kadali & Vedagiri, 2013; Yannis et al., 2010). Moreover, central tendency, dispersion, and distribution of gap acceptance data were presented and the size of traffic gaps rejected or accepted by pedestrians was discussed in several research findings (Chandra et al., 2014; Koh & Wong, 2014; Pawar & Patil, 2015). The probability of pedestrian gap acceptance was estimated by some scholars (Kadali & Perumal, 2012; Koh & Wong, 2014; Sun et al., 2003) to show that the gap size, number of waiting pedestrians, and age are critical influencing factors for pedestrians' crossing behaviors. Other influencing factors such as vehicle speed, pedestrian crossing direction, gap size, and age of the decision-making pedestrian were also studied (Pawar & Patil, 2015; Petzoldt, 2014; Yannis et al., 2010; Zhou, Zhang, Peng, Lv, & Qiu, 2016). Sun et al. (2003) used the probabilistic model and the binary logistic regression model, respectively, to describe pedestrian gap acceptance behaviors and driver yielding behaviors at mid-block locations. Oxley et al. (2005) carried out traffic simulation tests to analyze the influencing factors (such as pedestrian age, traffic speed, and time headway) for gap acceptance behaviors. Kadali and Perumal (2012) and Kadali and Q8 Vedagiri (2013) established a pedestrian gap acceptance model to reflect pedestrians' crossing behaviors. Yannis et al. (2010) investigated pedestrians' gap acceptance for mid-block crosswalks in urban areas, and the results reveal that this type of crossing decision is largely determined by the distance from incoming vehicles and the waiting time of pedestrians. Pawar and Patil (2015) observed the probability of accepting spatial gaps and found that pedestrians accepted smaller gaps while the conflicting vehicles were smaller, such as two-wheel motorcycles.

In summary, there is research that help to understand pedestrian crossing behaviors at uncontrolled crosswalks, where the gap is usually calculated according to the cross section of any crosswalk and the current gap was generally supposed to dominate pedestrian decisions. As shown in Fig. 1(a), the gap based on the cross section is too small to be accepted for pedestrians at roadsides. However, many pedestrians decided to cross the road from our observation, because the gaps for Lanes 1 and 2 are long enough (see Fig. 1(b)), the first vehicle in Lane 3 passed the crosswalk when pedestrians passed Lane 2; therefore, pedestrians can pass Lane 3 smoothly by adopting the subsequent gap rather than the current gap in Lane 3. The existing gap acceptance model cannot explain appropriately these complicated crossing behaviors at multi-lane crosswalks.

In this paper, the concept of lane-based gap (LGAP), which means the gaps are quantified over each lane, instead of over road cross section, has been proposed. Furthermore, for a multi-lane mid-block crosswalk, pedestrians will face a series of dynamic gaps, and they usually observe the gaps of each lane, then choose the appropriate LGAPs to cross the street (see Fig. 2). It is a multistep decision process rather than a one-kick decision. This paper analyzes pedestrian crossing behaviors and sets up a dynamic gap acceptance model based on LGAP to depict realistic pedestrian crossing behaviors in developing countries.