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Studying critical pedestrian behavioral changes for the safety assessment at signalized crosswalks

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ABSTRACT

Pedestrian-vehicle conflicts are one of the most important safety concerns at signalized intersections especially in urban areas. Conflicting vehicles and pedestrians select their maneuvers by predicting the other user behavior. Sudden behavioral changes of pedestrians such as sudden speed change (acceleration or deceleration) cannot be predicted by drivers, which can lead to safety hazards especially if these sudden behavioral changes occur near conflict areas. In this study, continuous pedestrian speed profiles were analyzed at signalized crosswalks to investigate the existence of such behavioral changes. A methodology is proposed to identify significant sudden changes of pedestrian speeds. The locations and timings of these sudden speed change events were analyzed, and the influencing factors such as crosswalk geometry and signal timing were studies and evaluated. Five signalized crosswalks at three intersections in Nagoya City were videotaped for analysis. Individual pedestrian maneuvers were extracted with image processing software. Empirical analysis showed that sudden acceleration events were observed at the entrance points to the pedestrian-vehicle conflict area, which highlights the significance of these events to pedestrian-vehicle conflict analysis. A multinomial logit model was developed to estimate the probability of a pedestrian making a sudden speed change as a function of different influencing factors. The results implied that the entering speed, necessary speed to finish crossing before the onset of the pedestrian signal red phase, and crosswalk length have a significant impact on speed change choices. This paper presents important suggestions to understanding pedestrian maneuvers in detail from the viewpoint of safety.

1. Introduction

Vehicle and pedestrian flows in urban areas have increased drastically over the years due to the increase in population density and economic growth. This magnified the interactions between pedestrians and vehicles to the degree that pedestrian–vehicle conflicts became the most severe traffic safety problem in urban areas. Majority of pedestrian-vehicle crashes occurs at pedestrian crossings where pedestrian maneuvers are significantly different from those in ordinary walking spaces because of the impacts of the crosswalk geometry, signal control, and presence of vehicles.

Policy makers around the world agree that pedestrian priority and safety have always been their primary objectives. However due to the increasing vehicle congestion in urban areas, the emphasis is often on improving the efficiency of vehicle movement which leads to negligence of pedestrian provisions making pedestrians vulnerable and prone to road crashes.

Most existing works have attempted to investigate variations in the walking speed at other pedestrian facilities, such as walkways and sidewalks. Few studies have addressed the issue of pedestrian speed at signalized crosswalks, which have significantly different operating and surrounding conditions compared to the others (Alhajyaseen, 2014). Although pedestrians at signalized intersections are given priority during the green phase, turning vehicles in conflict often do not give the right of way to pedestrians but tend to compete for it. Furthermore, long crosswalks, a short available green time, and other reasons may cause pedestrians to rush or suddenly change their speed without paying attention to the surrounding conditions (Iryo-Asano et al., 2014). In addition to other factors such as limited visibility and the intersection layout, pedestrian–vehicle accidents have become a major safety problem in urban areas that has resulted in a high rate of fatalities (National Police Agency in Japan, 2015). Many existing works on the mechanism of such crashes have concentrated on the driver behavior,

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assuming that it is the most critical factor. In reality, road users anticipate other users' behavior in order to avoid collisions. Thus, widely varying pedestrian behaviors and trajectories may result in misunderstanding their decisions, which can lead to safety problems. Sudden changes in pedestrian behavior while they cross, such as abrupt speed changes, cannot be predicted by the driver, which can cause severe conflicts. There is no reference in the literature for studying the microscopic behavioral changes of pedestrians at crosswalks from real world observations. Detection of the sudden changes in pedestrian behavior is also demanding for autonomous vehicles (Hashimoto et al., 2016). They need to ensure safety by accurate estimation of potential conflicts with pedestrians (Hashimoto et al., 2016). The existing methodologies to detect pedestrians simply consider the existence of surrounding pedestrians (Dollar et al., 2012), while they do not consider the pedestrians' sudden behavioral changes that may cause hazardous conflict. Therefore, understanding the characteristics of such behavior is important also for development of safer avoidance algorithms for autonomous vehicles. It is important to mention that assuming a conservative reaction of autonomous vehicle whenever there is a pedestrian approaching a crosswalk, will significantly deteriorate the mobility levels and reduce capacity. What we are looking for in this study, is to develop a methodology that can predict realistic pedestrian behaviors and as a result accurate arrivals at conflict areas which can be used to take informed and appropriate decisions by drivers or autonomous vehicles. This will improve mobility levels will insuring safety.

In previous studies, authors analyzed pedestrian speeds at signalized crosswalks and found that the walking speed increases with the elapsed time since the onset of the pedestrian green (PG) phase (Zhang et al., 2013). Furthermore, empirical analysis showed that pedestrians hurry when entering crosswalks as their green light flashes and then tend to significantly decrease their speed while crossing (Iryo-Asano et al., 2014). A methodology was proposed to estimate pedestrian travel speeds in the first and second halves of the crosswalk as a function of the crosswalk geometry and signal timings to estimate the needed crossing time when setting the pedestrian signal times (Iryo-Asano et al., 2014). Previous works on pedestrian speed profiles divided them into consecutive constant travel speeds (first and second halves of the crosswalk), which is sufficient for analyzing the pedestrian signal time settings but not for assessing the safety of pedestrian–vehicle conflicts. Studying the instantaneous pedestrian speeds and identifying possible sudden changes in pedestrian behavior while crossing is crucial for pedestrian safety analysis at crosswalks. The existence of such changes in the pedestrian speeds should be verified so that surrogate safety measures such as post-encroachment time can be quantitatively estimated to provide a reliable assessment of pedestrian–vehicle conflicts and their severity. This paper is a continuation of previous efforts (Iryo-Asano et al., 2014; Iryo-Asano and Alhajyaseen, 2014) aiming to investigate pedestrian behavioral changes at signalized crosswalks in terms of speed, and to identify influencing factors.

2. Literature review

In order to analyze the interactions between pedestrians and vehicles at intersections, it is important to gain better insights into the behavior of both pedestrians and vehicles. Most existing studies have concentrated on vehicle maneuvers, including speed, speed change, and gap acceptance behaviors; they assumed that vehicles are the main contributing element in pedestrian–vehicle crashes. Meanwhile, severe conflicts occur when road users fail to predict and properly react to other users' decisions. The widely varying behaviors and maneuvers of vehicles and pedestrians as well may lead to misunderstanding their decisions, which can result in severe conflicts.

Alhajyaseen et al. (2013a, 2013b, 2012a, 2012b) intensively analyzed turning vehicle maneuvers at intersections in Japan, including the paths, speed profiles, and gap acceptance. They found significant variations in vehicle paths and speeds at conflict points with pedestrians to be functions of the vehicle approaching speed, crosswalk location, and intersection geometry. These variations significantly affect the conflict area with pedestrians and the severities of the conflicts. As a complement, they analyzed pedestrian behavior microscopically (concentrating on crossing decision and speed) considering the impacts of the crosswalk geometry and signal timing parameters (Iryo-Asano et al., 2014; Iryo-Asano and Alhajyaseen, 2014). They concluded that pedestrian maneuvers widely vary depending on many factors, such as the timing of the crossing, signal indication, pedestrian speed, origin and destination, probability of encountering a turning vehicle, crosswalk geometry (length and width), presence of other pedestrians on the crosswalk, and cultural background. Such differing behaviors make it difficult for drivers to correctly predict pedestrian decisions, which increases the probability of improper maneuvers that put pedestrian safety at risk. Koh and Wong (2014) reached similar results; in their empirical analysis, they found that pedestrian crossing speeds significantly differ during the pedestrian green (PG) phase compared to the pedestrian flashing green (PFG) phase. Schmitz (2011) confirmed that the type of pedestrian signal significantly affects the pedestrian behavior and crossing speed. He found that pedestrian countdown timers increase the pedestrian crossing speed. Other studies (Supernak et al., 2013; Yang and Sun, 2013; Xu et al., 2013) have confirmed that aspects of the crosswalk layout such as the length, width, and presence of refuge islands have a significant effect on pedestrian compliance to signals.

Wang et al. (2011) studied the pedestrian compliance to signals and found that the probability of pedestrians violating a signal is influenced by the waiting time or delay, personal characteristics (e.g., age and gender), trip purpose, and traffic conditions (e.g., pedestrian flow rate and vehicular traffic volume). In a recent study by Hashimoto et al. (2016), a model based on Dynamic Bayesian Network is proposed to estimate pedestrian stop-go decision when approaching crosswalks. They claimed that the model is able to recognize the pedestrian crossing decision in a few seconds from the traffic signal and pedestrian position information. However pedestrian behavior while crossing including potential velocity changes is not analyzed. They highlighted the importance of such models for the active safety systems which is highly needed in traffic condition with growing demands in autonomous driving and Connected Vehicles.

Several other studies have analyzed the pedestrian average walking speed as an important factor for the operation and design of pedestrian facilities. Navin and Wheeler (1969) and Fruin (1971) were the first to perform macroscopic pedestrian speed analysis and have been followed by many researchers. The effects of age, gender, and other attributes have been addressed in several studies (e.g., Avineri et al., 2012) on providing slow walkers such as elderly people with the necessary clearance time (LaPlante and Kaeser, 2007). However, the pedestrian speed at crosswalks is important to not only determining the clearance time but also analyzing the probability of conflict with turning vehicles and the severity of these conflicts.

Several studies have analyzed pedestrian speeds at various facilities (e.g., sidewalks, walkways, and crosswalks) by considering the seasonality, gender, and age (Montufar et al., 2007; Tarawneh, 2001; Lam and Cheung, 2000). They all yielded the same conclusion that pedestrian speeds are significantly higher at crosswalks than at sidewalks and walkways. They suggested that the