Accident Analysis and Prevention 111 (2018) 23–33

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Full length article

A novel framework to evaluate pedestrian safety at non-signalized locations

Ting Fu[a,*], Luis Miranda-Moreno[a], Nicolas Saunier[b]

[a] Department of Civil Engineering and Applied Mechanics, McGill University, Room 268, Macdonald Engineering Building, 817 Sherbrooke Street West, Montréal, Québec H3A 0C3, Canada
[b] Department of Civil, Geological and Mining Engineering, Polytechnique Montréal, C.P. 6079, succ. Centre-Ville, Montréal, Québec H3C 3A7, Canada

ARTICLE INFO

Keywords:
Pedestrian-vehicle interaction
Distance-velocity model
Surrogate measures of safety
Crosswalk safety
Crosswalk treatment evaluation

ABSTRACT

This paper proposes a new framework to evaluate pedestrian safety at non-signalized crosswalk locations. In the proposed framework, the yielding maneuver of a driver in response to a pedestrian is split into the reaction and braking time. Hence, the relationship of the distance required for a yielding maneuver and the approaching vehicle speed depends on the reaction time of the driver and deceleration rate that the vehicle can achieve. The proposed framework is represented in the distance-velocity (DV) diagram and referred as the DV model. The interactions between approaching vehicles and pedestrians showing the intention to cross are divided in three categories: i) situations where the vehicle cannot make a complete stop, ii) situations where the vehicle's ability to stop depends on the driver reaction time, and iii) situations where the vehicle can make a complete stop. Based on these classifications, non-yielding maneuvers are classified as "non-infraction non-yielding" maneuvers, "uncertain non-yielding" maneuvers and "non-yielding" violations, respectively. From the pedestrian perspective, crossing decisions are classified as dangerous crossings, risky crossings and safe crossings accordingly. The yielding compliance and yielding rate, as measures of the yielding behavior, are redefined based on these categories. Time to crossing and deceleration rate required for the vehicle to stop are used to measure the probability of collision. Finally, the framework is demonstrated through a case study in evaluating pedestrian safety at three different types of non-signalized crossings: a painted crosswalk, an unprotected crosswalk, and a crosswalk controlled by stop signs. Results from the case study suggest that the proposed framework works well in describing pedestrian-vehicle interactions which helps in evaluating pedestrian safety at non-signalized crosswalk locations.

1. Introduction

Pedestrians, referred often as vulnerable road users, are highly susceptible to severe road injuries and fatalities when involved in vehicle crashes. For example, in 2013, 14% of total road crash fatalities reported in the US (NHTSA, 2015), and 15.6% of road crash fatalities in Canada were pedestrians (Transport Canada, 2015). A large proportion of crashes occur either at uncontrolled crossings (without stop signs or traffic signals) or at non-signalized crossings (without traffic signals), for instance, more than 70% of the intersection-related fatal crashes in the US in the years from 2010 to 2012 occurred at non-signalized intersections (McGee et al., 2015).

Road safety studies are traditionally limited to analysis based on historical crash data (Nabavi Niaki et al., 2015) (Abdel-Aty and Haleem, 2010), which suffers from problems such as low-mean small sample, underreporting, mislocation and misclassification (Fu et al., 2016). Moreover, recent treatments cannot be rapidly evaluated due to the lack of after-treatment crash data which requires long periods (multiple years) of observation (St-Aubin et al., 2013). To overcome such issues related to crash data analysis, proactive methods based on surrogate safety measures, that do not require crashes to occur, have been gained some momentum in the literature.

Several studies have used surrogate safety measures for identifying risk factors or evaluating treatment effectiveness (St-Aubin et al., 2013) (Zangenehpour et al., 2013) (Zangenehpour et al., 2016). Despite important developments in surrogate safety analysis, the issue of the relationship between surrogate measures and crash-based measures remains (Tarko et al., 2009). Compared to the vehicle safety literature, pedestrian safety has attracted much less attention, in particular surrogate safety measures for pedestrian-vehicle interactions at crosswalks. The vulnerability of pedestrians explains why vehicles should yield right-of-way to pedestrians at crosswalks. Yielding behavior is therefore a critical part of interactions at non-signalized intersections. Yielding should therefore be considered among other surrogate safety measures used in previous studies (e.g. time-to-collision or post-encroachment time). Past research has considered yielding compliance

* Corresponding author.
E-mail addresses: ting.fu@mail.mcgill.ca, ting.fu.tj@gmail.com (T. Fu), luis.miranda-moreno@mcgill.ca (L. Miranda-Moreno), nicolas.saunier@polymtl.ca (N. Saunier).

https://doi.org/10.1016/j.aap.2017.11.015
Received 20 March 2017; Received in revised form 9 November 2017; Accepted 11 November 2017
0001-4575/

(Lacoste et al., 2014) (Shurbutt and Van Houten, 2010), but their definition of yielding compliance is ambiguous. Furthermore, there are situations where it is impossible for the vehicle to yield considering its proximity and speed to the crosswalk at the occurrence of the pedestrian. Such situations are likely considered as violations in most previous studies.

This research aims to address the above-mentioned research gaps in the pedestrian safety literature. The main purpose is two-fold: i) to propose a new surrogate safety framework to investigate pedestrian-vehicle interactions at non-signalized crosswalks, and ii) using a case study, to apply the proposed approach to explore pedestrian safety issues and the efficiency of countermeasures at crosswalks.

2. Literature review

2.1. Pedestrian-vehicle interactions and surrogate safety measures for crosswalk safety

Due to the limitations of using crash data, many studies have attempted to use different surrogate safety measures to investigate pedestrian-vehicle interactions. Hydén depicted the general safety hierarchy framework of surrogate safety analysis, suggesting a relationship between crashes and conflicts, their position is the hierarchy representing their chance of resulting in a crash (Hydén, 1987). Laureshyn considered the validity and reliability of different surrogate safety measures in behavioral and road safety research (Laureshyn, 2010), and the indicators include time to collision (TTC), post-encroachment time (PET), gap time (GP), compliance with the yielding rules and stop sign requirements. Some researchers have used TTC and PET for pedestrian safety (Almodfer et al., 2015) (Tang and Nakamura, 2009), with (Almodfer et al., 2015) finding these measures as the most used. Some have indicated their preference for using PET in situations where road user trajectories are crossing (e.g. pedestrian safety at crosswalks) (Almodfer et al., 2015) (Tang and Nakamura, 2009). Conflicts between pedestrians and vehicles may be divided into discrete severity levels based on different PET and TTC thresholds (Malkhamah et al., 2005) (Ismail et al., 2011). Pedestrian-vehicle interactions are difficult to describe because of the unpredictable behavior of the road users (Almodfer et al., 2015), especially pedestrians whose direction, speed, and acceleration/deceleration can change rapidly. This paper will use the more general term of interactions instead of conflicts, as conflicts have specific definitions in existing traffic conflict techniques such as the Swedish traffic conflict technique (Hydén, 1987). Interactions are defined as situations where the road users of interest are close enough in time and space, such that they may interact with each other (Nicolas et al., 2010).

Different data generation techniques and sensors (e.g., loops, radar, GPS devices and video cameras), have been used to extract information for surrogate safety analysis (Stipancic et al., 2016) (Golob et al., 2004) (Lee et al., 2002). Among these sensors, video-based devices, which provide rich positional data and other information beyond the capabilities of most other devices, are the most promising (Robert, 2009). The development of video-based techniques (computer vision) has brought about the possibility of investigating yielding compliance and crossing decision in a more precise and microscopic way.

2.2. Yielding compliance and crossing decision studies

Many studies that are not explicitly in the literature on surrogate measures of safety have investigated vehicle-yielding behavior at non-signalized crosswalks (Lacoste et al., 2014) (Shurbutt and Van Houten, 2010) (Fitzpatrick et al., 2006). For example, Fitzpatrick used the driver yielding rate to check effectiveness of different crosswalk treatments through meta-analysis (Fitzpatrick et al., 2006). A study conducted in Winnipeg found crosswalks with overhead flashing devices had higher average yielding rates than those with the side-mounted passive signs (Lacoste et al., 2014). Shurbutt and Van Houten used yielding rate to validate the performance of the rectangular rapid-flashing beacon (RRFB) at non-signalized crosswalks (Shurbutt and Van Houten, 2010). Many studies have used "yielding compliance" to describe vehicle-yielding behavior (Lacoste et al., 2014) (Shurbutt and Van Houten, 2010) (Fitzpatrick et al., 2006). The yielding compliance of a driver at non-signalized crosswalks refers to situations where the driver yields to pedestrians following the traffic rules. The majority of past studies consider non-yielding maneuvers as violations and use the rate of non-yielding maneuvers to measure the yielding compliance. However, in some situations, vehicles are too close in time to the crosswalk to stop at the moment the pedestrian shows the intention to cross. In such situations, drivers cannot yield even if they want to, and such situations cannot be treated as violations. Only the study presented in (Shurbutt & Van Houten, 2010) has identified these situations and excluded them from violations in a simple way by using a fixed distance from the crosswalk. Furthermore, the definition of non-yielding maneuvers is often unclear and relatively subjective, in particular regarding the pedestrian's intent to cross.

Many researchers have looked into pedestrian crossing decisions. For example, Granié et al. investigated pedestrian crossing decisions under various urban environments through a survey using sets of photographs presenting five different environments (Granié et al., 2014). Participants' decision to cross or not, perception of comfort and safety, and elements influencing decision-making were collected and analyzed (Granié et al., 2014). Liu and Tung looked at the effects of age, time gap, time of day, and vehicle approaching speed on the decision of pedestrians to cross the road based on pre-recorded videos of different road scenes (Liu and Tung, 2014). Using the simulated road environment from a mid-range driving simulator, Oxley et al. conducted a study to analyze pedestrians' gap selection and their crossing decisions (Oxley et al., 2005). Due to the limited available techniques for data collection, most of these past studies have been based on off-road, laboratory experiments, such as tests in simulators, and picture- or video-based surveys, which may not properly reflect real situations.

2.3. Driver reaction on road safety

Driver response time, also called perception-response time or reaction time, has a great impact on road safety, creating significant interest in this area of research (Hick, 1952) (Hyman, 1953) (Koppa, 2000) (Green, 2009). The distribution of driver response time is often called the Hick-Hyman "Law" (Hick, 1952) (Hyman, 1953) .Vehicle yielding maneuvers at pedestrian crossings include two critical times (and corresponding distances): 1) a perception-response time, which allows the driver to observe the pedestrian's intention to cross and make a decision to yield, and 2) a time to brake or perform another evasive action if necessary. Driver response time at crosswalks refers to the time lag between detection of the pedestrian and the initiation of braking. Response time greatly affects driver's yielding behavior at crosswalks and the risk that pedestrians face when they are crossing the street. Therefore, response time needs to be considered in crosswalk safety studies, which is uncommon in the literature.

Response time varies between individuals and depends on various factors such as age, gender and driving experience, the appearance of the pedestrians, distraction, and the built environment (Kosinski, 2005). Different studies have looked into driver response time and different distributions have been recommended (Koppa, 2000) (Green, 2009). Many of these studies considered response time to expected and unexpected events. At crosswalks, drivers are aware of the presence of pedestrians, thus pedestrian crossing events should be considered as expected, which is associated with shorter reaction times compared to unexpected events (Fitch et al., 2010). Among the past studies, Koppa and Rodger decompose the driver braking response prior to the actual braking into perception-reaction time and movement time (the amount of time required to move the foot to the brake pedal). Results from this