Pedestrian–Vehicle Interaction at Unsignalized Crosswalks

Subjects: Engineering, Civil
Contributor: Harley Amado

A systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), to generate a document that supports the development of future research, compiling the various studies focused on the analysis of the pedestrian-vehicle interaction at unsignalized crosswalks. Firstly, 381 studies were identified by applying the search protocol in the database sources; however, only nine studies were included in this review because most of the studies are not focused on this type of crosswalks or have not considered the micro-simulation perspective. For each study, an analysis of the used methodology for data collection was carried out, in addition to what type of model it was applied, including the variables that represent the PVI (Pedestrian-Vehicle Interaction). The outcomes obtained by this systematic review show that although the video camera observation technique is the most used, it is possible to complement them with other tools to add specific field information. Additionally, variables such as the adjacent yields, speed variables vehicles, pedestrian attitude, and the number of pedestrians waiting at the crossing were those most used in the cellular automata model or micro-simulation, which are the commonly developed models to simulate this interaction.

Keywords: systematic review ; pedestrian-vehicle interaction ; unsignalized crosswalks ; driver yielding behavior ; crossing behavior ; yielding behavior

Rationale

According to the global status report on road safety for the year 2018 conducted by the World Health Organization (WHO), the problem of traffic fatalities is getting worse as they increased to 1.35 million in 2016. In other words, almost 3700 people die every day on the roads of the world [1]. Likewise, the same report highlighted that it is the eighth cause of death overcoming diseases such as HIV/AIDS, tuberculosis, and diarrheal diseases. Vulnerable road users such as the pedestrian, cyclist, and motorcyclist represent 54% of the deaths in 2016 (specifically the pedestrian represents 23%). The vulnerability presented by these users is due to the disadvantages they present in terms of protection, speed, and weight, with respect to the vehicle. This vulnerability of the human body should be a determining factor in the design of transit systems and the control of speed [2]. People who died, are injured, or end up disabled because of a collision, whether as a vulnerable road user or not, have a global social cost. According to Peden et al. [3], the economic cost of crashes and injuries caused by traffic amounts is estimated to be 1% of the gross national product (GNP) in low-income countries, 1.5% in revenues medium, and 2% in high income.

The moment in which the desired movements of a pedestrian and a vehicle intercept (conflict), the so-called pedestrian-vehicle interaction (PVI) occurs, which is dynamic as it happens to depend on various factors and situations [4]. This interaction originates in pedestrian crossings with and without light signals, as in the case of intersections and mid-block crossings. Pedestrian crossings outside these crossings (also known as jaywalking) also generate this type of interaction. The type of interaction may vary depending on the geometry of the road where it occurs, legal restrictions, and the criteria of the driver and pedestrian [2]. It is important to mention that the interaction between the pedestrian and the vehicle is dominated by a non-verbal language. It can cause situations in which the pedestrian makes a decision considering the driver's approval, but the latter makes an unexpected decision, bringing as a consequence a conflict or even an accident. According to Fu et al. [5], the disposition of the driver to yield and the assertiveness of the pedestrian are one of the many factors that can influence this interaction.

At pedestrian crossings that are not controlled by light signals (unsignalized crosswalk) the priority of the pedestrian is not clear, even with legislation supporting pedestrian priority, and this results in higher levels of accident and death of pedestrians compared to those controlled by pedestrian traffic lights [6][7][8][9][10]. Not yield to pedestrians and high speeds at the time of interaction in this type of crossings are part of the elements that influence this consequence. The

compliance rate of drivers at zebra crossings is likely to vary across locations [11]. It is relevant to mention that the PVI not only impacts the pedestrian safety but also induces traffic congestion of vehicles and decreases the capacity of the roads, as demonstrated by Golakiya et al. [12], showing that for volumes higher than 1550 pph, the capacity was reduced to 32% in an urban arterial.

In this context, PVI has been generating interest among researchers, government and local entities, and other organizations, whose purpose is to analyze, determine, and develop policies and safety measures that help combat and mitigate the accidents, inside and outside of the pedestrian crossings. However, Feliciani et al. [13] state that such research has been limited by a variety of factors, such as difficulty in obtaining empirical data through observations in the field, safety, and ethical concerns related to experiments with individuals in the real-world and the limited scope of the developed simulation models. In addition, it is worth noting that the investigation has had as one of the most relevant premises that yielding to a pedestrian is a critical component of the accessibility and safety of pedestrians. Therefore, a better understanding of the behavior of the driver at the moment of yielding to a pedestrian can be of great value for conducting a more optimal PVI analysis [14]. In fact, the PVI is separated into two main processes, the pedestrian walking behavior and the driver yielding behavior. The behavior of the pedestrian has been analyzed mainly based on the probability that a pedestrian has to accept a time gap [15][16][17]. On the other hand, driver behavior has been analyzed focusing on the identification of the factors that have a greater influence in yielding to pedestrians. Indeed, the action of yielding to a pedestrian is influenced by various factors, such as dynamics of the vehicle, characteristics of the driver, traffic volume, attributes of pedestrians, and concurrent events in the pedestrian crossing [14][17][18][19]. The analysis of the driver yielding behavior assumes more relevance to ensure road safety since the driver tends to assume the risk because he/she feels protected inside the vehicle in contrast to the pedestrian who will accept time gaps that not compromise her/his physical integrity at least in normal conditions (i.e., visibility, weather, cognitive functions, etc.).

Besides these two behavior perspectives, PVI has been analyzed separately by type of road crossing. Crossings controlled by light signals are characterized by establishing clearly the priorities, thus allowing to have a PVI in a more controlled environment. Manxia Liu et al. [20] developed a microscopic model at signalized intersections taking into account three important aspects of pedestrian behavior when crossing, such as the evasion behavior with counter-flow pedestrians, the following behavior with leader pedestrians, and the collision avoidance behavior with vehicles. Wonho Suh et al. [15] replicated the pedestrian behavior in a crosswalk using the Vissim software to analyze the waiting time of pedestrians and their behavior regarding compliance with the red sign. Another type of pedestrian crossing is the so-called jaywalker representing a pedestrian cross on a road without using the zebra. In these cases, the PVI has also been focused on studies such as Wang et al. [21], who proposed a micro-simulation model of pedestrian jaywalking in the mid-block street crossing. This model was calibrated and validated using the data collected in the field, concluding by the result that this kind of tool can be used to supplement current guidelines for pedestrian-related problems. Finally, the pedestrian crossing through the zebra is associated with a high number of accidents, based on the statistical data of accidents and deaths of pedestrians at junctions without signaling, in addition to the fact that in this type of crossing pedestrians are more likely to be exposed to the risk of being run over by vehicles due to lack of control of the signal and the unclear right of way [4]. The need to have a clearer knowledge of the attempts of analysis and modeling of the interaction that occurs when a pedestrian is interested in crossing the zebra and the approaching vehicle has been highlighted.

It should be noted that PVI may assume distinct characteristics depending on the context (type of road, type of crosswalk, weather, and so on) but also on each agent, i.e., pedestrian and driver (age, gender, distraction, etc.) Therefore, the research focused on this subject has been mainly based on a microscopic level approach. In particular, micro-simulation has been applied and developed, considering that each unit (or agent) is represented by a record that contains a unique identifier and a set of associated attributes. A set of rules is applied to these units that leads to simulated changes in state and behavior.

Due to the relevance of this kind of study, some authors already conducted literature reviews in this field. Papadimitriou et al. [22] in 2009 conducted a critical review and evaluation of the existing research on the behavior of pedestrians in urban areas focusing on two separate aspects, the choice of route and the behavior when crossing. Based on this review, the authors found the lack of a general and detailed consideration of pedestrian behavior along an entire trip in urban areas. Considering the literature review performed by Papadimitriou et al., it is possible to observe three studies that carried out a model of the crossing behavior of pedestrians taking into account the interaction with the vehicle. Although the review mentions the place where these interactions were observed in the studies, the characteristics of each of the models and the variables that were used for the analysis of the PVI by the authors were not described.

In addition, Mamidipalli et al. [16] in 2015 performed a review of the analysis methods and approach for data collection and performance estimation for pedestrian crossing modeling and pedestrian-vehicle interaction. The authors concluded that there had been a broad interest in describing driver attitudes and pedestrian crossing behaviors. To obtain the data in these investigations, three different data collection techniques have been adopted, namely observational, instrumented vehicle, and driving/pedestrian simulator approaches. Regarding the PVI models, the authors mention several studies that have analyzed the pedestrian addressing its approach to the crosswalk, the crossing behavior, and the choice of the route.

Those previous reviews provided an overview of some models and methods that have been used to model the PVI until 2015. Nevertheless, gaps can be pointed out regarding some issues that were not clearly identified, such as the type of PVI, the used data collection methodology, the type of site where the study was conducted, the type of model used, and the variables or influential parameters in the PVI.

Overall, there is a lack of scientific material that allows having a specific and detailed feedback of the different studies that have tried to model and analyse the PVI that occurs specifically at unsignalized crossings. In this context, the present work intends to cover this gap using a thorough methodology to conduct a systematic review to provide a compilation of the studies that have analyzed the PVI, allowing a comparison between the data collection methodologies, the applied models, the used variables and influential parameters. The outcomes of this review can provide a line of route for future analysis of the PVI in microscopic environments, which is a relevant tool to support policy decisions that may improve safety for pedestrians in this type of crossings.

Objetive

Taking into account the number of accidents occurring at unsignalized pedestrian crossings and the lack of attention paid to PVI generated in those crossings, the objective of this study was to carry out a systematic review to identify and examine the studies that have attempted to propose a simulation model in a microscopic environment for the analysis of PVI. In this sense, this document compiles the investigations carried out in the last years, describing the different approaches used for the analysis of the PVI, to be used as a source of base information, guiding the development of future research for the optimization and standardization of the analysis and modeling of the PVI at unsignalized crossings. Additionally, studies that have analyzed the factors that influence the behavior of the pedestrian and driver and their interaction were selected. The latter was assumed because the decision-making processes of the driver to yield to the pedestrian and/or the pedestrian to cross or not cross are issues relevant to the simulation model.

References

1. World Health Organization. Global Status Report on Road Safety 2018; World Health Organization: Geneva, Switzerland, 2018.
2. Schroeder, B.; Rouphail, N.; Salamati, K.; Hunter, E.; Phillips, B.; Elefteriadou, L.; Chase, T.; Zheng, Y.; Sisiopiku, V.; Mamidipalli, S. Empirically-based performance assessment and simulation of pedestrian behavior at unsignalized crossings. Southeastern Transportation Research, Innovation, Development and Education Center (STRIDE). 2014. Available online: https://stride.ce.ufl.edu/wp-content/uploads/2017/03/Schroeder-STRIDE-2012-016S-Final-Report.pdf (accessed on 30 March 2020).
3. Peden, M.; Scurfield, R.; Sleet, D.; Mohan, D. Informe Mundial Sobre Prevención De Los Traumatismos Causados Por El Tránsito; Organización Mundial de la Salud: Washington, DC, USA, 2004.
4. Lili Lu; Gang Ren; Wei Wang; Ching-Yao Chan; Jian Wang; A cellular automaton simulation model for pedestrian and vehicle interaction behaviors at unsignalized mid-block crosswalks. *Accident Analysis & Prevention* **2016**, *95*, 425-437, 10.1016/j.aap.2016.04.014.
5. Ting Fu; Luis Miranda-Moreno; Nicolas Saunier; A novel framework to evaluate pedestrian safety at non-signalized locations. *Accident Analysis & Prevention* **2018**, *111*, 23-33, 10.1016/j.aap.2017.11.015.
6. Naomi Kupferberg-Ben David; The role of the physical environment in child pedestrian accidents. *Journal of Advanced Transportation* **1994**, *28*, 171-187, 10.1002/atr.5670280206.
7. Lloyd, D.; Wilson, D.; Mais, D.; Deda, W.; Bhagat, A. Reported Road Casualties Great Britain: 2014 Annual Report; Department for Transport: London, UK, 2015.
8. I. Nazionale Di Statistica, Road Accidents in Italy. Available online: https://www4.istat.it/en/archive/203775 (accessed on 8 November 2019).

9. Charles V. Zegeer; J. Richard Stewart; Herman Huang; Peter Lagerwey; Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations: Analysis of Pedestrian Crashes in 30 Cities. *Transportation Research Record: Journal of the Transportation Research Board* **2001**, *1773*, 56-68, 10.3141/1773-07.
10. Carmen A. Pfortmueller; Mariana Marti; Mirco Kunz; Gregor Lindner; Aristomenis K. Exadaktylos; Injury Severity and Mortality of Adult Zebra Crosswalk and Non-Zebra Crosswalk Road Crossing Accidents: A Cross-Sectional Analysis. *PLOS ONE* **2014**, *9*, e90835, 10.1371/journal.pone.0090835.
11. Fitzpatrick, K.; Turner, S.; Brewer, M.A.; Improving pedestrian safety at unsignalized intersections. *Inst. Transp. Eng. ITE J.* **2007**, *77*, 34, .
12. Hareshkumar Dahyabhai Golakiya; Manish Patkar; Ashish Dhamaniya; Impact of Midblock Pedestrian Crossing on Speed Characteristics and Capacity of Urban Arterials. *Arabian Journal for Science and Engineering* **2019**, *44*, 8675-8689, 10.1007/s13369-019-03786-x.
13. Claudio Feliciani; Luca Crociani; Andrea Gorrini; Giuseppe Vizzari; Stefania Bandini; Katsuhiro Nishinari; A simulation model for non-signalized pedestrian crosswalks based on evidence from on field observation. *Intelligenza Artificiale* **2017**, *11*, 117-138, 10.3233/ia-170110.
14. Katayoun Salamati; Bastian J. Schroeder; Duane R Geruschat; Nagui Rouphail; Event-Based Modeling of Driver Yielding Behavior to Pedestrians at Two-Lane Roundabout Approaches. *Transportation Research Record: Journal of the Transportation Research Board* **2013**, *2389*, 1-11, 10.3141/2389-01.
15. Wonho Suh; Dwayne Henclewood; Aaron Greenwood; Angshuman Guin; Randall Guensler; Michael Hunter; Richard Fujimoto; Modeling pedestrian crossing activities in an urban environment using microscopic traffic simulation. *SIMULATION* **2013**, *89*, 213-224, 10.1177/0037549712469843.
16. Shrikanth V. Mamidipalli; Virginia P. Sisiopiku; Bastian J. Schroeder; Lily Elefteriadou; Katy Salamati; Nagui Rouphail; Related Information; Probit-Based Pedestrian Gap Acceptance Model for Midblock Crossing Locations. *Transportation Research Record: Journal of the Transportation Research Board* **2015**, *2519*, 128-136, 10.3141/2519-14.
17. Sun, D.; Ukkusuri, S.; Benekohal, R.; Waller, S. Modeling of Motorist-Pedestrian Interaction at Uncontrolled Mid-Block Crosswalks; Transportation Research Record: Washington, DC, USA, 2003.
18. Bastian J. Schroeder; Nagui Rouphail; Event-Based Modeling of Driver Yielding Behavior at Unsignalized Crosswalks. *Journal of Transportation Engineering* **2011**, *137*, 455-465, 10.1061/(ASCE)TE.1943-5436.0000225.
19. Robert J. Schneider; Aida Sanatizadeh; Mohammad Razaur Rahman Shaon; Zhaoxiang He; Xiao Qin; Exploratory Analysis of Driver Yielding at Low-Speed, Uncontrolled Crosswalks in Milwaukee, Wisconsin. *Transportation Research Record: Journal of the Transportation Research Board* **2018**, *2672*, 21-32, 10.1177/0361198118782251.
20. Manxia Liu; Weiliang Zeng; Peng Chen; Xuyi Wu; A microscopic simulation model for pedestrian-pedestrian and pedestrian-vehicle interactions at crosswalks. *PLOS ONE* **2017**, *12*, e0180992, 10.1371/journal.pone.0180992.
21. Wang, T.; Wu, J.; McDonald, M. A micro-simulation model of pedestrian-vehicle interaction behavior at unsignalized mid-block locations. In Proceedings of the 15th International IEEE Conference on Intelligent Transportation Systems, Anchorage, AK, USA, 16–19 September 2012; pp. 1827–1833.
22. Eleonora Papadimitriou; George Yannis; John Golias; A critical assessment of pedestrian behaviour models. *Transportation Research Part F: Traffic Psychology and Behaviour* **2009**, *12*, 242-255, 10.1016/j.trf.2008.12.004.