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Conflict Analysis of Pedestrian-Vehicle Interactions

Ahmad Kizawi, Attila Borsos*

University of Győr, Department of Transport Infrastructure and Water Resources Engineering, Egyetem tér 1, Győr, Hungary
borsosa@sze.hu

Walking is the most sustainable transportation mode, while pedestrians are the most vulnerable road users. Understanding the nature of their interactions with vehicles, particularly at unsignalized crossings, is critical to improving road safety. Due to advances in video-based vehicle trajectory processing, road safety analysis methods have evolved significantly, and there is an increasing preference for the use of Surrogate Measures of Safety (SMoS) to describe the road safety situation at a given location. There is a lack of such studies for pedestrian-vehicle interactions. The aim of this paper is to fill this gap and present preliminary results derived from video recordings at an unsignalized pedestrian crossing in Győr, Hungary. Post-encroachment time (PET) as a SMoS was generated using an automated road safety analysis software, TrafxSAFE, a product of Transoft Solutions. 594 videos (of approximately 85 h and 48 min) were analyzed in this study. It is concluded that there are differences in the probability of conflicts depending on the direction from which the pedestrian and the vehicle approach the crossing. Conflicts where pedestrians and vehicles approach the crossing in the same lane are slightly more likely to occur, as there is less time for the road users to take evasive action.

1. Introduction

Transportation sustainability is a worldwide target (Bencekri et al., 2021), and human-oriented and eco-friendly transportation solutions are gaining more attention (Ku et al., 2021). The safe movement of pedestrians and passengers is a critical component of a sustainable multimodal transport system. As walking is one of the sustainable modes of transport, pedestrians are considered to be the most vulnerable road user group. According to the World Health Organization's 2018 report (WHO, 2018), road traffic crashes are expected to be the eighth leading cause of death worldwide and the leading cause of death among people aged 15 – 29 y. Every year, more than 1.35 million people lose their lives, and approximately 50 million are injured in road traffic crashes, mostly in low-income countries. Consequently, the formulation, design, management, and safeguarding of facilities to promote efficient, comfortable, and safe pedestrian mobility in local areas, major transport hubs, and other public places is a major challenge for policymakers, transport engineers, and planners. Despite the recent emphasis on pedestrian safety, there is still a critical need to investigate the causal factors of accidents involving vulnerable road users (VRUs) and to reveal their relationship with road design characteristics (Bezerra, 2019). How human drivers and pedestrians interact, especially at unsignalized crossings, is still poorly understood (Kalantari et al., 2023). The aim of this paper is to contribute to this research.

2. Literature review

In the following subsections, some of the literature related to traffic conflict analysis studies in relation to pedestrian-vehicle interactions will be addressed.

2.1 Pedestrian-vehicle interactions

Within the complex network of urban traffic, pedestrians and vehicles coexist in shared spaces, with the result that they mutually influence each other's mobility. While the paths taken by vehicles tend to be more consistent and predictable, there are several problems with pedestrian movements. This is mainly due to pedestrians' tendency to make spontaneous decisions and their susceptibility to rapid changes in speed and direction (Kizawi and Borsos, 2021).

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The most common category of road traffic fatalities in the European Union in 2021 was that of drivers and occupants of passenger cars, accounting for 44.6 % of the total number of fatalities. Pedestrians were the second most important category, with 18.1 %, ahead of motorcyclists and their passengers with 16.6 %.

Previous studies have examined several aspects that influence pedestrian-vehicle interaction. Firstly, pedestrian demographic factors such as gender and age can influence these interactive behaviors (Li et al., 2023). A study by Zhang et al. (2017) suggests that women are more likely to be involved in serious conflicts. Older pedestrians tend to wait longer, cross at a slower pace, and turn their heads less frequently (Choi et al., 2019). Pedestrians in groups are also associated with less severe conflicts, according to research by Zhuang and Wu (2011).

Previous research has shown how vehicle characteristics can influence the dynamics of pedestrian-vehicle interactions (Li et al., 2023). For example, Saleh et al. (2020) found that there is a positive correlation between vehicle speed and the gap that pedestrians are willing to accept. In developing countries, heavier vehicles such as trucks have been found to have lower yielding rates than lighter vehicles, as demonstrated by Kadali and Vedagiri (2016).

According to Zhao et al. (2020), there is a relationship between traffic volume and pedestrian waiting time. Hamed's (2001) study showed that the time of day has a significant effect on pedestrian crossing attempts in terms of environmental characteristics.

The complexity of vehicle-pedestrian interactions increases when these encounters occur outside of designated pedestrian crossings or zebra crossings (Bella and Silvestri, 2021). Unlike in permitted pedestrian crossings, drivers are often caught unaware by jaywalkers; this unexpected behavior can lead to reduced driver reaction time and alter the dynamics of vehicle operation, as reported by Zheng et al. (2015).

2.2 Traffic conflict analysis

The concept of traffic conflict was originally introduced by Perkins and Harris (1967) as a replacement for accident data, which are often insufficient, unreliable, or inappropriate. The aim was to describe traffic events or incidents that were frequent, readily observable and accident-related. They characterized a traffic conflict as any scenario that could lead to an accident, and that requires evasive maneuvers such as braking or swerving. This elementary definition was subsequently extended to include categories of vehicle maneuvers and metrics of temporal and spatial separation between vehicles in conflict situations (Sayed and Zein, 1999).

Historically, road safety analysis has relied predominantly on accident data as its primary source. Over time, several problems have been identified with this type of data. These can be summarised as: (i) accidents are exceptional events in road traffic, resulting from the unfortunate coincidence of many low-probability events; (ii) the rarity of accidents makes it difficult to rely solely on such events for site-specific road safety analysis; (iii) there is a widespread problem of under-reporting, with the level of reporting often dependent on the severity of the accident and the types of road users involved; (iv) information on behavioral factors preceding the accident is rarely available (Laureshyn et al., 2010).

There is a need to use surrogate or complementary measures, such as road safety indicators, to improve the ability to: (i) more efficient and timely assessment of changes in road safety; (ii) detailed analysis of the relationship between design elements and risk; (iii) a deeper understanding of the relationship between behavioral factors and risk; (iv) a better understanding of the processes that define normal traffic scenarios as well as critical situations, including crashes. Regarding the analysis of vehicle-pedestrian conflicts, the regular encounters between vehicles and pedestrians at intersections deserve special attention for safety assessment. Instead of relying on historical crash data for road safety analysis, the use of non-crash events is becoming more popular (Laureshyn et al., 2010).

2.3 Surrogate measures of safety

The term "surrogate" indicates that the indicators are not dependent on the crash database. Instead, they are intended to be complementary tools for the analysis of historical data. Several different indicators were proposed and developed by different researchers in the 1970s and 1980s. More recently, several road safety indicators have been proposed and developed, including those related to VRUs. As there are many problems related to the safety analysis of VRUs, such as under-reporting problems of VRU crashes, there is a growing awareness in transport modes, including VRUs.

Several papers have described, summarised, and compared a set of safety indicators (Borsos et al., 2020). For example, Laureshyn et al. (2010) provided an overview of crash proximity and severity indicators. Zheng et al. (2014) clarified the characteristics of temporal and spatial proximity in traffic situations. An observed situation is considered a traffic conflict depending on the proximity in the distance and/or time of the involved road users. Two of the most popular indicators are time-to-collision (TTC) and post-encroachment time (PET). TTC is the time for a hypothetical collision between vehicles that would occur if they continued on their current course at their current speeds. TTC is a continuous indicator. The lowest value during the interaction is most commonly

used. PET is the difference between the time a vehicle leaves the conflict point (t1) and the time another vehicle arrives at that conflict point (t2) (Figure 1). If these time indicators are low, this indicates a higher risk of vehicle-pedestrian collisions. A PET value of zero indicates no time gap, indicating a potential collision.
PET and TTC have been found to be the most accurate indicators for assessing road safety at junctions due to their ease of measurement, consistency over time and relationship with other indicators (Allen et al., 1978). To measure TTC, we need to determine the time remaining at the conflict point at each time instant. To measure PET we only need to measure the passing times at the conflict point for both conflicting road users. PET can only take one value and is much easier to measure.

$$PET = t2 - t1$$

Figure 1: Procedure for calculating PET (t1 - time instant when the first road user leaves the conflict point, t2 – time instant when the second road user arrives at the conflict point)

2.4 Research gap and goals

Based on the literature review, it can be concluded that various aspects (e.g., vehicle dynamics, influence of age and gender, etc.) of pedestrian-vehicle interactions have been analysed by other researchers, but no in-depth study has been carried out to investigate the following aspects:

- the use of PET as a SMoS to describe the probability of pedestrian-vehicle conflicts;
- the differences (if any) in the probability of conflict depending on the direction from which the pedestrian and the vehicle approach the crossing.

Our hypothesis is that by using PET, we can find different patterns of conflict probabilities for different combinations of pedestrian and vehicle movements.
The novelty of our work is that it is based on a large-scale study, where a dataset was created by recording working day peak hours over more than two months, and fully automated software was used to detect interactions.

3. Site description and data collection

An unsignalized pedestrian crossing was selected in the city of Győr, Hungary, where pedestrian-vehicle interactions were video recorded. The zebra crossing is located in front of a primary school (47°40'46.5"N 17°38'18.6"E) where 1 minor injury crash was observed in the past 10 y (2013 - 2022). The pedestrian crossing with a refuge island is located on a two-lane road.
A Hikvision camera with a 180° wide field of view was mounted on a light pole above the pedestrian crossing, providing a view of both traffic lanes. The video camera was installed at the site for a period of two and a half months, from mid-May to the end of July. Peak hours were observed from 6:00 to 9:00 in the morning and from 14:00 to 17:00 in the afternoon on weekdays. The camera was set to motion detection mode. In total, approximately 4,000 videos were obtained. The videos without pedestrian-vehicle interactions were filtered out. In this study, 594 videos (of approximately 85 h and 48 min) were analyzed using TrafxSAFE software developed by Transoft Solutions. The software uses machine learning to detect, track, and analyze road user interactions. It reports data on road user classification, turning directions, speed, and conflict events, and videos can also be visually analyzed.
PET is calculated by looking at the trajectory of the two road users involved. The intersection of their trajectories is the conflict point. PET can be calculated by measuring the difference between the time when the first user leaves the conflict point and the time when the second arrives at the conflict point. The smaller this time value expressed in seconds, the more serious the interaction. Figure 2 shows two examples with PET values of 1.04 s and 0.36 s.

Figure 2: PET calculated based on trajectories in the TrafxSAFE software

4. Results

A total of 32,866 interactions were recorded, and after a number of filtering steps, 28,304 pedestrian-vehicle interactions were retained for further analysis. In relation to PET, the determination of traffic conflicts is typically dependent on the use of a predetermined threshold. Incidents where the PET values are lower than this set threshold are identified as either dangerous or indicative of potential conflict (near collision) scenarios. The use of a specific threshold of 3 s allows the quantification of traffic conflicts that can be classified as near collisions; 4,727 such interactions were found.

In the context of this research, four categories of pedestrian-vehicle observations are studied (Figure 3 and Figure 4, vehicle indicated by red arrow and pedestrian indicated by green arrow):

- Type (a) vehicle approaching from the left with a pedestrian crossing from the same lane (vehicle northbound, pedestrian westbound);
- Type (b) vehicle approaching from the left with a pedestrian crossing from the opposite lane (vehicle northbound, pedestrian eastbound);
- Type (c) vehicle approaching from the right with a pedestrian crossing from the same lane (vehicle southbound, pedestrian eastbound); and
- Type (d) vehicle approaching from the right with a pedestrian crossing from the opposite lane (vehicle southbound, pedestrian westbound).

These categories allow a comparative analysis, which leads to the conclusion that the collision potential is slightly increased when both pedestrians and vehicles share the same lane (types a) and c)). This conclusion is drawn from the observation that when the pedestrian and the driver approach the zebra crossing in different lanes (types b) and d)), both the pedestrian and the driver have more time to reach the potential collision point, giving them more time to take evasive action, either individually or collectively, to reduce the likelihood of a collision (Hamed, 2001).

Using the capabilities of the TrafxSAFE software, it is also possible to generate and export a speed heat map. This graphical representation can visually highlight the distribution of vehicle speeds. From Figure 5, it can be seen that the southbound direction has higher speed values, which also influences the distribution of PET values. Types c) and d) show a slightly higher probability of lower PET values (i.e., higher conflict severity) compared to their counterparts, types a) and b). This is consistent with previous research on the importance of speed as a factor in increasing the probability of conflict (Govinda et al., 2022).

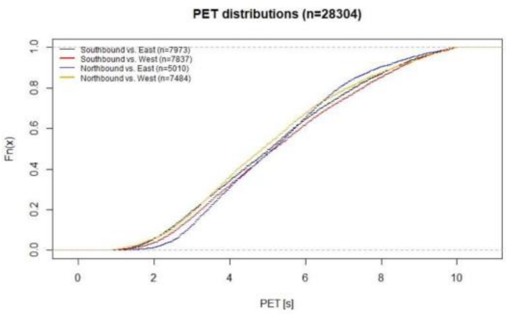

Figure 3: Cumulative distributions of PET values for the four observation types

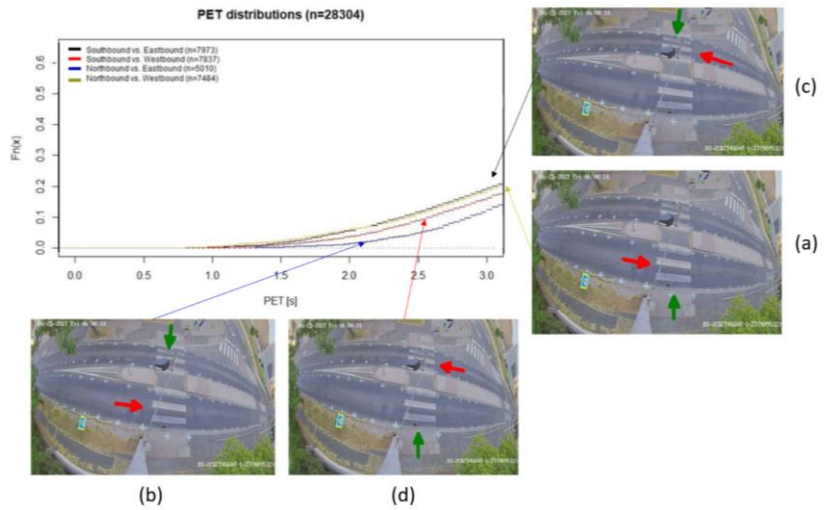

Figure 4: Cumulative distributions of PET values below the 3s threshold for the four observation types (Type (a) – vehicle northbound, pedestrian westbound, Type (b) – vehicle northbound, pedestrian eastbound, Type (c) – vehicle southbound, pedestrian eastbound, Type (d) – vehicle southbound, pedestrian westbound)

Figure 5: Speed heat map

5. Conclusions

This study investigated the safety of an unsignalized pedestrian crossing using video recordings and a temporal surrogate measure of safety, post-encroachment time. PET can be effectively used as a robust indicator to measure the probability of pedestrian-vehicle conflicts. Our research has shown that the nature of pedestrian-vehicle interactions (i.e., who is approaching the crossing from where) has an impact on the frequency and severity of conflicts. Conflicts where pedestrians and vehicles approach the crossing in the same lane are slightly more likely to occur, as there is less time for the road users to take evasive action. In addition to the pedestrian-vehicle movements, vehicle speed also influences the distribution of PET values, with higher speeds leading to a higher probability of conflict. Our further research direction is the application of extreme value theory, which, combined with surrogate measures of safety, can be used to estimate and compare crash probabilities for different scenarios.

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