Pedestrian Violations

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Pedestrians are a vulnerable group of road users. Worldwide, the number of pedestrian deaths annually in road traffic accidents is about 270,000, which exceeds 22% of all traffic mortalities. This rate reveals its critical role in traffic safety research. Of these, pedestrian accidents mainly occur at signalized intersections when pedestrians illegally pass-through crosswalks, which are highly dangerous due to the high risk of pedestrian–vehicle interactions. Illegal crossings mainly include pedestrians crossing at red lights or outside of marked crosswalks, and the former usually causes severe harm. This risky behavior may raise traffic safety issues between pedestrians and driving vehicles. As such, it is necessary to analyze pedestrian red-light violations at signalized intersections and to reduce the risk of pedestrian crossing violations.

Keywords: crosswalk ; risk evaluation ; geographical- and temporal-based risk ; red-light pedestrian violation

1. Introduction

Pedestrians are a vulnerable group of road users. Worldwide, the number of pedestrian deaths annually in road traffic accidents is about 270,000, which exceeds 22% of all traffic mortalities. This rate reveals its critical role in traffic safety research [1]. Of these, pedestrian accidents mainly occur at signalized intersections when pedestrians illegally pass-through crosswalks, which are highly dangerous due to the high risk of pedestrian–vehicle interactions. Illegal crossings mainly include pedestrians crossing at red lights or outside of marked crosswalks, and the former usually causes severe harm. This risky behavior may raise traffic safety issues between pedestrians and driving vehicles [2]. As such, it is necessary to analyze pedestrian red-light violations at signalized intersections and to reduce the risk of pedestrian crossing violations.

Herein, extensive efforts have been undertaken to investigate the influential factors of pedestrian crossing violations on red-light time. Among them, present studies can be divided into internal human factors and external environment by the differences in the purpose of the investigation. The internal human factors mainly consider the effects of age [3], gender [4], gap acceptance [5][6], mental effects [7], and crossing behavior selection as an individual or group of pedestrians [6]. External environment factors include built environment features [8], traffic conditions [9], the length of red-light time [10], time of the trip [11], social characteristics [12], and road crosswalk facilities [9][13]. It is a physical and mental decision-making process for pedestrians from the moment they arrive at a particular signalized intersection to the moment they are ready to violate the crossing. As the signal intersection is a complex traffic environment in urban transportation, the diversity of inherent personal characteristics and extrinsic intersection attributes can simultaneously affect pedestrian violations. This process has a high degree of uncertainty, and different pedestrians tend to use different crossing strategies under different crosswalk scenarios and waiting times.

However, most of the present studies on the risk evaluation of pedestrian violations have focused on the perspective of individual pedestrian characteristics and discussed the risk of illegal crossing from the perspective of pedestrians themselves. Fewer studies have discussed the risk of pedestrian crossing violations occurring from the effect of the entire crosswalk. Limited by the randomness and variability of pedestrians arriving at the crosswalk, measures to reduce the risk of violation from the pedestrian's own perspective are uncertain. Instead, a whole crosswalk perspective can provide some suggestions for stable improvements based on the external environment. As such, it is crucial to consider geographical characteristics and temporal trends of selected external factors in the risk evaluation of pedestrian violations.

2. Studies on the Geographical Risk of Pedestrian Violations

In the evaluation of geographical risk for pedestrians, pedestrian injuries are usually influenced by one specific factor or by the combination of several factors. In analyzing the risk affected by specific geographical factors, Nesoff et al. [14] discussed the geographic relationship between the spatial distribution of alcohol environments and pedestrian accidents in Baltimore City. Yao et al. [15] developed geographically weighted Poisson regression models for calculating the risk probability of a pedestrian collision when exposed to the roadway environment. Poulos et al. [16] introduced the

relationship between pedestrian violations and the density of the surrounding buildings and population. Furthermore, Chaudhari et al. [17] explored the composition of vehicle types and the geometric linearity of the different road segments on the impact of pedestrian injuries. In the studies of pedestrian crossing affected by multiple geographical risk factors, Fuentes and Hernandez [18] discussed the relationship between macroscopic factors such as land use type, building density, and socioeconomic characteristics in urban pedestrian fatal accidents in Mexico. Jang et al. [19] compared the probability and the factors of pedestrian accidents in central business districts and urban suburbs. Rankavat and Tiwari [20] analyzed the impact of pedestrian accidents in different building environments and compared the risk levels of pedestrians in four different buildings. In different types of cities, Avinash et al. [21] found that the different sizes of cities lead to different crossing speeds in pedestrian violations. The average crossing speed was measured to be higher in the mega city (1.205 m/s) as compared to the metro city (1.036 m/s).

In studies of pedestrian violations affected by external factors, Alonso, Oviedo-Trespalacios, Gene-Morales, and Useche [13] found that the influence of age-based differences in pedestrian walking behavior is significant. Comparing different genders in pedestrian behavior, Useche et al. [22] introduced that male pedestrians are usually more sensitive than females in risk perception and error behavior observation. Ma, Lu, and Zhang [6] developed a Bayesian network-based framework for evaluating the influencing factors of illegal pedestrian behavior. Aghabayk, Esmailpour, Jafari, and Shiwakoti [10] identified the factors that affect illegal pedestrian behavior at signalized and un-signalized intersections and compared the behavioral differences between individual and group pedestrians with different ages and genders.

In general, previous studies on the geographical risk of pedestrian violations have been performed mainly from the perspective of the pedestrians themselves and analyzed the effect level of pedestrian accidents or fatalities with the help of macroscopic data (such as socio-economic development, demographic characteristics, and urban road network), or one specific factor's data [23][24][25]. Different types of pedestrians present different crossing characteristics under different research scenarios in terms of travel patterns and traffic activities. However, fewer studies have focused on entire crosswalks at intersections to analyze the risk to pedestrians before an accident, which can help to propose improvements to mitigate the risk of pedestrian violations from the perspective of crosswalks. This topic is crucial to improve the safe environment at intersections.

3. Studies on the Temporal Risk of Pedestrian Violations

When pedestrians arrive at the intersection ready to cross, they will have a pre-judgment of violation decision during the waiting process. With pedestrian waiting times increasing, the probability of pedestrian violations also increases. As such, in this stage, the risk of pedestrian violations at the crosswalk is temporally variable. It is also essential to note the temporal change of pedestrian risk in this period. Tiwari et al. [26] examined the waiting duration of pedestrians at signalized intersections in India by a survival analysis method and found that the probability of risk significantly increases at the end of the waiting duration of red-light time.

Studying the effect via different pedestrian groups, Hamed [27] analyzed the relationship between the waiting time of pedestrians and the number of pedestrian groups. Liu, Alsaleh, and Sayed [11] compared the probability of violations for pedestrian groups under different numbers, different types of geographical locations, and different waiting times. Aghabayk, Esmailpour, Jafari, and Shiwakoti [10] examined the effects of different genders, ages, group crossings, and carry-ons on pedestrian crossing behavior or not, and found that distracted pedestrians had the greatest impact on pedestrian accidents.

In terms of different signal cycle lengths, Yang et al. [28] analyzed the relationship between pedestrian waiting time and crossing behavior. The study found that pedestrians are more inclined to end their waiting duration and engage in temporal violation behaviors as the waiting time increases. In a different cultural context, Sueur et al. [29] found that French pedestrians take more risks than Japanese pedestrians, and males take more risks than females, in the survival analysis model. The survival models have also found applications in the analysis of the reaction time of vehicle drivers. In a recent study by Pawar and Velaga [30], the driver's reaction time (based on the response to an event) was examined with the help of a parametric survival model. The results suggested that the reaction of young drivers was 21% faster than that of mature drivers during the pedestrian crossing event.

In terms of external factors on pedestrian temporal risk, Dhoke et al. [31] developed a COX proportional risk model to analyze the joint effects of individual pedestrian characteristics and external environmental factors at intersections on pedestrian waiting times. Raoniar, Maqbool, Pathak, Chugh, and Maurya [12] pointed out that regardless of whether the crosswalk is signal-controlled or not, the waiting time for crossing should not exceed 50 s, otherwise the probability of pedestrians crossing illegally will increase.

In summary, research can benefit from pedestrian waiting time data collected utilizing interviews, questionnaires, video trajectory recording and so on [12][32][33]. These studies have pointed out the maximum waiting times for pedestrian crosswalk violations and described the changing trends in the risk of pedestrians, from pedestrians arriving at crosswalks to the occurrence of the violation. However, the aforementioned studies did not reflect the effects of various external factors on the risk of the pedestrian violations involved. The impact of different levels of external factors on the temporal risk of pedestrian violations is of different degrees. For example, the waiting time for pedestrians under different crossing facilities is different.

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