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Measures of activity-based pedestrian exposure to the risk of vehicle-pedestrian collisions: Space-time path vs. potential path tree methods

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ABSTRACT

Research on the extent to which pedestrians are exposed to road collision risk is important to the improvement of pedestrian safety. As precise geographical information is often difficult and costly to collect, this study proposes a potential path tree method derived from time geography concepts in measuring pedestrian exposure. With negative binomial regression (NBR) and geographically weighted Poisson regression (GWPR) models, the proposed probabilistic two-anchor-point potential path tree (PPT) approach (including the equal and weighted PPT methods) are compared with the deterministic space-time path (STP) method. The results indicate that both STP and PPT methods are useful tools in measuring pedestrian exposure. While the STP method can save much time, the PPT methods outperform the STP method in explaining the underlying vehicle-pedestrian collision pattern. Further research efforts are needed to investigate the influence of walking speed and route choice.

1. Introduction

Pedestrians represent one of the most vulnerable groups of road users in motorized societies. In low-income countries, the share of pedestrian fatalities in total road deaths (around 35% on average in 2010) is often the highest among all road users (World Health Organization, 2013). In high-income countries, the percentage of pedestrian fatalities often remains high. According to the World Health Organization (2013), pedestrians accounted for about 27% of road traffic fatalities in the WHO European region. In Hong Kong, more than half of the road traffic deaths were pedestrians during the last decade (2001–2010) (Transport Department, 2014). The high share of pedestrians in traffic collisions is a serious public health problem that requires attention. Although there has not been a lack of research on vehicle-pedestrian collisions, most studies that took into account the characteristics of the road network focused on road intersections (Lee and Abdel-Aty, 2005; Kennedy, 2008; Miranda-Moreno et al., 2011; Pulugurtha and Sambhara, 2011). In reality, vehicle-pedestrian collisions do not just happen around road junctions. They can happen at mid-block locations or places where there are supposed to be few conflicts between vehicles and pedestrians. Take our case study as an example (further discussed below), 73.2% of the vehicle-pedestrian collisions occurred at non-junction locations and 36.9% happened on road segments without any pedestrian crossing. Hence, for local network-based analysis, it is important to include all road segments in the transport network where potential vehicle-pedestrian conflicts can occur.

The measurement of pedestrian exposures has always been an important research topic, but there is no consensus on the best pedestrian exposure measure. For local network-based analysis, recent efforts on pedestrian exposure measures focused on people's activities in the context of time geography (Lam et al., 2013, 2014). Lam et al. (2014) developed space-time path (STP) and potential path tree (PPT) methods to measure pedestrian exposures. However, the probabilistic PPT method they proposed is applicable to short home-based trips only using one base or anchor point, that is, home, for the analysis. In other words, all trips are assumed to have the same pattern of "home-destination-home". To bridge the research gap, this paper aims to further develop the PPT method which can be applied to trips of all types with different origins and destinations, that is, two anchor points. Moreover, two sub-categories of the two-anchor-point PPT method are developed by taking into consideration the route choice of pedestrians. The equal PPT (EPPT) method assumes that

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all walking paths are equally likely to be taken; and the weighted PPT (WPPT) method puts heavier weights on routes (namely the shortest paths) which are more likely to be chosen.

Then, these two PPT methods are compared with the STP method in estimating vehicle-pedestrian collision risks by using two collision prediction models, that is, the negative binomial regression (NBR) and geographically weighted poisson regression (GWPR). The objectives are twofold. Firstly, it aims to better understand the relative role of pedestrian exposure and other risk factors. Secondly, it aims to shed some light on the applications of general and spatial models in road safety analysis, particularly in areas where vehicle-pedestrian collisions are not just happening at road junctions but are more dispersed throughout the road network. However, the aim is neither to compare these two collision modelling techniques theoretically nor to prove/suggest that one of them is superior in all empirical situations.

In terms of scientific contributions, this paper breaks new ground by developing two network-based pedestrian exposure measures using the probabilistic two-anchor-point PPT methods. Moreover, the performances of different pedestrian exposure measures are compared using two collision prediction models both to better understand the relative role of pedestrian exposure and other risk factors, and to shed some light on the applications of general and spatial models in road safety analysis.

The following section will review the literature on pedestrian exposure measures, vehicle-pedestrian collision risk factors and collision prediction models. Section 3 will introduce the methodology. Compared with traditional methods, activity-based approaches have strengths at the local network level. Hence, a district in Hong Kong is chosen as the study area. Following data descriptions, the ways in which different pedestrian exposures are calculated by the STP and PPT (including both EPPT and WPPT) methods are presented. Then, the two statistical models of NBR and GWPR will be introduced briefly. The model results will be compared to better understand the vehicle-pedestrian collision risks, the explanatory power of different pedestrian exposure measures, and the usefulness of applying general and spatial models in road safety analysis. Finally, conclusions and further research directions will be presented.

2. Literature review

2.1. Pedestrian exposure measures

In the literature, area-based and trip-based measures have been widely used to estimate pedestrian exposure (Greene-Roesel et al., 2007 Wundersitz and Hutchinson, 2008). Examples of area-based methods include the size of population and population density within predefined spatial units such as census blocks (Wier et al., 2009; Chakravarthy et al., 2010; Cottrill and Thakuriah, 2010). As these area-based exposure measures can easily lead to erroneous conclusions by obscuring the variability of pedestrian activities within an area (Lam et al., 2014), trip-based measures including distance travelled and time spent walking have also been applied in road safety studies (Jonah and Engel, 1983). In addition, pedestrian volumes, named point-based exposure measures hereafter, can be obtained by counting the number of pedestrians passing through designated measurement points during an observation period (Davis and Braaksma, 1988). Table 1 describes the classification of major measurement tools. All of the approaches mentioned above, namely the area-based, trip-based and point-based methods, are deterministic and aggregate in nature.

Recently, activity-based approaches which use travel diary data of individuals' activity-travel patterns have been proposed by Lam et al. (2013, 2014). The disaggregate approach considers not only selected points in a pedestrian network but the entire road network that pedestrian activities may take place. Moreover, pedestrian movements are conceptualized as disaggregate paths within a transport network rather than aggregate volumes/densities within an area. It is recognized that pedestrian movements (like traffic flows) are network-constrained phenomena (Loo and Yao, 2013). The approach also has the strength of reflecting the disaggregate route choices of people. In Lam et al. (2013, 2014), time geography (Hägerstrand, 1970) was employed to measure pedestrian exposure to vehicle-pedestrian collisions. Using the STP method, pedestrian exposure is calculated based on the shortest paths along the network that connect consecutive control points. Lam et al. (2014) demonstrated that the STP method has greater explanatory power than the traditional area-based method in accounting for vehicle-pedestrian collisions at the local network level. Their STP approach is deterministic because it is based on the assumption that pedestrians will only choose the shortest paths when walking from one place to another. In reality, the route choice of pedestrians is complex and people do not always choose the shortest paths. Taking into consideration these uncertainties, Lam et al. (2014) also proposed a probabilistic method to calculate pedestrian exposure by integrating the concepts of Potential Path Area (PPA) and PPT. The concept of PPA is used to analyze potential movements in Euclidean space which encloses all potentially reachable locations a person can feasibly reach given an individual's specific constraints such as travel mode, speed and time budget (Hägerstrand, 1974; Miller, 2005). As PPA shows the locations that an individual can possibly occupy given the constraints, it represents locations where exposure events may occur (Miller, 2004). PPT can be regarded as an adaptation of PPA to the network space, which is a subset of road network representing all accessible paths that this person can take (Miller, 1991; Shaw, 2006). The PPT method has been widely used for studying human travel behavior in terms of measuring accessibility to particular locations (Kim and Kwan, 2003; Raubal et al., 2007; Farber et al., 2011; Lee et al., 2010). It was first applied

Table 1
Classification of pedestrian exposure measures.

	Deterministic	Probabilistic
Aggregate	• Place-based • Trip-based • Point-based	–

Disaggregate	• STP	• PPT
		• Single-anchor-point
		• Two-anchor-point
		  • EPPT
		  • WPPT