Accident Analysis and Prevention 96 (2016) 12–21

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

# Macro-level safety analysis of pedestrian crashes in Shanghai, China

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ARTICLE INFO

*Article history:*
Received 30 November 2015
Received in revised form 17 July 2016
Accepted 21 July 2016

*Keywords:*
TAZ-level safety analysis
Pedestrian crashes
Spatial weight features
Bayesian Conditional Autoregressive Model
Transportation safety planning

ABSTRACT

Pedestrian safety has become one of the most important issues in the field of traffic safety. This study aims at investigating the association between pedestrian crash frequency and various predictor variables including roadway, socio-economic, and land-use features. The relationships were modeled using the data from 263 Traffic Analysis Zones (TAZs) within the urban area of Shanghai – the largest city in China. Since spatial correlation exists among the zonal-level data, Bayesian Conditional Autoregressive (CAR) models with seven different spatial weight features (i.e. (a) 0–1 first order, adjacency-based, (b) common boundary-length-based, (c) geometric centroid-distance-based, (d) crash-weighted centroid-distance-based, (e) land use type, adjacency-based, (f) land use intensity, adjacency-based, and (g) geometric centroid-distance-order) were developed to characterize the spatial correlations among TAZs. Model results indicated that the geometric centroid-distance-order spatial weight feature, which was introduced in macro-level safety analysis for the first time, outperformed all the other spatial weight features. Population was used as the surrogate for pedestrian exposure, and had a positive effect on pedestrian crashes. Other significant factors included length of major arterials, length of minor arterials, road density, average intersection spacing, percentage of 3-legged intersections, and area of TAZ. Pedestrian crashes were higher in TAZs with medium land use intensity than in TAZs with low and high land use intensity. Thus, higher priority should be given to TAZs with medium land use intensity to improve pedestrian safety. Overall, these findings can help transportation planners and managers understand the characteristics of pedestrian crashes and improve pedestrian safety.



## 1. Introduction

Pedestrians play an important role in travel modes around the world. In Shanghai, the largest city in China, 35.1% of the residents in the urban area walked for their travel needs in 2012, with the average daily walking distance at 0.9 km in the center of Shanghai (Shanghai Urban and Rural Construction and Transportation Development Institute, 2013). Pedestrians are regarded as the most vulnerable road users due to their fragility, slow movement and lack of lighting equipment. Therefore, they have a higher risk of traffic crash involvement than the drivers and passengers of motorized vehicles (Zhang et al., 2014). In particular, pedestrian fatalities accounted for 22% of the traffic crash fatalities worldwide and 25% in China (World Health Organization, 2013). With rapid urbanization and motorization, pedestrian crashes in China have surged in recent years.

In order to discover and identify specific contributing features for pedestrian crash occurrences, crash locations are usually aggregated into spatial units such as segments, intersections, zones, and so forth (Lee et al., 2015b). Micro-level safety analysis focuses on specific roadway entities such as roadway segments, intersections, corridors, etc., and macro-level safety analysis focuses on zonal-level traffic crashes at various levels of area-aggregation such as census tract (Cottrill and Thakuriah, 2010; Ukkusuri et al., 2011; Abdel-Aty et al., 2013), Traffic Analysis Zone (TAZ) (Siddiqui et al., 2012; Abdel-Aty et al., 2013; Wang et al., 2013; Lee et al., 2015b), and block group (Noland et al., 2013). Micro-level analysis is effective in identifying and solving safety problems at one specific location, but it becomes more difficult to capture spatial trends and problems in a larger area. Compared to micro-level safety analysis, macro-level safety analysis can more effectively identify safety problems in a larger area, and thus is more useful in helping establish long-term planning policy to improve safety. Researchers have performed many safety analyses using zone-based data and

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http://dx.doi.org/10.1016/j.aap.2016.07.028
0001-4575/

identified relationships between pedestrian crash frequency and related features (Cottrill and Thakuriah, 2010; Ukkusuri et al., 2011; Abdel-Aty et al., 2013), and it has been shown that spatial correlation is an important factor when establishing the statistical model for macro-level safety analysis. Bayesian spatial analysis with CAR (Conditional Autoregressive) priors, which can effectively accommodate the spatial autocorrelations of study units, has therefore become prevalent in current research (Siddiqui et al., 2012; Noland et al., 2013; Wang and Kockelman, 2013).

Shanghai is characterized by the highest urbanization rate (88.86%) in China in 2010 (China International Urbanization Development Strategy Research Committee, 2012), high density of population (23.0 million in 2010 (Bureau of Statistic of Shanghai, 2011)), large motor vehicle ownership (3.1 million in 2010 (Bureau of Statistic of Shanghai, 2011)), high density of roadway network (8.0 km/km$^2$) and typical mixed traffic flow. Pedestrian crashes were not equally distributed throughout the analysis area – they were spatially concentrated in the center of Shanghai. In particular, more than two thirds of pedestrian crash hot zones (ranking in the top 15% of total crash counts) were in the 54 TAZs within the Inner Ring in the Puxi area (see Fig. 1), which is more densely developed than the Pudong area. These 54 TAZs accounted for just 12.3% of the analysis area, but 38.2% of pedestrian crashes overall. The 54 TAZs consisted of three majority land use types: residential and commercial (31.5%); commercial, residential and official (27.8%); and exhibition, financial and tourism (27.8%). Commercial and residential areas were the key zones for pedestrian aggregation, which is associated with pedestrian crash occurrence (Kim et al., 2006; Loukaitou-Sideris et al., 2007; Ukkusuri et al., 2011). Traffic safety was set as the primary objective for the next decade in the Shanghai Transportation Development White Paper (Shanghai Municipal People's Government, 2014). As the White Paper underscored the need of discovering risk factors and improving pedestrian safety, higher priority will be given to the safety of walking and biking in short-distance travel to protect these convenient and comfortable travel modes.

In summary, the main purposes of this study are to: (a) develop macro-level pedestrian crash models to investigate the relationship between pedestrian crashes and various roadway, socio-economic, and land use features in Shanghai; (b) compare the seven spatial weight features as CAR priors in Bayesian framework and analyze the spatial correlation among the analysis areas; (c) identify the features which have significant influence on pedestrian crashes; and (d) provide suggestions and references for transportation planners and managers on improving pedestrian safety in the traffic system of China.

## 2. Literature review

### 2.1. Macro-level predictors for pedestrian crashes

In most previous studies of pedestrian crashes, macro-level crash prediction models were developed to relate the crashes to a variety of explanatory zonal features (including roadway, traffic, socio-economic, and land use characteristics). Research on these features will be introduced below separately.

In examining the relationship between pedestrian crashes and roadway characteristics, traffic engineers have found that total number of intersections is linked to the number of pedestrian crashes, as intersections with higher numbers of pedestrians crossing have led to higher probabilities of vehicle-pedestrian crashes (Siddiqui et al., 2012; Abdel-Aty et al., 2013). A large percentage of these crashes have occurred on major urban arterial roads (Miles-Doan and Thompson, 1999). However, as Miles-Doan and Thompson (1999) have argued, transportation planners have ignored the needs of pedestrians along arterials. Length of minor roads have been shown to have significant effects on crashes as well (Quddus, 2008), and studies have also explored how speed limit affects pedestrian crashes (Kim et al., 2010; Abdel-Aty et al., 2013 ; Lee et al., 2015a,b). A recent TAZ-level analysis found that a greater number of pedestrian crashes occurred on roadway segments with 25 and 35 mph PSL (Posted Speed Limit) as compared to PSLs higher than 35 mph (Abdel-Aty et al., 2013). Additionally, a greater proportion of roadway segments with PSLs higher than or equal to 55 mph was found to significantly decrease pedestrian crashes. In other words, pedestrian crashes are more likely to occur in areas with many low-speed local roads (Lee et al., 2015a,b).

Significant correlations have been found between pedestrian crashes and traffic characteristics (Loukaitou-Sideris et al., 2007; Wier et al., 2009; Abdel-Aty et al., 2013; Lee et al., 2015b). Vehicle Miles Traveled (VMT) has been positively associated with pedestrian crashes in TAZ-level analysis (Abdel-Aty et al., 2013; Lee et al., 2015b). Researchers also found that the Average Annual Daily Traffic (AADT) is a statistically significant predictor of pedestrian crashes (Loukaitou-Sideris et al., 2007; Wier et al., 2009). Kim et al. (2010) investigated the safety effects of different vehicle types on pedestrian crashes, and found that trucks tended to increase the likelihood of pedestrian crash occurrence by 370%.

Another set of studies has examined the relationship between pedestrian crashes and socio-economic characteristics. The most frequently analyzed features, such as population (Kim et al., 2006; Ukkusuri et al., 2011; Lee et al., 2015b), population density (Loukaitou-Sideris et al., 2007; Siddiqui et al., 2012), employment population (Wier et al., 2009; Siddiqui et al., 2012), employment density (Loukaitou-Sideris et al., 2007) and proportion of unemployed population (LaScala et al., 2000), all had positive effects on pedestrian crashes in previous studies. The number of vulnerable road users, including children and older people, has been found to be significantly correlated with pedestrian crashes. A higher number of pedestrian crashes have been associated with a higher density of children (Abdel-Aty et al., 2013) and a lower percentage of resident population aged 65 and older possibly due to the decrease of physical activity (Wier et al., 2009). As for economic features, median household income had negative effect on pedestrian crashes (Siddiqui et al., 2012; Lee et al., 2013), while percentage of residents living below the poverty line (Wier et al., 2009; Lee et al., 2015a) and proportion of household without vehicles (Noland et al., 2013; Lee et al., 2015b) all had positive effects on pedestrian crashes. Similarly, areas with a greater proportion of uneducated residents show a positive effect on pedestrian crashes (Ukkusuri et al., 2011), while a greater proportion of high school graduates or higher shows a negative effect (LaScala et al., 2000). The TAZ-level pedestrian exposure variable is also critical in a pedestrian crash prediction model. Pedestrian exposure is an abstract concept that reflects the opportunity for a potentially harmful pedestrian-vehicle interaction to occur. However, pedestrian exposure is very difficult to measure directly since this would involve tracking the movements of all people at all times (Greene-Roesel et al., 2007). Therefore, a good alternative exposure measure is sought as surrogate. Greene-Roesel et al. (2007) summarized five common metrics used to describe pedestrian exposure including population, number of pedestrians, trips, distance traveled, and time spent traveling. In this study, population was used as a surrogate for pedestrian exposure.

Land use features could influence human activity and potentially lead to pedestrian crashes. Land use types generating pedestrian traffic (such as parks, commercial and retail facilities, high-density housing, schools) have been associated with larger numbers of pedestrian crashes (Kim et al., 2006; Wedagama et al., 2006; Loukaitou-Sideris et al., 2007; Ukkusuri et al., 2011). Ng et al. (2002) investigated 27 types of land use features in Hong Kong and found