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A multivariate spatial model of crash frequency by transportation modes for urban intersections

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ABSTRACT

This study proposes a multivariate spatial model to simultaneously analyze the occurrence of motor vehicle, bicycle and pedestrian crashes at urban intersections. The proposed model can account for both the correlation among different modes involved in crashes at individual intersections and spatial correlation between adjacent intersections. According to the results of the model comparison, multivariate spatial model outperforms the univariate spatial model and the multivariate model in the goodness-of-fit. The results confirm the highly correlated heterogeneous residuals in modeling crash risk among motor vehicles, bicycles and pedestrians. In regard to spatial correlation, the estimates of variance for spatial correlations of all three crash modes in the multivariate and univariate models are statistically significant; however, the correlations for spatial residuals between different crash modes at adjacent sites are not statistically significant. More interestingly, the results show that the proportion of variation explained by the spatial effects is much higher for motor vehicle crashes than for bicycle and pedestrian crashes, which indicates spatial correlations between adjacent intersections are significantly different between the motor vehicle and non-motorized modes.

1. Introduction

Non-motorized transportation modes (i.e., walking and cycling) generate health, environmental and social benefits, such as decreasing energy consumption, reducing congestion, keeping healthy and improving livability. Many communities have thus encouraged the development of multimodal transportation systems and advocated a shift from motor vehicles to non-motorized modes of transportation (Tasic and Porter, 2016). Given the increasing popularity of non-motorized travel activities, crashes involving pedestrians and bicyclists have become a major concern in improving traffic safety, especially at urban intersections where various traffic conflicts between motor vehicles, cyclists and pedestrians need to be accommodated. Transportation professionals have sought a variety of safety improvement interventions for urban intersections to maintain multimodal traffic safety.

Statistical modeling of the inter-relationship between crash frequency by different transportation modes and potentially confounding factors associated with intersections assists in developing safety improvement programs to achieve safe multimodal transportation. Based on the approach of crash modeling, numerous studies have investigated crashes between

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pedestrians and motor vehicles (Shankar et al., 2003; Lee and Abdel-Aty, 2005; Pulugurtha and Sambhara, 2011), bicycles and motor vehicles (Wang and Nihan, 2004; Schepers et al., 2011; Strauss et al., 2013) and multiple vehicle crashes (Abdel-Aty and Radwan, 2000; Chin and Quddus, 2003; Wang and Huang, 2016) at intersections. However, these published studies have merely focused on single-user outcomes rather than multiple crash outcomes, i.e. motor vehicle, cyclist and pedestrian crashes. As the crash risks for different modes are probably inconsistent (i.e. certain factors may reduce crash occurrences for traveler category A but increase crash occurrences for traveler category B), these single-outcome models may not be suitable for multimodal safety analysis.

The paper by Strauss et al. (2014) is one of the few studies that have investigated the multimodal injury risk analysis for intersections. The study established three bivariate Bayesian Poisson models to analyze the injury and traffic flow outcomes for motorized, cyclist and pedestrian modes at both signalized and non-signalized intersections on the island of Montreal, Canada. The results quantified the effect of traffic flows, geometric design such as crosswalk length and the number of lanes on the occurrence of crashes for motor-vehicle occupants, cyclists and pedestrians. However, independent crash frequency models were employed by separating the transportation modes to examine the contributing factors. Such independent equations of crash frequency by mode ignore the potential correlations that may exist across different categories of road users. Most notably, there may be common unobserved factors that simultaneously affect the frequency of crashes by transportation mode at intersections. For example, signal timing strategies could influence traffic operations for both drivers and pedestrians/cyclists. As another example, when a vehicle brakes suddenly to avoid a pedestrian crossing the street, a rear-end collision may occur. Therefore, it may be advisable to simultaneously model the occurrence of motor-vehicle, cyclist and pedestrian crashes in a single modeling framework. Ignoring such simultaneity, when it exists in fact, would lead to inefficient and biased parameter estimations.

Recently, numerous studies have applied multivariate models for estimating the traffic crash count under different types of classification, such as crash frequency by severity level (Park and Lord, 2007; Ma et al., 2008; El-Basyouny and Sayed, 2009; Aguero-Valverde and Jovanis, 2009; Barua et al., 2014, 2016; Zhan et al., 2015; Zeng et al., 2017), or crash frequency by collision type (Ye et al., 2009; El-Basyouny et al., 2014; Aguero-Valverde et al., 2016). For example, Park and Lord (2007) developed a multivariate Poisson regression that jointly predicted crash frequencies at different severity levels at intersections using a Bayesian estimation approach. Ye et al. (2009) deployed a simultaneous equations model for intersection crashes that could account for observed and unobserved factors contributing to crash frequencies by collision type. Lee et al. (2015) modeled the correlation among crash frequency by transportation mode at traffic zone level. Heydari et al. (2017) investigated crash correlates of walking and cycling at signalized intersections using a flexible multivariate latent class approach. More detailed descriptions about multivariate models in safety analysis could be found in the review papers by Mannering and Bhat (2014).

Spatial correlation has been confirmed to be an important issue that should not be ignored in the development of crash modeling, since crash data often have observations that are in close spatial proximity (Quddus, 2008; Dong et al., 2016). The inclusion of spatial correlation has two main advantages: i) spatial correlation sites estimate the "pool strength" from neighboring sites, thereby improving model parameter estimation (Aguero-Valverde and Jovanis, 2008); and ii) spatial dependence can be a surrogate for unknown and relevant covariates, thereby reflecting unmeasured confounding factors (Dubin, 1988; Chiou et al., 2014). The consideration of spatial correlation for intersections in the urban road network is especially essential since the adjacent intersections tend to share similar road environment characteristics and thus the traffic participants' characteristics and behaviors tend to be similar (Abdel-Aty and Wang, 2006; Guo et al., 2010; Xie et al., 2013, 2014). Meanwhile, the coordination of signals between adjacent intersections promotes platoons of vehicles crossing intersections and thus leads to correlated traffic flow patterns.

This study aims to propose a multivariate spatial modeling approach to investigate multimodal crash prediction models for urban intersections so as to (a) simultaneously identify factors contributing to crash risks for all intersection travelers including pedestrians, cyclists and motor vehicles; (b) assess the correlations of crash counts by different transportation modes at individual intersections and spatial correlations of varying modes between adjacent intersections. The proposed multivariate spatial model is developed using a multivariate CAR distribution under a Bayesian framework given its capability of modeling both multivariate heterogeneity and multivariate spatial correlation (Barua et al., 2014). Considering the effects of spatial correlation on the crash count by different transportation modes, the proposed model may take advantage of the existing correlation between crashes of different transportation modes within intersections, but also "borrowing" the strength from its adjacent intersections to improve the crash frequency estimates.

2. Methodology

The Poisson regression-based model is the foundation in crash frequency data analyses. The Poisson regression model has been widely used because the stochastic crash occurrence is generally assumed to be a Poisson process.

2.1. Univariate model

This section presents the formulation of a univariate Poisson log-normal regression model for comparison to the proposed multivariate model. The probability of an intersection having crashes per time period is given by this formula: