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Macroscopic modeling of pedestrian and bicycle crashes: A cross-comparison of estimation methods

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ABSTRACT

The paper presents a cross-comparison of different estimation methods to model pedestrian and bicycle crashes. The study contributes to macro level safety studies by providing further methodological and empirical evidence on the various factors that influence the frequency of pedestrian and bicycle crashes at the planning level. Random parameter negative binomial (RPNB) models are estimated to explore the effects of various planning factors associated with total, serious injury and minor injury crashes while accounting for unobserved heterogeneity. Results of the RPNB models were compared with the results of a non-spatial negative binomial (NB) model and a Poisson-Gamma-CAR model. Key findings are, (1) the RPNB model performed best with the lowest mean absolute deviation, mean squared predicted error and Akaiki information criterion measures and (2) signs of estimated parameters are consistent if these variables are significant in models with the same response variables. We found that vehicle kilometers traveled (VKT), population, percentage of commuters cycling or walking to work, and percentage of households without motor vehicles have a significant and positive correlation with the number of pedestrian and bicycle crashes. Mixed land use is also found to have a positive association with the number of pedestrian and bicycle crashes. Results have planning and policy implications aimed at encouraging the use of sustainable modes of transportation while ensuring the safety of pedestrians and cyclist.

1. Introduction

Walking and cycling are active transportation modes that are being promoted as sustainable, healthy, environmentally friendly, inexpensive and convenient for short distance journeys. Whether it was for commuting or leisure, over 1.9 million people cycled in Australia in 2008, and most people are pedestrians at some point in their journey. Bicycle use in Australia has increased markedly in recent years (Austroads, 2010). The Australian National Cycling Strategy aims to double the number of people cycling in Australia by 2016 (Austroads, 2010).

Despite the environmental and health benefits of walking and cycling, users of these modes are sometimes exposed to a higher risk of injury and fatality in road crashes. Pedestrians and cyclists are often referred to as "vulnerable road users", a term which is applied to those at greater risk in traffic. In the event of a crash, they have little or no protection compared to other road users (ATC, 2011). Despite relatively lower distance traveled compared to other road users, pedestrians comprise 17% of all serious transportation-related injuries and 13% of all road fatalities in Australia (BITRE, 2013; Senserrick et al., 2014). Since the 1990s, cyclist deaths in road crashes have constituted on average between 2%–3% of the total deaths in road crashes in Australia (BITRE, 2013). Thus in total, pedestrian and cycling crashes constitute over 15% of all fatalities.

Current urban transportation policies in major Australian cities are geared towards increasing the share of walking and cycling. Due to the vulnerability of pedestrians and cyclists, policies to increase their mode share must be accompanied with measures to increase their safety. Understanding various factors contributing to the occurrence of pedestrian and cycling crashes is necessary for developing such policies and measures.

A number of studies in the past investigated the factors that influence the occurrence of pedestrian and bicycle crashes. However, these studies were mostly undertaken at the micro level, looking at pedestrian and bicycle crashes at specific sections of the roadway or an intersection. At the macro-level, pedestrian and bicycle crash modeling with implications for transportation planning is scarcely researched (Siddiqui et al., 2012). Some of the studies analyzed both pedestrian and bicycle crashes (Dumbaugh

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and Li, 2010; Siddiqui et al., 2012; Zhang et al., 2015) while others concentrated only on pedestrian crashes (Clifton and Kreamer-Fults, 2007; Cottrill and Thakuriah, 2010; Loukaitou-Sideris et al., 2007; Wier et al., 2009) or bicycle crashes (Wei and Lovegrove, 2013).

One important issue when data is aggregated at the macro-level is unobserved heterogeneity. Unobserved heterogeneity occurs when some of the many factors affecting the frequency of crashes are either not observable or such data may be nearly impossible to collect (Mannering and Bhat, 2014). In the situation where these unobserved factors tend to correlate with observed factors, there is the potential danger of bias and erroneous statistical inferences (Greene, 1991; Mannering and Bhat, 2014; Washington et al., 2010). There has been great interest in recent years in models that incorporate unobserved heterogeneity (Mannering and Bhat, 2014). A more recent study that addressed the issue of unobserved heterogeneity in bicycle and pedestrian crashes is the work of Siddiqui et al. (2012) which used a Bayesian spatial framework to capture the effects of spatial unobserved heterogeneity in both bicycle and pedestrian models.

In this study, random parameter models that have the potential to capture unobserved heterogeneity by allowing parameters to vary across observations are adopted. The study aims to investigate pedestrian and bicycle crashes at the macro-level to provide a decision-support tool to facilitate a proactive approach for assessing safety implications of different network planning initiatives and policies. This will be done by explicitly accounting for the issue of unobserved heterogeneity by developing multiple random parameter negative binomial (RPNB) models; three for pedestrian crashes and three for bicycle crashes. As there is currently no modelling technique capable of addressing the issue of heterogeneity in parameter estimates and spatial autocorrelation simultaneously, the study also seeks to investigate which of these two problems has a greater effect and therefore needs to be addressed first. To answer this question the performance of the RPNB models is compared to that of the Poisson-Gamma-CAR models. The study creates another variable, land use mix index in addition to residential, commercial and industrial land use variables to assess how land use mix affects both pedestrian and bicycle crashes.

The remainder of the paper is organized as follows. The next section provides a comprehensive literature review. The paper proceeds with a description of the study area and data used in the model estimation. This is followed by a discussion of the methodology. Model estimation results are then presented, together with a discussion of the findings. The last section provides concluding remarks.

2. Previous research

2.1. Factors influencing macro-level pedestrian and bicycle crashes

Transportation safety research has been broadly divided into two main streams; micro and macro level studies to understand the main factors affecting the frequency and severity of road crashes. At the micro level, researchers investigate specific types of crashes (e.g. fatal crashes, serious injury crashes) at a specific micro level roadway entity such as an intersection or a freeway segment. While macro level crash analysis which is the interest of this study involves aggregation of crashes at specific geographic units such as census blocks, statistical areas and traffic analysis zones.

Previous research has investigated how traffic and environmental characteristics affect pedestrian safety at different levels of spatial aggregation. Traffic volume is a significant predictor of pedestrian crashes (Dumbaugh and Li, 2010; Lascala et al., 2000; Lee and Abdel-Aty, 2005; Loukaitou-Sideris et al., 2007; Wier et al., 2009). Injury severity on the other hand is determined by factors such as the level of vehicular speed (Ewing and Kreutzer, 2006; Siddiqui et al., 2012). For example, Lee and Abdel-Aty (2005), comprehensively analyzed vehicle–pedestrian crashes at intersections in Florida and found that a higher average traffic volume at intersections increases the number of pedestrian crashes; however, the rate of increase is steeper at a lower average traffic volume. Other road and environmental characteristics associated with pedestrian crashes include the roadway length (Lee and Abdel-Aty, 2005), the number of intersections (Dumbaugh and Li, 2010; Kim et al., 2010), and street design features (Ewing and Kreutzer, 2006).

Other pedestrian crash predictors are socio-economic and demographic factors. An area's socioeconomic deprivation level which is usually measured by proxy factors such as percentage of households without vehicles, the level of household income, the unemployment rate and the type of household dwelling have been found to associated with pedestrian crashes (Cottrill and Thakuriah, 2010; Graham and Glaister, 2003; Loukaitou-Sideris et al., 2007; Siddiqui et al., 2012). In general households with higher levels of income experience lower pedestrian crashes than those with lower income levels (Cottrill and Thakuriah, 2010; Loukaitou-Sideris et al., 2007). Similarly, households without vehicles were found to have a positive association with pedestrian crashes (Siddiqui et al., 2012). Population characteristics are also found to have an important association with pedestrian crashes (Aguero-Valverde and Jovanis, 2006; Demetriades et al., 2004; Fontaine and Gourlet, 1997; Johnson et al., 2004; Noland and Quddus, 2004b). It is generally found that the elderly take a longer time to cross the road, increasing their exposure to traffic injury (Demetriades et al., 2004; Zegeer et al., 1996). According to Johnson et al. (2004) children may have a higher exposure to traffic because they tend to play on streets and sidewalks, and generally do not understand a driver's perspective and have a hard time anticipating how drivers will behave. They may also be more likely to enter into conflicts with vehicles due to their less developed cognitive, perceptual and motor skills and lack of awareness about road safety.

Similarly, the type of land use in an area has also been identified in the literature to have a relationship with pedestrian crashes. It has been observed that pedestrian crashes are likely to increase with an increase in the land area used for residential activities (Hadayeghi et al., 2007; Loukaitou-Sideris et al., 2007; Siddiqui et al., 2012; Wier et al., 2009). For example, Hadayeghi et al. (2007) expected the number of collisions to increase by 0.02% for every 1000 m^2 increase in residential areas for each zone. Other land use activities such as commercial, industrial, retail, and parks were also found to have an association with pedestrian crashes (Kim et al., 2006; Pulugurtha et al., 2013; Wedagama et al., 2006). Clifton and Kreamer-Fults (2007) limited their study to the vicinity of public schools in Baltimore, Maryland and found that the presence of recreational facilities on the school site is positively associated with pedestrian crash occurrence and injury severity.

There is limited research focusing specifically on bicycle crashes at the macro-level. The work of Jacobsen (2003) is perhaps one of the earliest macro-level studies that included bicycles. He showed that the number of pedestrian and cycle crashes would increase at roughly 0.4 power of the measure of people walking or bicycling. In other words, a community doubling its bicycle use could expect a 32% increase in injuries. Jacobsen (2003) however did not include any socio-economic, demographic or land use characteristics in his study. Looking at how land use and population influences bicycle crashes, Wedagama et al. (2006) developed generalized linear models that explain how an increase in retail land-use will increase cyclist casualties during working hours.

Some recent studies on cycling crashes have included both socio-economic and demographic data (Gladhill and Monsere,