Analytic Methods in Accident Research 16 (2017) 117–132

Contents lists available at ScienceDirect

Analytic Methods in Accident Research

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

The effects of neighborhood characteristics and the built environment on pedestrian injury severity: A random parameters generalized ordered probability model with heterogeneity in means and variances

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ARTICLE INFO

Article history:
Received 3 July 2017
Received in revised form 6 October 2017
Accepted 6 October 2017
Available online 20 October 2017

Keywords:
Pedestrian injury severity
Neighborhood characteristics
Built environment
Generalized ordered probability model
Unobserved heterogeneity

ABSTRACT

Transportation infrastructure facilities and pedestrian/driver behaviors are associated with neighborhood characteristics and the built environment. However, the effects of neighborhood characteristics and the built environment on pedestrian injury severity are not well documented. To investigate and quantify the effects of neighborhood characteristics and built environment on pedestrian injury severity, a random parameters generalized ordered probit model with heterogeneity in means and variances was proposed to consider the ordinal nature of injury data and the issue of threshold and unobserved heterogeneity. A total of 3867 pedestrian-vehicle crashes that occurred in Florida Department of Transportation District 7 from 2011 to 2014 were analyzed. Based on the estimation results, three factors (African American community, school zone, and bus stop area) related to neighborhood characteristics and the built environment were identified to have significant influence on pedestrian injury severity. Pedestrian-vehicle crashes that occurred in African American community or bus stop area are less likely to involve incapacitating and fatal injuries. The presence of a school within a 0.5-km buffer from a crash leads to a decreased probability of fatal injury and an increased probability of incapacitating injury. In addition, the estimated parameter for elderly pedestrian indicator ($50 < \text{age} \leq 65$) was found to be random with significant heterogeneity in both mean and variance (where the mean and variance are associated with intersection-related crash indicator). Compared to younger pedestrians ($\text{age} \leq 30$), 74.3% of elderly pedestrians who are involved in intersection-related crashes are more likely to suffer severe injury (fatal or incapacitating injury), while 52.4% of elderly pedestrians who are not involved in intersection-related crashes are more likely to suffer severe injury.

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https://doi.org/10.1016/j.amar.2017.10.001
2213-6657/

1. Introduction

People of all ages, income groups, and fitness levels need to walk for every day travel, recreation, or getting to and from work. In recent years, public transit, which is reached primarily on foot, has gained significantly increased use (Shinkle et al., 2008). In addition, as pointed out by Gotschi and Mills, almost 25% of vehicle-based trips in the US can be completed within a 20-min walk (Gotschi and Mills, 2008). Walking, as an active travel mode, can address multiple woes (fuel consumption, air pollution, and obesity) that are closely associated with the large number of short vehicle-based trips (Frumkin et al., 2004). However, due to the high number of pedestrian fatalities, public confidence in choosing walking as a travel mode has been negatively affected. Based on statistical analysis from the National Highway Traffic Safety Administration (NHTSA), pedestrian traffic fatalities in the US recently have become an increasing proportion of total traffic fatalities, with almost 1 pedestrian killed every 1.6 h in 2015 (NHTSA, 2017). To improve public confidence in walking and reduce the social costs of pedestrian-vehicle crashes, it is important to develop countermeasures for reducing pedestrian crash frequency and pedestrian injury severity. Currently, many safety programs have been implemented that aim at reducing pedestrian-involved crash frequency. However, programs that focus on reducing the probability of severe injury (incapacitating or fatal injury), which may be different from programs to reduce pedestrian crash occurrence, receive less attention. The development of proactive and effective countermeasures for mitigating pedestrian injury severity requires a thorough understanding of the contributing factors affecting pedestrian-involved crash severities.

In recent years, many studies have been conducted on evaluating the effects of contributing factors on pedestrian injury severity. Pedestrian injury severity, the dependent variable in severity modeling, is typically categorized into five levels: fatal injury, incapacitating injury, non-incapacitating injury, possible injury, and property damage only. Pedestrian injury severities in previous studies have been modeled as either a binary response outcome (Sze and Wong, 2007; Moudon et al., 2011) or a multiple response outcome (Kim et al., 2008, 2010). The contributing factors (independent variables) considered in previous studies have included one or more of the following categories of variables: (1) neighborhood characteristics and built environment; (2) driver characteristics and driving behaviors; (3) pedestrian characteristics and walking behaviors; (4) vehicle types and traffic characteristics; and (5) roadway characteristics and environmental factors. The specific effects of potential contributing factors on injury severity of pedestrian-vehicle crashes from the previous studies are summarized in Table 1.

As illustrated in Table 1, the effects of neighborhood characteristics (population density, African American community, household income level, etc.) and the built environment (schools, shopping centers, bars and clubs, etc.) on pedestrian injury severity are not well documented. For example, there is no consensus regarding whether pedestrian-involved crashes occurring near a school are more likely to increase the probability of severe injury (Clifton et al., 2009; Zahabi et al., 2011). However, both pedestrian and driver behaviors are believed to be influenced by neighborhood environment and culture (Moudon et al., 2011). In addition, transportation infrastructure facilities also have proved to be associated with neighborhood characteristics and built environment. For example, Gibbs et al. found that, relative to high-income areas, low-income areas typically have more limited infrastructure facilities (lighting, sidewalks, crosswalks, traffic calming devices, etc.) (Gibbs et al., 2012). Thus, the impacts of neighborhood characteristics and the built environment on pedestrian injury severity need more investigation.

Due to the ordinal characteristics of pedestrian injury-severity levels, the application of unordered models (multinomial logit model, nested logit model, mixed logit model, etc.) would lose all information reflected by the ordering (Savolainen et al., 2011). Ordered probability models (ordered probit model, ordered logit model, and their random parameter forms, etc.) can consider the ordinal nature of injury-severity data. Because these models can represent the ordinal outcome probabilities by partitioning the uni-dimensional latent propensity into as many categories as the injury severity levels through a set of thresholds (Eluru and Yasmin, 2015). However, the standard ordered probability models have two major limitations (Washington et al., 2011): 1) standard ordered probability models place a restrictive and monotonic impact of contributing factors on the probabilities of pedestrian injury severities (McCullagh, 1980); and 2) unlike unordered models, the ordinal outcomes in ordered probability models are not independent of each other, all parameters in ordered probability models would be erroneously estimated if under-reporting issues of lower-severity crashes present (Yamamoto et al., 2008). Several generalized versions of standard ordered probability model proposed to relax the first limitation have been summarized in a review paper (Eluru and Yasmin, 2015). To be specific, some researchers relaxed the limitation by allowing the threshold values to be varied across crashes (Ierza, 1985; Eluru et al., 2008; Fountas and Anastasopoulos, 2017), while some researchers relaxed the limitation by distinguishing the exogenous variables into two groups – the coefficients of variables not-varying and coefficients of variables varying across injury-severity levels (Peterson and Harrell, 1990; Wang and Abdel-Aty, 2008). Regarding to the second limitation, Kim et al. pointed out that under-reporting problem would be less of an issue for pedestrian-vehicle crashes because both pedestrians and drivers have their own motivations to report the crash (Kim et al., 2008).

In addition, unobserved factors (pedestrian's physical condition, etc.), correlated with the observed variables (pedestrian's age, etc.), may cause the issue of unobserved heterogeneity. Ignorance of the unobserved heterogeneity issue may lead to biased and inconsistent parameter estimation, erroneous inferences, and predictions (Mannering et al., 2016). To resolve this issue, both latent segmentation-based approach and random parameters approach have been introduced into generalized ordered probability models in the current literature (Eluru et al., 2008; Wang and Abdel-Aty, 2008; Yasmin et al., 2014a,b;