Journal of Safety Research 57 (2016) 9–17

Contents lists available at ScienceDirect

Journal of Safety Research

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

Investigating the risk factors associated with pedestrian injury severity in Illinois

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ARTICLE INFO

Article history:
Received 10 November 2015
Received in revised form 19 January 2016
Accepted 9 March 2016
Available online 21 March 2016

Keywords:
Pedestrian crash
Injury severity
Safety
Ordered-response model
Model comparison

ABSTRACT

Introduction: Pedestrians are known as the most vulnerable road users, which means their needs and safety require specific attention in strategic plans. Given the fact that pedestrians are more prone to higher injury severity levels compared to other road users, this study aims to investigate the risk factors associated with various levels of injury severity that pedestrians experience in Illinois. *Method:* Ordered-response models are used to analyze single-vehicle, single-pedestrian crash data from 2010 to 2013 in Illinois. As a measure of net change in the effect of significant variables, average direct pseudo-elasticities are calculated that can be further used to prioritize safety countermeasures. A model comparison using AIC and BIC is also provided to compare the performance of the studied ordered-response models. *Results:* The results recognized many variables associated with severe injuries: older pedestrians (more than 65 years old), pedestrians not wearing contrasting clothing, adult drivers (16–24), drunk drivers, time of day (20:00 to 05:00), divided highways, multilane highways, darkness, and heavy vehicles. On the other hand, crossing the street at crosswalks, older drivers (more than 65 years old), urban areas, and presence of traffic control devices (signal and sign) are associated with decreased probability of severe injuries. *Conclusions and practical applications:* The comparison between three proposed ordered-response models shows that the partial proportional odds (PPO) model outperforms the conventional ordered (proportional odds—PO) model and generalized ordered logit model (GOLM). Based on the findings, stricter rules to address DUI driving is suggested. Educational programs need to focus on older pedestrians given the increasing number of older people in Illinois in the upcoming years. Pedestrians should be educated to use pedestrian crosswalks and contrasting clothing at night. In terms of engineering countermeasures, installation of crosswalks where pedestrian activity is high seems a promising practice.

1. Introduction

Despite considerable advances in the vehicle industry and safety of occupants, the safety of pedestrians as the most vulnerable road users is yet a major concern. Overall road fatalities as well as driver and pedestrian fatalities were calculated by running a query on the Fatality Analysis Reporting System (FARS) database spanning from 2004 to 2013—a 10-year time interval (NHTSA, 2015). Within this time period, the total number of traffic fatalities decreased by 23.6% in 2013 compared to 2004 (an average decrease of 2.9% per year), and the total driver fatalities decreased by 28.9%. However, the total number of pedestrian fatalities increased by 15.9% (from 4028 fatalities in 2004 to 4668 fatalities in 2013). It should also be noted that the share of driver fatalities dropped from 54.1% in 2004 to 50.3% in 2013, while these numbers for pedestrians are 9.4% and 14.3%, respectively. Specifically related to Illinois, the share of pedestrians increased from 11.5% in 2004 to 12.6% in 2013, while the total number of traffic fatalities dropped by 26.9%.

With the number of cars and total vehicle miles traveled (VMT) increasing in the upcoming years, the need for more robust safety interventions based on actual crash data analysis is warranted. In this study, the Illinois pedestrian crash data (those caused by single vehicles without any passengers colliding with single pedestrians) were analyzed using ordered-response models to consider the ordered nature of crash severity. The main objective is for the results of this study to provide meaningful insight into pedestrian crash severity for the state of Illinois. Addressing this particular consideration as the main objective to save lives by suggesting safety measures, this study also compares performances of three different ordered-response models.

The rest of this paper is organized as follows: A review of prior research on pedestrian injury severity is provided in Section 2. The database used for analysis along with descriptive statistics of the possible risk factors are presented in Section 3. Ordered-response models (i.e., conventional ordered logit, generalized ordered logit model, and partial proportional odd model), their formulations, and their

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http://dx.doi.org/10.1016/j.jsr.2016.03.004
0022-4375/

applications as well as pseudo-elasticity are discussed in Section 4. In Section 5, the proposed model is applied to the crash data set and parameter estimates, and average direct pseudo-elasticities for each injury severity level are calculated. Finally, Section 6 concludes this paper and provides safety recommendations.

2. Prior research

Several studies in the past have analyzed pedestrian crashes and the level of severity incurred by these road users and identified the role of possible risk factors as well as appropriate countermeasures using a variety of statistical methods (Roudsari, Mock, & Kaufman, 2005; Nasar & Troyer, 2013; Al-Shammari, Bendak, & Al-Gadhi, 2009; Tarko & Azam, 2011; Sarkar, Tay, & Hunt, 2011; Strandroth, Rizzi, Sternlund, Lie, & Tingvall, 2011; Oh, Kang, Kim, & Kim, 2005; Mohamed, Saunier, Miranda-Moreno, & Ukkusuri, 2013; Ulfarsson, Kim, & Booth, 2010; Eluru, Bhat, & Hensher, 2008; Cinnamon, Schuurman, & Hameed, 2011; Gårder, 2004; Moudon, Lin, Jiao, Hurvitz, & Reeves, 2011; Tay, Choi, Kattan, & Khan, 2011).

Zajac and Ivan (2003) used the ordered probit model to study the injury severity of pedestrian crashes on rural two-lane highways without any type of control (stop sign or traffic signal) in Connecticut from 1989 to 1998. The focus of their study was on roadway and area features that could possibly affect the injury severity outcome of pedestrians. They found that variables such as clear roadway width, vehicle type, driver alcohol involvement, and being older than 65 years could significantly influence pedestrian injury severity. Furthermore, significantly different injury severities were found in compact residential areas compared to low-density residential areas, with the latter experiencing higher pedestrian injury severity.

In another pioneering study, Lee and Abdel-Aty (2005) used police-reported pedestrian-involved crashes in Florida over 4 years (from 1999 to 2002) to examine the possible correlation between various factors and pedestrian crashes using the log-linear model. They discovered that middle-aged (26–64 years old) male drivers and pedestrians are more likely to be involved in such crashes. In terms of vehicle type, passenger cars were associated with more pedestrian crashes than any other types. Other than these factors, undivided roads, higher number of lanes, and intoxicated drivers driving during nighttime were over-represented when it comes to pedestrian crashes. A severity analysis was also conducted in this study using the ordered probit model to figure out the effect of different factors on injuries and fatalities of pedestrians. It showed that older and intoxicated pedestrians, speeding vehicles, reduced visibility for both pedestrians and drivers, and larger vehicles are likely to worsen the injury of crashes.

Kim, Ulfarsson, Shankar, and Kim (2008) used a heteroskedastic generalized extreme value model to explore the injury severity of pedestrians in crashes. Providing a better fit than the multinomial logit model, the developed model highlighted the effect of several factors in increasing the probability of fatalities. Notable factors include intoxicated driving, which increases the probability of fatal pedestrian injury by 2.7 times, and darkness (with or without streetlights), which poses 2–4 times greater risk of fatalities to pedestrians. Factors such as increasing driver age, driving during PM peak hours, and crossing at crosswalks were associated with a lower risk of fatalities for pedestrians.

Kim, Brunner, and Yamashita (2008) analyzed a comprehensive database of police-reported pedestrian-involved accidents from 2002 to 2005 in Hawaii using logistic regression techniques. Their findings were categorized into three groups. At first they provided a general scheme of the pedestrian crashes. This analysis was followed by comparing at-fault drivers with at-fault pedestrians. Finally, their study was completed by providing a deeper understanding of a variety of human, temporal, and environmental factors influencing pedestrian injuries and the at-fault party (pedestrian or driver) during a pedestrian–vehicle crash.

Kim, Ulfarsson, Shankar, and Mannering (2010) used a mixed logit model to explore the effect of several potential determinants on the injury severity of pedestrians while accounting for possible unobserved heterogeneity that is believed to be of importance, particularly in pedestrian injury severity analysis due to unobserved pedestrian-related factors (e.g., physical health, strength, behavior). Using pedestrian crashes from 1997 to 2000 in North Carolina, their findings unveiled several significant factors affecting the likelihood of fatal injuries for pedestrians. For instance, darkness without streetlights, trucks, freeways, and speeding were found to increase the probability of fatalities by 400%, 370%, 330%, and 360%, respectively.

Several studies have tried to divide the existing data sets into sub-data sets either based on the geographical location or the type of facility. For example, Aziz, Ukkusuri, and Hasan (2013) analyzed pedestrian–vehicle crash data from 2002 to 2006 in New York City and divided it into five boroughs: the Bronx, Brooklyn, Manhattan, Queens, and Staten Island. They determined different risk factors for each of the studied boroughs by developing mixed logit models and using the likelihood ratio statistic to justify the need for separate models. Accordingly, different sets of countermeasures were suggested to be considered for these boroughs in the New York City.

Using the same approach, Islam and Jones (2014) investigated a 5-year pedestrian–vehicle crash data set with pedestrians being at fault and developed two separate injury severity models for rural and urban areas. Their study clearly emphasized the differences between the significant variables based on the type of setting. For example, crashes occurring during weekends were found to significantly affect the severity of pedestrian injuries in urban areas, while this parameter was not found to be significant in rural areas. Furthermore, only three variables were identified to be common in both rural and urban areas, including dark light condition, 2-lane roadways, and pedestrians younger than 12 years.

Haleem, Alluri, and Gan (2015) hypothesized that there might be differences in the injury outcome of pedestrians at signalized and non-signalized intersections. Two separate models for these intersections were developed by exploring this assumption and considering several factors, including geometric predictors, traffic variables, road user characteristics, and environmental predictors. According to the results, differences among risk factors for these two intersections were identified. For example, while average annual daily traffic (AADT) significantly affected the injury severity of pedestrians at signalized intersections, this parameter was not found to be significant for non-signalized intersection.

According to the aforementioned literature review and to the author's knowledge, there is no study to address pedestrian injury severity in Illinois. Furthermore, the studies that use partial proportional odds (PPO) model for pedestrian injury severity analysis are rare and none has compared this model with other ordered-response models. This study uses a PPO model as an ordered-response model to explore the effect of various risk factors of the pedestrian injury severity in Illinois as the main objective. Also, the study provides appropriate safety countermeasures and recommendations to improve the safety of pedestrians based on the analysis results.

3. Data

The data used in this study are based on the police-reported roadway crash data in Illinois, which is accessible through the Illinois crash database. The database is separated into three different text files (crash, person, and vehicle), including a wide range of various characteristics and information regarding each of these categories. The crash file includes information such as type of collision (pedestrian, fixed object, etc.), temporal distributions of the crash (e.g., weekend/weekday, season, time of day), number of vehicles and persons involved, number of injuries for each severity level, type of traffic control device, city class in terms of the population, environmental condition (e.g., lighting,