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Analysis of the injury severity of crashes by considering different lighting conditions on two-lane rural roads

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ABSTRACT

Introduction: Many studies have examined different factors contributing to the injury severity of crashes; however, relatively few studies have focused on the crashes by considering the specific effects of lighting conditions. This research investigates lighting condition differences in the injury severity of crashes using 3-year (2009–2011) crash data of two-lane rural roads of the state of Washington. *Method:* Separate ordered-probit models were developed to predict the effects of a set of factors expected to influence injury severity in three lighting conditions; daylight, dark, and dark with street lights. A series of likelihood ratio tests were conducted to determine if these lighting condition models were justified. *Results:* The modeling results suggest that injury severity in specific lighting conditions are associated with contributing factors in different ways, and that such differences cannot be uncovered by focusing merely on one aggregate model. Key differences include crash location, speed limit, shoulder width, driver action, and three collision types (head-on, rear-end, and right-side impact collisions). *Practical Applications:* This paper highlights the importance of deploying street lights at and near intersections (or access points) on two-lane rural roads because injury severity highly increases when crashes occur at these points in dark conditions.

1. Introduction

1.1. Background

Road crashes comprise a major public health challenge that requires concentrated efforts for effective and sustainable prevention. Worldwide, 1.2 million people are known to die in road crashes each year and millions of others sustain injuries, with some suffering permanent disabilities (World Health Organization, 2013). In consideration of these issues, injury severity has been a primary interest to researchers in traffic safety, since such research would be aimed not only at prevention of crashes but also at decreasing the severity of them. One way to accomplish injury research is by identifying the significant factors affecting injury severity. These factors include behavioral characteristics of drivers (age, gender, driving under influence of alcohol, etc.), environmental factors and roadway characteristics (weather, surface, lighting conditions, roadway geometry, etc.), traffic conditions, vehicle characteristics (body type and age), and types of collisions (direction of impact or occurrence of a rollover).

Roadway lighting condition has long been considered to be significant parameter to the frequency and severity of traffic crashes. Although many studies have explored the effects of factors influencing injury severity, the relationships between these factors, crash severity and lighting conditions, are still not completely understood. Most of these studies have investigated the effects of lighting conditions by using indicator variables representing different lighting conditions as independent variables in regression models. However, in determining injury severity, the problem is further complicated by the fact that there is a complex interaction between variables that can vary significantly across different lighting conditions. This interaction, especially on two-lane rural roads, depends on many factors; the most significant of them is drivers' visibility to observe roadway components, such as oncoming traffic, roadside objects, and so forth. For example, it is expected that darkness inhibits drivers' visibility, allowing less time for last-minute maneuvering and braking in moments before collision, resulting in more severe crashes.

This paper analyzes lighting condition differences in crash injury severities using the crash data of two-lane rural roads of the state of Washington. The ordered probit model is employed to obtain a better understanding of the complex interactions between lighting conditions and contributing factors found in the dataset. The primary objective of this study is to estimate which of these factors become significant in affecting the probability of injury severity in a crash under three major lighting conditions; daylight, dark, and dark with street lights (dark-lighted).

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Using an unbalanced panel data, this study develops separate models for these lighting conditions. Also, by using the marginal effects of the developed models, it investigates the effects of independent variables on different injury severity levels. Finally, these models are compared to identify the significant differences between the effects of the contributing factors on injury severity in the three lighting conditions.

The remainder of the paper is organized as follows. A review of prior literature is presented followed by the methodology applied to model crash injury severity. The data description is given in the third section. Next, the model specification tests are explained and the results are presented. To identify patterns and differences, a comparison analysis of the models is given and the final section summarizes the findings and presents the conclusions.

1.2. Review of prior studies

Many studies have focused on estimating and modeling traffic crashes and their consequences. A large number of these studies have been conducted to determine significant factors influencing the increased levels of injury severity of crashes. Also, various techniques have been employed in order to explore the effects of these factors on injury severity. These techniques can be classified into four major groups: discrete outcome models, data mining methods, soft computing, and other methods (Mujalli & De Oña, 2013). In addition, we can categorize the contributing factors into five groups: driver conditions, vehicle characteristics, road geometry and traffic conditions, environmental conditions, and types of collisions (Lee & Li, 2014).

From the methodological standpoint, the discrete outcome models are of the most practical techniques employed to analyze crash injury severity (Bedard, Guyatt, Stones, & Hirdes, 2002; Wood & Simms, 2002; Pai & Saleh, 2008; Xie, Zhao, & Huynh, 2012, Washington, Karlaftis, & Mannering, 2012; Dong, Richards, Huang, & Jiang, 2013; Obeng, 2011; Pahukula, Hernandez, & Unnikrishnan, 2015). Multinomial logit and ordered logit/probit models have been found to be the most prominent types of discrete outcome models used for traffic crash severity analysis (Savolainen, Mannering, Lord, & Quddus, 2011). For instance, Dong et al. (2013) have estimated the effects of the characteristics of traffic, driver, geometry, and environment on injury severity of truck-involved crashes with a multinomial logit model. Their results indicated that lower traffic volume with higher truck percentage was associated with fatal/incapacitating injury, while a non-standard geometric design was the main cause of non-incapacitating crashes. Also, they concluded that the effects of weather are significant for the possible injury category, while driver condition is the principal cause of property damage-only crashes. Also, Obeng (2011) developed separate fixed-effects ordered probit models by gender differences to explore factors affecting injury severity at signalized intersections. The explanatory variables included the characteristics of the crash, vehicle, and driver. He found major gender differences on the impacts of driver condition, seatbelt use, and airbag deployment on injury severity risks. In addition, he pointed out that better and more in-depth information about gender differences in injury severity risks were gained by estimating separate models for females and males.

Some of past crash severity-related studies have suggested that environmental factors such as lighting conditions are closely related to the increased levels of injury severity (Duncan, Khattak, & Council, 1998; Khorashadi, Niemeier, Shankar, & Mannering, 2005; Rana, Sikder, & Pinjari, 2010; Zhu & Srinivasan, 2011; Obeng, 2011; Pahukula et al., 2015). For example Duncan et al. (1998), using ordered probit models, examined the injury sustained by passenger-car occupants in the case of rear-end collisions between heavy trucks and passenger cars. They indicated that darkness increases the severity of rear-end crashes. Khorashadi et al. (2005) analyzed the differences between rural and urban injury severities of crashes involving large trucks. They captured the effects of lighting conditions by using indicator variables representing different times of day as independent variables in a multinomial logit model. Their study, for instance, suggested that crashes in the morning (5:31–8:00) are less likely to result in evident or fatal injury category in both urban and rural areas. Another study with 10-year crash data for the state of Illinois was carried out with a mixed logit method and found that non-bright conditions significantly increases the probability of severe injuries or fatality in multivehicle crashes (Chen & Chen, 2011). Using the ordered probit models, Zhu and Srinivasan (2011) analyzed 4 years of data from the Large Truck Crash Causation Study (LTCCS). They found that crashes happening during "dark but lighted" conditions (7:30 p.m. to 5:30 a.m.) lead to most severe crashes relative to dark and daylight lighting conditions. In addition, Xie et al. (2012) utilizing a latent class logit model, studied the injury severity of single-vehicle crashes on rural roads. Quite surprisingly, their results indicated that darkness can increase drivers' probabilities of being involved in no-injury crashes. They claimed that drivers tend to be more cautious when it is dark without street lights.

In contrast to the other literature, in which they captured the effects of lighting conditions by using independent variables, Pahukula et al. (2015) focused on the effects of time of day on injury severity. They developed mixed logit models by using the Crash Records Information System (CRIS) database in Texas including large truck-involved crashes occurring on urban freeways between 2006 and 2010. Crashes were separated into five time periods including early morning, morning, mid-day, afternoon, and evening. The results of the individual time of day models demonstrated noticeable differences among the outcome of these models. These differences suggested that different time periods have different significant factors to each injury severity level. The main differences comprised the traffic volume, lighting condition, roadway surface condition, time of year, and percentage of trucks on the road. The authors also highlighted the significance of analysis of injury severity on the basis of individual time of day models.

Overall, almost all of the current literature captured the effects of lighting conditions on crash severity by using an independent variable approach representing association of darkness with the variation of injury severity levels. However, such an approach appears to be limited because different factors under different lighting conditions interact with each other and influence injury severity in complex ways. With this in mind, the intent of the present study is to capture the effects of different factors on injury severity levels under different lighting conditions by using completely separate models. The model estimation results indicate that modeling injury severity in specific lighting conditions is associated with the contributing factors in different ways.

2. Methodology

As discussed in the literature, many studies have used discrete outcome models including ordered probit/logit models, nested logit models, and multinomial logit models (see Savolainen et al., 2011). However, since injury severity levels are commonly recorded in the ordinal scale, some studies suggested unordered discrete choice models such as multinomial or nested logit models, while accounting for the categorical nature of dependent variables, are at the expense of neglecting ordered nature of the injury levels (Greene & Hensher, 2010; Borooah, 2002; Pai & Saleh, 2008; Wang & Abdel-Aty, 2008; Obeng, 2011; Zhu & Srinivasan, 2011). In consideration of this issue, the ordered probit model was used to achieve the purpose of this study.

This research uses an unbalanced panel data for crashes on two-lane rural roads and estimates separate fixed-effects[2] ordered probit models for the three lighting conditions: daylight, dark, and dark-lighted. The effects of the explanatory variables on the injury levels are explored

[2] To account for the possibility of unobserved heterogeneity due to the unbalanced panel data three possible approaches can be used. They are to estimate a latent class, fixed-effects or random-effects model (Obeng, 2011). In this study, we estimate fixed-effects models using STATA13 software.