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Exploring driver injury severity patterns and causes in low visibility related single-vehicle crashes using a finite mixture random parameters model

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HIGHLIGHTS

- Examined driver injury severities in low visibility related crashes.
- Developed a finite mixture random parameters model.
- Captured both within- and between-class unobserved heterogeneity.

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ABSTRACT

Low visibility is consistently considered as a hazardous factor due to its potential leading to severe fatal crashes. However, unlike the other inclement weather conditions that have attracted extensive research interests, only a few studies have been conducted to investigate the impacts of risk factors on driver injury severity outcomes in low visibility related crashes. A three-year crash dataset including all low visibility related crashes from 2010 to 2012 in four South Central states, i.e., Arkansas, Louisiana, Texas, and Oklahoma, is adopted in this study. A finite mixture random parameters approach is developed to interpret both within-class and between-class unobserved heterogeneity among crash data. After a careful comparison, a two-class finite mixture random parameter model with normal distribution assumptions is selected as the final model. Estimation results show that three variables, including *young (specific to injury*, I*)*, *male (specific to serious injury and fatality*, F*)*, and *large truck (specific to serious injury and fatality*, F*)*, are found to be normally distributed and have significant impacts on driver injury severities. Variables with fixed effects including *rural*, *wet*, *60 mph or higher*, *no statutory limit*, *dark*, *Sunday*, *curve*, *rollover*, *light truck*, *old*, and *drug/alcohol impaired* also have significant influences on driver injury severities. This study provides an insightful understanding of the impacts of these variables on driver injury severity outcomes in low visibility related crashes, and a beneficial reference for developing countermeasures and strategies to mitigate driver injury severities under these conditions.

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1. Introduction

Driving under inclement weather conditions is more challenging, as the adverse weather may degrade significant safety performance that compromises normal driving conditions, e.g., low skid resistance on road surface, strong crosswinds, low visibility, etc. Previous studies have demonstrated that serious injuries are more likely to occur under such weather conditions (Chiou et al., 2014; Shaheed et al., 2016; Behnood and Mannering, 2017). Among all the inclement weather conditions, low visibility, mainly associated with fog, dust, or smoke, is one of the most hazardous factors due to its considerable adverse impacts. According to National Highway Traffic Safety Administration, over 9% of weather-related crash fatalities during 2005–2014 occurred due to low visibility, though low visibility related crashes only accounted for around 3% in all weather-related crashes (NHTSA, 2016). In addition, low visibility also plays a significant role in pedestrian- and cyclist-involved collisions in mixed traffic flows, since it becomes much challenging for the nonmotorized traffic to be seen during such conditions, and may result in serious injuries. Thus, special attention is needed to investigate the underlying mechanisms of low visibility related crashes that contribute to such severe injury outcomes. It is noted that, although rain or snow may also cause low visibility, crashes influenced under these conditions mainly result from low skid resistance, and therefore are excluded in this study.

When analyzing driver injury severity, most previous studies considered low visibility as an item of the weather variables and combined it with other conditions, e.g., clear, rain, etc. (Eluru et al., 2012; Zou et al., 2014; Haleem and Gan, 2015). Unlike other weather-related crashes (e.g., rain- or snow-related crashes), crashes occurred under low visibility conditions were not fully investigated in the existing literature. It might be possible because of the lack of clear documentation of such weather conditions in crash datasets. Based on our thorough literature review, there are some existing studies that provide theoretical and empirical contributions to the body of knowledge in low visibility related crash modeling and analysis (Uc et al., 2009; Abdel-Aty et al., 2012; Shaheed and Gkritza, 2014; Norros et al., 2016). For instance, a study conducted by Virginia Department of Transportation (VDOT) reported that almost all the primary fog crashes occurred in fog-prone stretch areas, and most of them involved secondary crashes leading to severe injuries and property damages (Lynn et al., 2002). Given the fact that fog fades the colors and reduces the contrasts in the scene with respect to their distances from the driver, Tarel et al. (2012) proposed an innovate approach to facilitate camera-based Advanced Driver Assistance Systems (ADAS) on the processing fog images and enhance safety performance. A multilevel ordered logistic model was utilized to examine the effects of various risk factors using low visibility crash dataset from Florida between 2003 and 2007. Results showed these crashes were more prevalent on high-speed roads, undivided roads, roads with no sidewalks and two-lane rural roads, and tended to involve more vehicles and result in more severe injuries (Abdel-Aty et al., 2011). Other similar studies using different approaches also provided meaningful insights for analyzing low visibility related crashes (McCann and Fontaine, 2016; Wu et al., 2018a,b).

Based on our best understanding, only a few analytic methods have been proposed to investigate the contributing factors and their impacts on driver injury severity in low visibility related crashes. Therefore, additional methodological approaches should be developed and tested in terms of their appropriateness in analyzing low visibility related crashes. The current studies have indicated that heterogeneity modeling is a promising means for traffic safety researchers to provide more accurate estimation when analyzing crash data extracted from police reports (Milton et al., 2008; Russo et al., 2014). Although the collected crash data are sufficient to provide all detailed attributes with multiple variables and descriptions, some unobserved factors cannot be fully addressed. For instance, occupants in the same age range (i.e., young, middle-aged, or old), may demonstrate significantly different attributes from each other, including perception/reaction time, physical conditions, etc., which may make the impacts of the age variable on injury severities different from one observation to the other. Interested readers can find detailed examples of explanatory variable analyses with possible heterogeneous effects conducted by Mannering et al. (2016). If the unobserved heterogeneity in the dataset is not fully addressed, the impacts of the observed variables on injury severities are then constrained to be constant across all the observations, which may result in biased estimation and erroneous predictions. In addition, the injury severities of affected occupants are often modeled as discrete severity outcomes (for instance, fatal injury, incapacitating injury, visible injury, complaint of injury or possible injury, and no apparent injury), once the crash is observed. Therefore, discrete choice models accounting for unobserved heterogeneity are required for analyzing the commonly collected crash datasets. Of all the various approaches that can meet the aforementioned requirements, mixed logit model, a type of random parameter models, has been widely adopted (Chen and Tarko, 2014; Russo et al., 2014; Ye and Lord, 2014; Coruh et al., 2015; Wu et al., 2016). For instance, Kim et al. (2010) applied a mixed logit model to analyze pedestrian injury severities in pedestrian-vehicle crashes, and discovered that the effect of pedestrian ages was normally distributed across observations, and the probability of fatal injuries increased substantially with the increase of pedestrian ages. Ye and Lord (2014) verified that random parameters models outperformed traditional discrete choice models in crash severity modeling by allowing the same parameter to vary across observations based on the predefined distributions, but might result in a complex multimodal distribution with unexpected shapes and skewness.

A finite mixture approach (also known as a latent class model) is another popular approach to address unobserved heterogeneity. It is designed to seek the observations of homogeneous characteristics and gather them into different groups. Shaheed and Gkritza (2014) utilized this approach to investigate the factors that affect crash severity outcomes in single-vehicle motorcycle crashes based on the crash data in Iowa from 2001 to 2008, and the unobserved heterogeneity issue was addressed by two distinct crash data classes identified by the model. Considerable heterogeneity was also verified across the subtypes in a study conducted by Behnood et al. (2014) with a two-class finite mixture model that explored the differences in driver-injury severity between sober and alcohol-impaired drivers. Some other studies applied this approach also provided an in-depth understanding of its applicability and effectiveness (Afghari et al., 2016; Behnood and Mannering, 2016; Yu et al., 2017). However, a limitation of the finite mixture approach is that it is difficult to determine the optimal number of subtypes, and the unobserved heterogeneity, although reduced, might still exist