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Heterogeneous impacts of gender-interpreted contributing factors on driver injury severities in single-vehicle rollover crashes

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ABSTRACT

In this study, a mixed logit model is developed to identify the heterogeneous impacts of gender-interpreted contributing factors on driver injury severities in single-vehicle rollover crashes. The random parameter of the variables in the mixed logit model, the heterogeneous mean, is elaborated by driver gender-based linear regression models. The model is estimated using crash data in New Mexico from 2010 to 2012. The percentage changes of factors' predicted probabilities are calculated in order to better understand the model specifications. Female drivers are found more likely to experience severe or fatal injuries in rollover crashes than male drivers. However, the probability of male drivers being severely injured is higher than female drivers when the road surface is unpaved. Two other factors with fixed parameters are also found to significantly increase driver injury severities, including *Wet* and *Alcohol Influenced*. This study provides a better understanding of contributing factors influencing driver injury severities in rollover crashes as well as their heterogeneous impacts in terms of driver gender. Those results are also helpful to develop appropriate countermeasures and policies to reduce driver injury severities in single-vehicle rollover crashes.

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1. Introduction

Rollover crashes are far more likely to result in severe outcomes than the other types of crashes. In 2010, the National Highway Traffic Safety Administration (NHTSA, 2010) released that the proportion of rollover vehicles in fatal crashes was 20.6%, which was more than 4 times that in injury crashes (4.5%) and nearly 10 times that in property damage only crashes (2.1%). These data indicate that rollover crashes are a critical issue requiring more research and increased efforts from traffic safety enhancement agencies. In the State of New Mexico, there were 2258 rollover crashes occurring in 2011, which accounted for 5.2% of the total number of crashes. However, those crashes resulted in 127 fatalities accounting for 36.2% of total fatalities in crashes. Thus, there have been many studies on the characteristics of rollover crashes, especially on those which resulted in fatalities (Fréchède et al., 2011; National Highway Traffic Safety Adminstriation, 2007, 2002). Some studies investigated the behavior of vehicles or injury mechanisms in order to prevent rollover of vehicles or severe injury outcomes (Chen et al., 2012; Inamasu and Guiot, 2009; Mattos et al., 2013; van der Westhuizen and Els, 2013). For example, van der Westhuizen and Els (2013) proposed using slow active suspension control to reduce the body roll angle of the vehicle and thus decrease the probability of rollover crashes. Chen et al. (2012) proposed a lateral stiffness coefficient to evaluate the effectiveness of rollover protective structures (ROPS), which could help to design safer ROPS. Some studies focused on specific types of injuries in rollover crashes, such as thoracolumbar junction injuries (Inamasu and Guiot, 2009), cervical injuries, and thoracic spine injuries (Bambach et al., 2013b). However, the process of rollover crashes is so complex that there is still no effective method to prevent their occurrences. Other studies have focused on identifying contributing factors and their impacts on rollover crash severities (Bambach et al., 2013a; Conroy et al., 2006; Farmer and Lund, 2002; Fréchède et al., 2011; Hu and Donnell, 2011; Treacy et al., 2002; Whitfield and Jones, 1995). For instance, Conroy et al. (2006) compared 27 occupants having severe

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injuries and 606 occupants with no injuries or minor injuries in rollover crashes and found that occupants were more likely to be injured severely when their seatbelts were used improperly or they were injured by the vehicle interior side and roof. However, most of those studies fail to consider the heterogeneity among drivers which may also have impacts on injury severities in a rollover crash.

In a rollover crash, driver capability of observing and appropriately reacting to geometric changes and weather related changes on road surface may play the most important role in determining the crash severity. Therefore, the heterogeneity among drivers and its impacts on injury severities have attracted more attention in recent studies. For instance, Obeng (2011) identified a significant difference between the effects of factors on female and male driver injury severity levels. Morgan and Mannering (2011) found substantial differences across age/gender groups under dry, wet, and snow/ice-covered roadways. Amarasingha and Dissanayake (2014) concluded that gender difference was found in injury severities of young drivers in a crash. Chen et al. (2016a,b) found the injury severity discrepancy between males and females in rollover crashes. Therefore, it is of great importance to investigate the role of gender as a significant factor in determining driver injury severities in rollover crashes in order to better understand their unique characteristics and attributes.

In terms of statistical models used in previous studies of crash severity, the logistic models, including binary logit and multinomial logit models, were mostly used to identify and compare the factors which have significant impacts on injury severities in rollover crashes (Farmer and Lund, 2002; Hu and Donnell, 2011; National Highway Traffic Safety Adminstriation, 2007). Many models, such as ordered probit models (Duncan et al., 1998; Jiang et al., 2013; Rifaat and Chin, 2007), multinomial logit models (Chen et al., 2015b; Savolainen and Mannering, 2007; Wu and Zhang, 2016; Wu et al., 2015), nested logit models (Chang and Mannering, 1999; Patil et al., 2012; Savolainen and Mannering, 2007), etc. were developed to analyze crash severities recently. Among those models, parameters were fixed for all observations by assuming that the impacts of contributing factors on injury severities were the same across observation, which may not reflect the heterogeneity among observations. Therefore, mixed logit models were used in many studies to account for individual heterogeneity of factor impacts on injury severities by allowing parameters to follow a distribution and randomly vary across observations (Chen and Chen, 2011; Moore et al., 2011; Train, 2009; Wu et al., 2014). In most of the studies employing mixed logit models, the distribution parameters (mean and standard deviation) were assumed to be fixed, indicating the variations of random parameters could not change when the distribution parameters were estimated. Only limited studies tested the probability of a heterogeneous mean for random parameter distributions (Kim et al., 2013, 2010). In order to better understand the role of gender in rollover crash severities, a mixed logit model with a heterogeneous mean, which is a function of the variable, *Female*, was conducted in this study.

The objective of this study is to identify contributing factors for driver injury severities in single-vehicle rollover crashes. To fill the gap that no studies have investigate the heterogeneous impacts of factors on injury severities due to gender for rollover crashes, a mixed logit model with heterogeneous means was conducted to provide a more comprehensive understanding of rollover crashes. The results will help to develop effective countermeasures and policies for severe injury prevention in rollover crashes.

2. Data desctription

The data used in this study majorly concentrate on all single-vehicle rollover crashes occurring in the State of New Mexico from 2010 to 2012, which were obtained from the New Mexico Department of Transportation (NMDOT), the Traffic Safety Division (TSD) and the Division of Government Research (DGR) at the University of New Mexico. In this database, the code, CLASS, is used to classify the different types of crashes. It is a rollover crash when the value of this code is equal to "01". Based on the variable, NVEH, which indicates the total number of vehicle involved in crashes, rollover crashes which only one vehicle get involved in are selected into this study. All types of vehicles including *Passenger Car*, *Pickup*, *Truck*, *Van and Other Four Wheel*, were explored. Rollover crashes happened on the left/right side of the road and on the roads are all included in this study. After screening out observations with missing data in variables, a total of 4022 single-vehicle rollover crashes were used for model estimation in this study. Each record is at the individual level and contains all information about characteristics of crashes and drivers. Table 1 presents the distributions of the single-vehicle rollover crashes across driver injuries for each variable considered in the study. The variable, *Severity*, is used to classify driver injury outcomes into five categories: *No Injury* (46.0%), *Possible Injury* (19.0%), *Non-incapacitating Injury* (23.5%), *Incapacitating Injury* (9.4%) and *Fatality* (2.1%). As suggested by previous studies (Chen et al., 2016b, 2015a), due to the small size of the last two categories and their similarities of injury severity attributes, they were combined as one category, which was named *Incapacitating Injury and Fatality*.

3. Methodology

3.1. Mixed logit model

This study aims to investigate impacts of various environmental factors as well as driver characteristics on driver injury severities in rollover crashes using mixed logit models. Assuming that the parameters can vary randomly across observations by following a distribution, the mixed logit models can account for individual heterogeneity of contribution factors' effects on injury severity outcomes. Furthermore, in order to analyze the difference between injury severities of male drivers and female drivers, the mean of random parameters can be specified as a function of the explanatory variable, *Female*, in the mixed logit models. Following the previous studies of Bhat (2003), Chen and Chen (2011), Kim et al. (2010) and Train (2009), a mixed logit model is conducted to begin with a propensity function that individual driver n suffering from injury severity i out of I total number of injury severity categories as follows:

$$S_{in} = \boldsymbol{\beta_{in}} \boldsymbol{X_{in}} + \varepsilon_{in} \quad (1)$$

where $\boldsymbol{\beta_{in}}$ is the vector of parameters estimated for injury severity i, which are allowed to vary randomly across observations in the mixed logit models, $\boldsymbol{X_{in}}$ is the vector of explanatory variables determining driver injury severities, and ε_{in} is a stochastic error term. If ε_{in} is assumed to follow generalized extreme value distribution, a standard multinomial logit model can be written as:

$$P_{in} = \frac{\exp\left[\boldsymbol{\beta_{in}} \times \boldsymbol{X_{in}}\right]}{\sum_{\forall I} \exp\left[\boldsymbol{\beta_{in}} \times \boldsymbol{X_{in}}\right]} \quad (2)$$

where $P_n(i)$ is the probabilities of driver n suffering injury outcome i. In order to overcome the limitation of multinomial logit models that cannot account for the individual heterogeneity, a mixed logit model is developed as follows:

$$P_{in} = \int \frac{exp\left[\boldsymbol{\beta_{in}} \times \boldsymbol{X_{in}}\right]}{\sum_{\forall I} exp\left[\boldsymbol{\beta_{in}} \times \boldsymbol{X_{in}}\right]} f\left(\beta|\varphi\right) d\beta \quad (3)$$

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