Accident Analysis and Prevention 72 (2014) 105–115

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Mixed logit model-based driver injury severity investigations in single- and multi-vehicle crashes on rural two-lane highways

Qiong Wu[a,1], Feng Chen[b,2], Guohui Zhang[a,*], Xiaoyue Cathy Liu[c,3], Hua Wang[d,4], Susan M. Bogus[a,5]

[a] Department of Civil Engineering, University of New Mexico, MSC01 1070, 1 University of New Mexico, Albuquerque, NM 87131, United States
[b] Key Laboratory of Road and Traffic Engineering of the Ministry of Education, Tongji University, 4800 Cao'an Road, Shanghai 201804, China
[c] Department of Civil and Environmental Engineering, University of Utah, 110 Central Campus Drive, 2137 MCE, Salt Lake City, UT 84112, United States
[d] School of Transportation Science and Engineering, Harbin Institute of Technology, No. 73 Huanghe Rd., NanGang Dist., Harbin 150090, China

ARTICLE INFO

Article history:
Received 21 January 2014
Received in revised form 18 June 2014
Accepted 19 June 2014

Keywords:
Injury severity
Mixed logit model
Rural two-lane highway
Transferability

ABSTRACT

Crashes occurring on rural two-lane highways are more likely to result in severe driver incapacitating injuries and fatalities. In this study, mixed logit models are developed to analyze driver injury severities in single-vehicle (SV) and multi-vehicle (MV) crashes on rural two-lane highways in New Mexico from 2010 to 2011. A series of significant contributing factors in terms of driver behavior, weather conditions, environmental characteristics, roadway geometric features and traffic compositions, are identified and their impacts on injury severities are quantified for these two types of crashes, respectively. Elasticity analyses and transferability tests were conducted to better understand the models' specification and generality. The research findings indicate that there are significant differences in causal attributes determining driver injury severities between SV and MV crashes. For example, more severe driver injuries and fatalities can be observed in MV crashes when motorcycles or trucks are involved. Dark lighting conditions and dusty weather conditions are found to significantly increase MV crash injury severities. However, SV crashes demonstrate different characteristics influencing driver injury severities. For example, the probability of having severe injury outcomes is higher when vans are identified in SV crashes. Drivers' overtaking actions will significantly increase SV crash injury severities. Although some common attributes, such as alcohol impaired driving, are significant in both SV and MV crash severity models, their effects on different injury outcomes vary substantially. This study provides a better understanding of similarities and differences in significant contributing factors and their impacts on driver injury severities between SV and MV crashes on rural two-lane highways. It is also helpful to develop cost-effective solutions or appropriate injury prevention strategies for rural SV and MV crashes.

1. Introduction

Crashes occurring on rural two-lane highways are more likely to result in severe driver incapacitating injuries and fatalities (Khorashadi et al., 2005; Nordfjærn et al., 2010). According to statistical data released by the Local and Rural Road Safety program, there were 19,259 people killed in crashes on rural highways, which accounted for nearly 57% of total crash-related fatalities in the U.S. in 2009, while the annual vehicle miles traveled (VMTs) on rural highways are only approximately 34% of these on entire highway networks (Federal Highway Administration, 2010). In New Mexico, although crashes occurring on rural highways accounted for only 20% of total crashes, those rural crashes resulted in 222 fatalities which constitute almost 65% of total crash-related fatalities in 2010 (New Mexico Department of Transportation (NMDOT), 2010). Compared to crashes occurring in urban areas, rural two-lane highway-related crashes are associated with a series of significant attributes, such as high speed, low seatbelt usage rate, poor pavement conditions, etc. (Cafiso et al., 2010; De Oña et al., 2011, 2013; Karlaftis and Golias, 2002; Khorashadi et al., 2005). Additionally, 72% fatal crashes in the United States occur on two-lane highways (NHTSA, 2011), These data indicate that it is critical to investigate

* Corresponding author. Tel.: +1 505 277 0767; fax: +1 505 277 1988.
E-mail addresses: wuqiong1034@unm.edu (Q. Wu), chenfeng.csu@gmail.com (F. Chen), guohui@unm.edu (G. Zhang), cathy.liu@utah.edu (X.C. Liu), wanghua@hit.edu.cn (H. Wang), sbogus@unm.edu (S.M. Bogus).
[1] Tel.: +1 505 507 1986.
[2] Tel.: +86 21 6958 3813.
[3] Tel.: +1 801 587 8858.
[4] Tel.: +86 451 86283036.
[5] Tel.:+1 505 277 1395.

http://dx.doi.org/10.1016/j.aap.2014.06.014
0001-4575/

the unique characteristics and attributes associated with rural two-lane highway crashes in order to better understand their significant causal factors determining driver injury severities.

Numerous research efforts have been undertaken to investigate various contributing factors and their impacts on crash frequencies and severities on rural roads, including rural two-lane highways (Abdel-Aty and Radwan, 2000; Bella, 2013; Brown and Cline, 2001; Cafiso et al., 2010; De Oña et al., 2011; Farah et al., 2009; Gårder, 2006; Hu and Donnell, 2011; Ivan et al., 1999; Park et al., 2012; Siskind et al., 2011; Travis et al., 2012; Zajac and Ivan, 2003; Zhang and Ivan, 2005). For example, Farah et al. (2009) analyzed drivers' passing decisions on two-lane rural highways using an interactive driving simulator. De Oña et al. (2011) studied the impacts of a variety of causal factors, such as crash type, driver age and lighting condition on crash injury outcomes on Spanish rural highways. Karlaftis and Golias (2002) found that rural road geometry and traffic volume are significant attributes for the risk of traffic crashes, regardless of the number of lanes. Since substantial differences have been observed in injury characteristics between single-vehicle (SV)-involved and multi-vehicle (MV)-involved crashes, those two types of crashes have been investigated, respectively (Chen and Chen, 2011; Geedipally and Lord, 2010; Ivan et al., 1999; Savolainen and Mannering, 2007; Ulfarsson and Mannering, 2004). For instance, in Ulfarsson and Mannering's study (2004), SV and two-vehicle crashes were modeled, respectively, since their differences could not be accurately captured by one model. Injury severities of rural SV crashes were analyzed by Xie et al. (2012) and they found that explanatory variables, including driver age, seat belt usage and speed were closely related to driver injury severities.

These previous studies provided in-depth insights and verified the necessity to analyze contributing factors of driver injury severities in SV and MV-involved crashes, respectively. In this study, mixed logit models are developed to identify significant attributes in terms of driver behavior, environmental characteristics, vehicle–infrastructure interactions, etc. and quantify their impacts on driver injury severities in rural two-lane highway related SV and MV crashes. Random parameters associated with significant variables are identified and their indeterminate effects on driver injury outcomes are analyzed for both SV and MV crashes. Crash data including information regarding crashes, vehicles, and drivers, were collected on rural two-lane highways in New Mexico from 2010 to 2011 and utilized to extract various attributes including roadway geometric features, driver behavior, weather conditions, environmental characteristics, traffic compositions and dynamics, etc. More than 80% of rural highways are two-lane highways in New Mexico (United States Road Assessment Program (USRAP), 2006), and this study specifically concentrates on rural two-lane highway-related crash injury severity investigations. Elasticity analyses and transferability tests were conducted in order to better understand the quantitative impacts of significant contributing factors on driver injury severities and the models' generality. The model specifications and estimation results indicate that there are significant differences in causal attributes determining driver injury severities between SV and MV crash models although certain contributing factors are found to be identical in both models.

This paper is organized as follows. Previous studies regarding rural SV and MV crash injury severity analyses and related research methodology are summarized in Section 2. In Section 3, a brief description of data is presented, followed in Section 4 by an explicit explanation of the proposed mixed logit model structures and specifications for SV and MV crashes. Section 5 provides model estimation results and discussions. Model specification justification and transferability tests are detailed in Section 6. Finally, conclusions and future research recommendations are presented in Section 7.

2. Literature review

A number of studies have been conducted to investigate contributing factors and their impacts on crash frequencies and severities on rural two-lane highways based on different modeling approaches (Abdel-Aty and Radwan, 2000; Bella, 2013; Cafiso et al., 2010; Karlaftis and Golias, 2002; Kashani and Mohaymany, 2011; Pardillo-Mayora et al., 2010; Park et al., 2012; Persaud and Mucsi, n.d.; Persaud et al., 2004). For example, Cafiso et al. (2010) developed a comprehensive model based on a unique combination of exposure, geometry, consistency and context variables for rural two-lane highways. Park et al. (2012) proved the positive impact of wider edge lines of two-lane rural highways via empirical Bayes, time series and generalized linear regression analyses. They recommended prevalent installation of the wider edge lines. Bella (2013) explored the effect of driver perception of roadside configurations on two-lane rural roads. Abdel-Aty and Radwan (2000) investigated significant variables for accident occurrence on rural two-lane highway segments divided with homogenous traffic flow and geometry features, and concluded that these features were significantly related to crash occurrences. Some studies also investigated specific types of crashes occurring in rural two-lane highways (Farah et al., 2009; Gårder, 2006). Farah et al. (2009) analyzed drivers' passing decisions on rural two-lane highways using an interactive driving simulator. Gårder (2006) studied head-on crashes on rural two-lane highways in Maine and concluded that wider shoulders and more travel lanes are usually associated with more severe crash injury outcomes.

Most of the existing studies have investigated rural crash injury severities by integrating SV and MV-involved crashes together as a whole. More recently, researchers started to explore SV and MV crash characteristics separately to better understand the unique contributing factors for SV and MV crash injury outcomes. Savolainen and Mannering (2007) developed a nested logit model and a multinomial logit model to analyze motorcyclists' injury severities in SV and MV crashes, respectively. Chen and Chen (2011) investigate a various explanatory variables for truck-involved SV and MV crashes on rural highways in order to develop more effective strategies for severe truck driver injury prevention. Chiou et al. (2013) modeled driver injury severities in two-vehicle crashes around signalized intersections in Taiwan based on a bivariate generalized ordered probit model. Geedipally and Lord (2010) employed Poisson-gamma models to explore the separate modeling effect of SV and MV crashes on predicting confidence intervals. They proved the necessity of the separation of SV and MV crashes in highway accident analysis. Ivan et al. (1999) analyzed the distinctiveness of contributing factors in determining SV and MV crash severities on rural roads.

In terms of research methodology, various econometric modeling approaches have been applied to analyze crash injury severities and significant contributing factors. Due to the ordinal nature of injury outcomes (for example, ranging from no injury, to injury and fatal), ordered choice models became popular in crash injury severity modeling (Kaplan and Prato, 2012; Mohamed et al., 2013; Pai and Saleh, 2008). Alternatively, multinomial logit models have also been applied to overcome some limitations of ordered choice models during the past decades (Hu et al., 2010; Hu and Donnell, 2011; Shankar and Mannering, 1996). Furthermore, nested logit models have been employed for crash severity analyses in order to partially address the endogenous correlations among different severity outcomes (Abdel-Aty and Keller, 2005; Lee and Mannering, 2002). Those studies provided in-depth insights into significant causal factors determining crash severities, however, most of them are based on the assumption that all parameters estimated in the models were constant across observations and overlook their heterogeneous impacts on crash injury outcomes. In order to address