Accident Analysis and Prevention 106 (2017) 399–410

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Investigation of factors affecting the injury severity of single-vehicle rollover crashes: A random-effects generalized ordered probit model

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ARTICLE INFO

Keywords:
Rollover
Injury severity
REGOP model
Mixed logit model

ABSTRACT

Rollover crashes are responsible for a notable number of serious injuries and fatalities; hence, they are of great concern to transportation officials and safety researchers. However, only few published studies have analyzed the factors associated with severity outcomes of rollover crashes. This research has two objectives. The first objective is to investigate the effects of various factors, of which some have been rarely reported in the existing studies, on the injury severities of single-vehicle (SV) rollover crashes based on six-year crash data collected on the Malaysian federal roads. A random-effects generalized ordered probit (REGOP) model is employed in this study to analyze injury severity patterns caused by rollover crashes. The second objective is to examine the performance of the proposed approach, REGOP, for modeling rollover injury severity outcomes. To this end, a mixed logit (MXL) model is also fitted in this study because of its popularity in injury severity modeling. Regarding the effects of the explanatory variables on the injury severity of rollover crashes, the results reveal that factors including dark without supplemental lighting, rainy weather condition, light truck vehicles (e.g., sport utility vehicles, vans), heavy vehicles (e.g., bus, truck), improper overtaking, vehicle age, traffic volume and composition, number of travel lanes, speed limit, undulating terrain, presence of central median, and unsafe roadside conditions are positively associated with more severe SV rollover crashes. On the other hand, unpaved shoulder width, area type, driver occupation, and number of access points are found as the significant variables decreasing the probability of being killed or severely injured (i.e., KSI) in rollover crashes. Land use and side friction are significant and positively associated only with slight injury category. These findings provide valuable insights into the causes and factors affecting the injury severity patterns of rollover crashes, and thus can help develop effective countermeasures to reduce the severity of rollover crashes. The model comparison results show that the REGOP model is found to outperform the MXL model in terms of goodness-of-fit measures, and also is significantly superior to other extensions of ordered probit models, including generalized ordered probit and random-effects ordered probit (REOP) models. As a result, this research introduces REGOP as a promising tool for future research focusing on crash injury severity.

1. Introduction

Road crashes are the leading cause of serious injuries and fatalities and also incur huge economic losses and serious social repercussions, especially in developing countries. Rollover crashes are among other road collision types (e.g., rear-end, pedestrian-involved, head-on, etc.) which have been recognized as the main cause of death and injury in traffic crashes (Chen et al., 2016c). Rollovers occur when a vehicle rotates at least one-quarter turn about its lateral or longitudinal axis, which after rolling, the vehicle may come to rest on the side, upside down on the roof, or upright on all wheels (Conroy et al., 2006). Compared to other collision types, although rollovers rarely take place, they are responsible for a notable number of serious injuries and fatalities (Khattak et al., 2003; Pape et al., 2008; Keall and Newstead, 2009; Funk et al., 2012; Wu et al., 2016). For example, Pape et al. (2008) reported that rollovers comprise about 60% of serious single-vehicle (SV) crashes of heavy vehicles. Islam et al. (2016) indicated that rollover crashes accounted for only 2% of motor vehicle crashes for the year 2010 in the U.S., but they were responsible for 20% of all fatal crashes. Chen et al. (2016c) implied that rollovers made up only 5.2% of total crashes in New Mexico, but resulted in 34.6% of total fatal crashes and 36.2% of occupant fatalities. These figures imply that

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http://dx.doi.org/10.1016/j.aap.2017.07.008
Received 11 February 2017; Received in revised form 2 July 2017; Accepted 5 July 2017

rollover crashes are of great concern to transportation officials and researchers, and hence emphasize the increasing need for mitigating the severity outcomes of such collisions. To do so, it is necessary to first identify the significant factors contributing to injury severity of rollovers, so that cost-effective countermeasures can be developed for reducing this challenge. Traditionally, crash prediction models are common tools applied for establishing the relationship between crash injury severity and various explanatory variables. To analyze crash severity outcomes, discrete choice models are widely used, since injury severity data are represented by discrete categories, such as property damage only, slight injury, serious injury, and fatal. In this domain, there are numerous studies in the literature that have utilized discrete choice techniques to model the crash severity outcomes. However, the amount of studies analyzing injury severity of rollover crashes is still insufficient when compared to countless efforts devoted to other crash types. In fact, only little research has investigated the causes and factors associated with rollover crashes. This is mainly due to the randomness and rarity of rollover events, which can be an obstacle for researchers to investigate the factors associated with this collision type. Another possible reason is the lack of detailed information regarding various risk factors, especially on road links. Moreover, most existing studies have paid little attention to the safety effects of different explanatory variables related to driver, weather condition, the environment, road design, and vehicle characteristics on rollover severity levels. Hence, this research extends the current literature and introduces additional variables not considered in previous studies focusing on rollover crashes, as will be shown in the "Data Description" section. The primary objective of this study is to analyze the impacts of various risk factors associated with road-specific attributes, driver characteristics, traffic conditions, vehicle features, and environmental conditions on the injury severity of single-vehicle (SV) rollover crashes. To do this, a random-effects generalized ordered probit (REGOP) model was employed using 6-year (2007–2012) crash data collected on the Malaysian federal roads. REGOP model is an advanced version of ordered probit model, since it can accommodate the ordinal nature of the injury severity levels while relaxing some restrictive assumptions of its conventional counterparts, such as traditional ordered probit model or generalized ordered probit model. To the authors' knowledge, although REGOP model has already been developed in other research fields (Baba, 2009, Mentzakis and Moro, 2009; Brown and Roberts, 2011), there have been almost no studies to employ that model in the area of injury severity modeling, except for one study conducted by Hosseinpour et al. (2014) which applied the REGOP to analyze the injury severity of head-on crashes. In the context of crash injury severity, the majority of related studies have generally applied conventional modeling approaches, such as classical ordered logit or probit models, to examine the injury severity outcomes. Nevertheless, these models suffer from a number of restrictive assumptions, such as the parallel regression assumption and the issue of unobserved heterogeneity, which may exist in crash data. These issues are the major motivations for this research to use a relatively new but more sophisticated model which relaxes the limitations associated with the aforementioned traditional crash severity models. Therefore, the secondary objective of this study is to evaluate the performance of the proposed model, REGOP, in modeling the injury severities of rollover crashes when compared to other widely-used crash severity models. To this end, a mixed logit model (MXL) was also applied using the same data set. MXL models are commonly applied in the literature for modeling crash injury severity. The remainder of this paper is organized as follows. Section 2 presents a review of previous research that has focused on rollover crashes, followed by a brief background on crash injury severity models. Section 3 describes the study area and the characteristics of the data used. The methodology used for modeling the injury severity of rollover crashes is explained in Section 4. The estimation results and the interpretation of parameter estimates are then presented in Section 5. The key findings and conclusions of the study, as well as recommendations for further research are provided in Section 6.

2. Literature review

A limited amount of studies have been conducted to analyze rollover crashes. For example, Farmer and Lund (2002) analyzed the association of the driver, vehicle, and roadway environment with the likelihood of vehicle rollover in SV crashes in the United States. They pointed out that young drivers and crashes at rural curves are more likely to encounter rollover crashes. Also, in terms of vehicle type, the authors indicated that light trucks are twice as likely as cars to experience rollover crashes. Khattak et al. (2003) employed 3-year crash data (1996–1998) collected in North Carolina to analyze the effects of driver behaviors, roadway conditions, vehicle factors on truck rollovers and resulting occupant injury severity in SV crashes. The authors concluded that driver behavior, sharp curves, and turning maneuvers are among the most significant factors increasing the probability of severe rollover crashes. Khattak and Rocha (2003) investigated rollover crashes involving sport utility vehicles (SUVs). The number of quarter turns in rollover crashes and injury severities were modeled by using weighted negative binomial models and weighted ordered logit models, respectively. The results showed that SUVs are more likely than passenger cars to roll over and hence injure their occupant drivers more severely. Using 128 injury cases in three rollover coach crashes in Sweden, Albertsson et al. (2006) analyzed the injury outcome, mechanisms and the possible injury reduction for occupants when using a seatbelt. The authors highlighted the importance of using seat belts in a coach to reduce the risk of serious injury in rollover crashes and also emphasized the importance of other measures, such as higher side window panels and retentive glazing to prevent the occupants from being ejected. Conroy et al. (2006) compared 27 occupants sustaining severe injuries and 606 occupants with no injuries or minor injuries to determine occupant, vehicle, and crash characteristics affecting severe injury outcomes in rollover crashes. The authors indicated that the improper use of seatbelt and the vehicle interior side and roof are main causes of injury severity in rollover crashes. McKnight and Bahouth (2009) conducted a study to reveal causes of truck rollover crashes. The results showed that almost half of the rollover crashes resulted from failing to adjust speed to curves, brake condition, loads, road surface, and intersections. Keall and Newstead (2009) performed an analysis to identify the factors associated with the highest risk of rollovers occurred in New Zealand and three Australian states including Victoria, Queensland, and Western Australia. Separate logistic regression models were applied to data for those jurisdictions from 1993 to 2004. Hu and Donnell (2011) applied a binary logit model and a multinomial logit approach to model the severity of cross-median and median rollover crashes, respectively, using 5 years of crash data collected on rural divided highways in Pennsylvania. The results confirmed that the severity outcomes of median rollover crashes were directly related to the presence of horizontal curves, unbelted drivers, steeper median cross-slopes, and narrower medians. Islam et al. (2016) applied a mixed logit model to identify the significant factors related to the injury severity of rollover crashes in Alabama, USA. In the model developed for the rollover crashes, variables such as roadway downgrade, female drivers, and daylight were significant, while the remaining variables including driver fatigue, driver or occupant wearing a seat belt, and freeway were significant only in the pickup model. Using 3-year (2010–2012) crash data in New Mexico, Wu et al. (2016) employed a mixed logit model to examine the heterogeneous impacts of gender interpreted contributing factors on driver injury severities of rollover crashes. The results implied that female drivers are more likely to experience severe or fatal injuries in rollover crashes than male drivers. Wet roadway condition and being under influence of alcohol were also two other factors that significantly increase driver injury severities. Chen et al. (2016c) utilized support vector machine (SVM) models to analyze driver injury severity outcomes in rollover crashes based on two-year crash data collected in the state of New Mexico, USA. The results revealed that factors including driving environmental conditions, crash time, number