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The interactive effect on injury severity of driver-vehicle units in two-vehicle crashes

Qiang Zeng, [a] Huiying Wen, [a] Helai Huang, [b,*]

[a] School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, Guangdong 510641, PR China
[b] Urban Transport Research Center, School of Traffic and Transportation Engineering, Central South University, Changsha, Hunan 410075, PR China

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ABSTRACT

This study sets out to investigate the interactive effect on injury severity of driver-vehicle units in two-vehicle crashes. A Bayesian hierarchical ordered logit model is proposed to relate the variation and correlation of injury severity of drivers involved in two-vehicle crashes to the factors of both driver-vehicle units and the crash configurations. A total of 6417 crash records with 12,834 vehicles involved in Florida are used for model calibration. The results show that older, female and not-at-fault drivers and those without use of safety equipment are more likely to be injured but less likely to injure the drivers in the other vehicles. New vehicles and lower speed ratios are associated with lower injury degree of both drivers involved. Compared with automobiles, vans, pick-ups, light trucks, median trucks and heavy trucks possess better self-protection and stronger aggressivity. The points of impact closer to the driver's seat in general indicate a higher risk to the own drivers while engine cover and vehicle rear are the least hazardous to other drivers. Head-on crashes are significantly more severe than angle and rear-end crashes. We found that more severe crashes occurred on roadways than on shoulders or safety zones. Based on these results, some suggestions for traffic safety education, enforcement and engineering are made. Moreover, significant within-crash correlation is found in the crash data, which demonstrates the applicability of the proposed model.

1. Introduction

Due to the enormous losses resulting from highway traffic crashes, reducing the severity of injury sustained by crash-involved roadway users has long been a prominent concern of transportation agencies and vehicle manufacturers (Savolainen, Mannering, Lord, & Quddus, 2011). In the field of highway safety research, considerable efforts have also been devoted to gain a better understanding of how the relevant factors affect the degree of injury severity, which is expected to provide useful suggestions for laws, regulations and countermeasures aimed at mitigating crash severity. According to the extant traffic safety research literature, the contributing factors to injury severity refer to the driver's demographic or behavioral characteristics, the vehicle's technical characteristics, roadway conditions and environmental factors at the time and place of crash occurrence. Because crash injury severity is generally categorized into discrete levels, in order to model its relationship with the risk factors, logit and probit models and a number of their variations have been proposed, ranging from ordered models (Khattak, Kantor, & Council, 1998), Bayesian hierarchical (Huang, Chin, & Haque, 2008)/simultaneous (Ouyang, Shankar, & Yamamoto, 2002) models, bivariate (Lee & Abdel-Aty, 2008)/multivariate (Winston, Maheshri, & Mannering, 2006) models, and nested logit model (Shankar & Mannering, 1996), to random parameter model (Milton, Shankar, & Mannering, 2008), Markov switching multinomial model (Malyshkina & Mannering, 2009) and their mixed versions (Eluru & Bhat, 2007; Huang, Siddiqui, & Abdel-Aty, 2011; Zoi, Cohen, & Karlaftis, 2010). Besides, some data mining techniques, such as the neural network (Abdelwahab & Abdel-Aty, 2001, 2002; Chimba & Sando, 2009; Delen, Sharda, & Bessonov, 2006; Zeng & Huang, 2014b; Zeng, Huang, Pei, Wong, & Gao, 2016), classification and regression tree (Chang & Wang, 2006), and support vector machine (Li, Liu, Wang, & Xu, 2012) have also been used as they exhibit better nonlinear approximation performance than traditional discrete outcome models (Please refer to Savolainen et al. (2011) and Mannering and Bhat (2014) for more detailed descriptions and assessments of these models). Although the analytical methods have been advanced continually in the past decades, when the injury severity of each driver-vehicle unit in two-/multi-vehicle crashes is analyzed, the driver-specific and vehicle-specific factors of only itself are considered at most cases. The impact of the counterpart involved in the same crash on the injury degree of the subject driver-vehicle unit has rarely been explored.

Recently, a quantity of studies has been focused on crash compatibility (Fredette, Mambu, Chouinard, & Bellavance, 2008; Huang, Hu &

* Corresponding author.
E-mail addresses: zengqiang@scut.edu.cn (Q. Zeng), hywen@scut.edu.cn (H. Wen), huanghelai@csu.edu.cn (H. Huang).

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Abdel-Aty, 2014; Huang, Hu & Zheng, 2014; Huang, Li, & Zeng, 2016; Huang et al., 2011; Toy & Hammitt, 2003; Wenzel & Ross, 2005), which is deemed as a critical criterion for evaluating a vehicle's safety performance. In these studies, the variations in vehicle incompatibility (such as pickups versus cars) were found to significantly affect the injury severity outcomes of all drivers when a crash occurs. According to Hollowell and Gabler (1996), a vehicle's incompatibility is the combination of its crash worthiness (i.e. the self-protective capacity) and its crash aggressivity (i.e. the hazardousness imposed on the other vehicle(s)) in the collision. Specifically, the vehicle incompatibility refers to the differences of vehicle design with respect to mass, geometry, structure, etc. Therefore, significant distinction was found in the crash worthiness and aggressivity of different vehicle types (Fredette et al., 2008; Huang et al., 2011; Toy & Hammitt, 2003) and models (Huang, Hu & Abdel-Aty, 2014; Huang, Hu & Zheng, 2014; Huang et al., 2016). In addition to the crash aggressivity, as Toy and Hammitt (2003) argued, some driver factors of the subject vehicle may also impact the injury severity of the driver of the other vehicle with which it collides. However, only the effect of crash aggressivity was analyzed in the previous research. A plausible speculation is that the driver-vehicle units in a two-/multi-vehicle crash interact and the attributes of each driver-vehicle unit may have significant effects on the severity of the injuries incurred by all involved drivers.

In this study, to empirically analyze the interactive effect on injury severity of driver-vehicle units, a two-vehicle crash dataset was obtained from the Florida Department of Highway Safety and Motor Vehicles (DHSMV). The factors of both driver-vehicle units together with the crash configuration ones are used as the independent variable in the hierarchical ordered logit (HOL) model for analyzing the injury severity of each driver in a two-vehicle crash. The analyzed results are also expected to provide some new directions for traffic safety education, enforcement and engineering. The rest of this paper is organized as follows. First, the collected crash data are preprocessed and their statistical characteristics are presented. Then, the specific structure and estimation process of the proposed analytical method are illustrated. After that, the estimation results are discussed in details. Finally, some specific recommendations for traffic safety improvement by education, enforcement and engineering are made and directions for future research are presented.

2. Data preparation

The 2007 crash data set from the Florida DHSMV is used for the research. For convenience of investigating the interaction of driver-vehicle units, the analysis focuses on two-vehicle crashes and only the crashes with complete information on the factors as listed in Table 1 are extracted, resulting in a total of 12,834 driver-vehicle units involved in 6417 crashes.

The injury severity of each driver is used as the dependent variable, since driver injury records are generally more complete in the obtained dataset and their seating position is fixed compared with the counterparts of other occupants. In the original crash reports from Florida, the severity of driver injury is divided into five ordered categories: Category 1 – no injury (O); Category 2 – possible injury (C); Category 3 – non-incapacitating injury (B); Category 4 – incapacitating injury (A) and Category 5 – fatality (K). Among our extracted crash data, only 15 (0.12%) involvements resulted in fatalities. Therefore, they are combined with incapacitating injuries to constitute the fourth category (incapacitating injury/fatality) of injury severity, as shown in Table 1.

Five driver-specific factors (age, gender, fault, alcohol/other drugs use and safety equipment use) and four vehicle-specific factors (year, type, point of impact and speed ratio) are analyzed in the study and categorized based on existing definitions in the previous studies (Abdelwahab & Abdel-Aty, 2001, 2002; Delen et al., 2006; Huang et al., 2011). In addition, three crash configuration factors (work area, location and crash type) which can partially reflect the collision circumstances, are also included in the set of explanatory variables.

Table 1
Descriptions and statistics of variables.

Variables	Description	Percent
Response variable		
Injury severity	No injury/property damage only = 1	70.4%
	Possible injury = 2	16.9%
	Non-incapacitating injury = 3	9.9%
	Incapacitating injury/fatality = 4	2.8%
Driver-specific factors		
Driver age	<25 = 1 (reference case)	25.4%
	25–65 = 2	65.5%
	>65 = 3	9.1%
Driver gender	Male = 1 (reference case)	55.3%
	Female = 2	44.7%
Alcohol/other drugs use	No drink or drugs = 1 (reference case)	98.0%
	Drink or drugs = 2	2.0%
Safety equipment	No use of safety equipment = 1 (reference case)	6.0%
	Use of safety equipment = 2	94.0%
Driver fault	At fault = 1 (reference case)	38.2%
	Not at fault = 2	61.8%
Vehicle-specific factors		
Vehicle year	<2002 = 1 (reference case)	52.8%
	2002–20,067 = 2	47.2%
Vehicle type	Automobile = 1 (reference case)	71.7%
	Van = 2	7.6%
	Light truck/pick-up = 3	18.5%
	Medium/heavy truck = 4	2.2%
Speed ratio	<0.5 = 1 (reference case)	35.8%
	0.5–1.0 = 2	59.5%
	>1 = 3	4.7%
POI	Point of impact: 21 points are grouped into four levels:	
	Level 1 = 1 (reference case)	69.5%
	Level 2 = 2	19.5%
	Level 3 = 3	10.8%
	Level 4 = 4	0.2%
Crash configuration factors		
Location	On road = 1 (reference case)	97.7%
	Not on road = 2	2.3%
Work area	Collision location in relation to work zone:	
	None = 1 (reference case)	94.8%
	Nearby = 2	3.2%
	Entered = 3	2.0%
Crash type	Rear end = 1 (reference case)	35.9%
	Head on = 2	8.3%
	Angle = 3	55.8%

With regard to points of impact (POIs), the original Florida crash reports record 21 different locations in a vehicle. Apart from undercarriage (no. 18), overturn (no. 19), windshield (no. 20) and trailer (no. 21), the others are shown in Fig. 1. Following the categorization in the previous studies (Huang, Hu & Abdel-Aty, 2014; Huang et al., 2011, 2014b, 2016), these locations were divided into four levels based on the estimated effects on injury severity. Nine POIs (nos. 1–2, 5–7, 9–10, 14, 21) constitute Level 1. Most of them are the farthest from the driver's seat, such as the front and rear passenger side of the

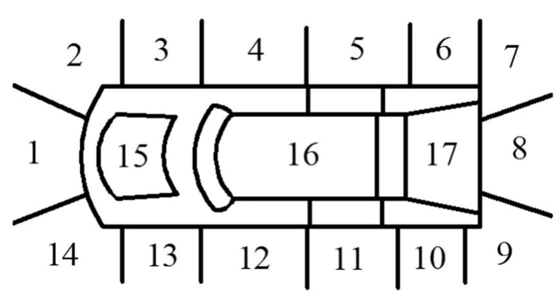

Fig. 1. Points of impact (POIs).

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