ANALYSIS OF DRIVER INJURY SEVERITY IN SINGLE-VEHICLE WORK ZONES CRASHES

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ABSTRACT

Prevention of work zone injury crashes is one of the priorities of highway safety improvement. To make more informed decisions on reducing severe crashes, it is necessary to understand the relationship between injury severity and potential risk factors. Instead of analyzing more aggregated work zone crash data, this paper focuses on drivers' injury severity under single-vehicle crashes in freeway construction work zones. It describes the use of ordered probit model to investigate the risk of different injury levels sustained by drivers with broad considerations of driver characteristics, vehicle features, work zone characteristics and crash characteristics. The reported crash data collected in freeway construction work zones between 2006 and 2011 in New Jersey were used to estimate the probit model. The modeling results show that gender, personal physical status, vehicle features (type and age), curve existence and speed limit at the crash location, driver errors and crash types are the critical factors. Specifically, overturn crashes were associated with more severe injuries for their drivers whereas non-fixed object crashes were less severe. Male drivers in newer passenger cars in work zones located at curved segments with lower speed limits sustained less severe injuries.

Keywords: Work Zone, Injury Severity, Driver Injury, Ordered Probit, Single-Vehicle Crash

INTRODUCTION

The presence of work zones directly affects the safety of road users and highway workers. According to the latest safety statistics by the National Highway Traffic Safety Administration (NHTSA, 2012), 576 work zone fatalities occurred in the United States in 2010. Approximately 85 percent of those killed in work zone were drivers and their occupants. In addition to these fatalities, more than 37,000 injuries resulted from motor vehicle crashes in work zones. As shown by many studies such as Paulsen *et al.* (1978) and Garber and Woo (1990), crash rates increase in the presence of work zones compared to normal road conditions. This rise can be attributable to the complexity of the work zone traffic control that interrupts traffic flow and creates various traffic conflicts. However, exact reasons why many severe crashes occur at work zones are still not clear. A complete understanding of the risk factors associated with work zone crash occurrence and injury severity is essential for the development of effective countermeasures to reduce the number of fatalities and injuries and to enhance traffic operation and safety within work zones.

The objective of this paper is to establish a statistical relationship correlating drivers' injury severity of single-vehicle crashes in freeway construction work zones and a set of contributing factors. Previous studies showed that a large proportion of these single-vehicle crashes occurred in construction zones on Interstate highways/freeways (Li and Bai, 2008a). In addition, the proportion of injury crashes for single-vehicle crashes was significantly higher than for multiple-vehicle crashes (Zhao and Garber, 2001). Such high severity of injuries sustained by drivers involved in these crashes is of considerable interest to highway agencies. Therefore, this paper attempts to examine the probability of different levels of injury by using an ordered probit regression model, thereby recognizing the important contributing factors.

This paper is organized as follows. The next section provides a brief review of studies on work zone safety issues. The data used in this study is then explained. This is followed by the description of the study methodology. Modeling results and discussion are then presented. Lastly, the major findings of the study are summarized in the final section.

LITERATURE REVIEW

Many studies examined work zone safety issues but mostly focused on developing the descriptive statistics of work zone crash data to investigate the characteristics of crash experience, consequences, temporal and spatial distributions at work zones. (Nemeth and Migletz, 1978; Rouphail *et al.*, 1988; Hall and Lorenz, 1989; Garber and Woo, 1990; Sorock *et al.*, 1996; Lin *et al.*, 1997; Bryden *et al.*, 1998; Raub *et al.*, 2001; Chambless *et al.*, 2002; Garber and Zhao, 2002; Schrock *et al.*, 2004; Bushman *et al.*, 2005; Müngen and Gürcanli, 2005; Salem *et al.*, 2006; Harb *et al.*, 2008b; Jin *et al.*, 2008; Li and Bai, 2008a; Ullman *et al.*, 2008; Dissanayake and Akepati, 2009; Akepati and Dissanayake, 2011a). Generally, these studies suggested that the presence of work zones increased the likelihood of crash occurrence (Graham *et al.*, 1978; Paulsen *et al.*, 1978; Garber and Woo, 1990; Casteel and Ullman, 1992; Pal and Sinha, 1996; Khattak *et al.*, 1999; Venugopal and Tarko, 2000; Khattak *et al.*, 2002; Qi *et al.*, 2005; Harb *et al.*, 2008a; Ullman *et al.*, 2008; Ozturk *et al.*, 2013; Yang *et al.*, 2013). Crashes were found to unevenly distribute across different segments of a work zone. The work zone activity area was the predominant location of crashes, and rear end was the predominant crash type (Nemeth and Migletz, 1978; Hargroves, 1981; Nemeth and Rathi, 1983; Pigman and Agent, 1990; Garber and Zhao, 2002; Schrock *et al.*, 2004; Srinivasan *et al.*, 2008; Zhu *et al.*, 2010). Comparisons between daytime and nighttime work zone crashes suggested no clear evidence that increase in crash rate is more significant at night (Casteel and Ullman, 1992; Daniel *et al.*, 2000; Ullman *et al.*, 2004; Udoka, 2005; Ullman *et al.*, 2006; Ullman *et al.*, 2008).

Crash records provide information about the severity of crashes namely, property damage, injury and fatality. There is still no broad consensus in the literature whether the work zones are the reason for more severe crashes (Bai and Li, 2007). For example, some studies reported that work zone crashes were more severe than non-work-zone crashes (Pigman and Agent, 1990; Zhao and Garber, 2001), but other studies found no significant differences (Hall and Lorenz, 1989; Chambless *et al.*, 2002). In addition, there are some cases for which work zone crashes were found to be less severe than non-work-zone crashes (Nemeth and Migletz, 1978; Hargroves, 1981; Ha and Nemeth, 1995).

There is only a limited number of studies focused on modeling the relationship between the attributes of work zone crashes and the severity levels sustained by road users (Khattak *et al.*, 2003; Khattak and Targa, 2004; Qi *et al.*, 2005; Li and Bai, 2007, 2008b, 2009; See *et al.*, 2009; Meng *et al.*, 2010; Akepati and Dissanayake, 2011b; Elghamrawy, 2011; Meng and Weng, 2011; Weng and Meng, 2011). These studies partially investigated the effect of user attributes, road conditions, environmental conditions, vehicle characteristics, crash characteristics and work zone configurations on work zone crash severity. Table 1 provides a summary of these modeling studies. In most modeling efforts, severity is categorized as an ordinal dependent variable of multiple levels (i.e., no injury, injury, and fatal). Advanced statistical techniques were employed to analyze the links between crash severity and other related independent variables. As seen from Table 1, the popular methods for crash severity analysis were focused on logistic regression (LR) for fatality analysis and ordered probit (OP) model for multiple-level of injury spectrum. Depending on the objective, the unit of analysis varies across studies and includes crash level of severity, vehicle level of severity, driver severity and occupant severity.

Injury severity of work zone crashes is determined by a number of factors mentioned above. Findings from literature synthesis are, to a large extent, consistent. Factors most commonly found to increase work zone crash severity include high speed limit at work zone (Khattak *et al.*, 2003; Khattak and Targa, 2004; Li and Bai, 2008b, 2009; Akepati and Dissanayake, 2011b; Elghamrawy, 2011; Meng and Weng, 2011; Weng and Meng, 2011), driving at nighttime (Khattak and Targa, 2004; Qi *et al.*, 2005; Li and Bai, 2008b, 2009; Weng and Meng, 2011), driving under influence (i.e., alcohol/drug) (Qi *et al.*, 2005), vehicle age (Meng and Weng, 2011; Weng and Meng, 2011), number of vehicles and persons involved in crash (Khattak *et al.*, 2003; Khattak and Targa, 2004; Qi *et al.*, 2005), and truck-involved crash (Qi *et al.*, 2005; Li and Bai, 2008b, 2009; Weng and Meng, 2011). In contrast, the deployment of safety equipment such as seat-belt and airbag appears to significantly decrease the level of injury severity (Akepati and Dissanayake, 2011b; Meng and Weng, 2011; Weng and Meng, 2011). Additionally, flagger control at work zones reduced the level of injury severity (Qi *et al.*, 2005; Li and Bai, 2008b). Interestingly, adverse weather was also found to be associated with lower level of injury severity (Khattak *et al.*, 2003; Akepati and Dissanayake, 2011b; Weng and Meng, 2011).

However, studies also report conflicting findings on some factors such as light condition, user age, gender, and number of lanes. For instance, Li and Bai (2008b, 2009) found that poor light conditions increased the level of injury severity, while others presented that good light conditions may increase the level of injury severity (Akepati and Dissanayake, 2011b; Weng and Meng, 2011). Li and Bai (2008b, 2009) concluded that male drivers are associated with increased severity, while Weng and Meng (2011) suggested the opposite for construction and utility work zones. Akepati and Dissanayake (2011b) observed that young drivers are associated with higher severity but Li and Bai (2008b, 2009) and (Weng and Meng, 2011) both reported the opposite.Elghamrawy (2011) and Weng and Meng (2011) both found that crash injury severity was positively correlated with the number of lanes, whereas Li and Bai (2008b) and Meng and Weng (2011) found a negative correlation between severity and the number of lanes.

Based on our review of previous research, significant gaps remain in understanding the relationships between work zone crash injury severities and potential risk factors. Limited studies focused on examining the injury severity at driver level compared to crash-level and occupant-level studies. Different roles between driver and occupants in a vehicle determine their dissimilarity of consequences suffered from the crash. Therefore, understanding the differences in risk factors between driver and occupants is valuable for constructing effective safety strategies towards drivers.

Table 1 Summary of work zone crash injury severity modeling studies

Category	Reference	Khattak & Targa (2004)	Qi et al. (2005)	Li & Bai (07, 08, 09)	See et al. (2009)	Elghamrawy (2011)	Khattak et al. (2003)	Weng & Meng (2011)	Meng et al. (2010)	Akepati & Dissanayake (2011)	Meng & Weng (2011)
	Methodology	OP, OLS	OP	LR	LR	OL	OP, OLS	LR	QRA	OP	LR, GA
	Unit of analysis	Crash Level	Crash Level	Crash Level	Crash Level	Crash Level	Crash/Vehicle Level	Driver Level	Occupant Level	Occupant Level	Occupant Level
Timeline	Time of day			X	X	X		X			
	Day of week			X				X			
Environmental conditions	Light condition	X		X		X	X	X	X	X	X
	Weather condition	X		X	X	X	X	X		X	X
	Road surface condition			X		X		X		X	X
Road conditions	Road class		X	X		X					
	Road alignment			X	X			X			
	Roadway divided by median	X				X	X				
	Median width						X				
	Road surface type			X							
	Number of lanes			X		X		X			X
	Lane width					X					
	Posted speed limit	X		X		X	X	X		X	X
	Area information		X	X	X						
	Road special feature			X		X					
	ADT				X	X					
Road user attributes	Driver age			X			X	X		X	
	Dirver gender			X			X	X		X	
	Driver race						X				
	Driver vision obstruction						X				
	Occupant age								X		
	Occupant gender										X
	Dirving under the influence						X				
	Seat position										X
Vehicle characteristics	Vehicle type						X		X	X	
	Vehicle age							X			X
	Traveling speed						X				X
Work zone information	Type of work zone	X	X			X	X	X			
	Traffic control	X	X	X		X	X	X		X	X
	Workers present									X	
	Work zone activity	X					X				X
	Work zone duration		X								
	Type of work being done	X	X				X			X	
	Work effect on the roadway	X	X		X		X				
Crash Information	Location within work zone	X	X				X			X	
	Number of vehicles involved	X	X	X			X		X		X
	Number of persons involved	X					X				
	Alcohol consumption				X				X		X
	Truck involved in crash		X	X				X			X
	Crash type	X					X		X	X	
	Contributing circumstances		X	X						X	X
	Vehicle pre-crash actions						X			X	X
	First/most harmful event	X					X	X		X	
	Incident location		X	X	X	X				X	X
	Restraint use							X		X	X
	Airbag deployment							X		X	X

Note: LR-- logistic regression; OP-- ordered probit model; OL-- ordered logit model; OLS-- ordinal least squares model; QRA-- quantitative risk assessment; GA-- genetic algorithm

DATA DESCRIPTION

Data Source

Crash data used in subsequent model estimations were obtained from the New Jersey statewide crash database (NJDOT, 2012). Crash-related attributes including roadway characteristics, environmental conditions, crash characteristics, driver information, vehicle information and occupant information were extracted for each crash in the database. The original data were kept in four separate tables, including crash table (crash summary), driver table (driver information), vehicle table (vehicle information), and occupant table (occupant information). In crash table, each crash was described by one single data row regardless of the number of vehicles involved. The other three tables described information about each individual (vehicle or person) in a row as multiple vehicles, drivers or occupants involved in the same crash. A unique case number was shared among these tables to link essential information about the crash, drivers, vehicles and occupants in involved in a crash together. Injury severity of each victim involved in a crash was described by his/her physical condition, which was coded five levels: (1) no injury, (2) complaint of pain, (3) moderate injury, (4) incapacitating injury, and (5) killed.

Work zone crash data between 2006 and 2011 were extracted. After removing about 10 percent of data with missing values, 2,187 single-vehicle crashes occurred in freeway construction work zones were selected for analysis. Among these crashes, 1,726 (78.9 percent) were non-injury crashes and the remaining 461 (21.1 percent) were crashes associated with different levels of driver injury.

Contributing Attributes

In order to develop driver injury severity models, it is necessary to pre-select potential contributing attributes. In this study we determine the contributing attributes based on two steps. The first step is to review all possible attributes that are available in the statewide crash database, and refer to some key attributes that are frequently used in the literature, as shown in Table 1. The next step is to select attributes that are available in the crash records, and are likely to have influence on crash severity in New Jersey conditions.

Following these two steps, 19 attributes are initially hypothesized to have some association with injury severity levels. These attributes are grouped in terms of timeline (time of day and day of week), environmental conditions (light, weather, and road surface condition), road user dependent variables (age, gender, license state, and driver under influence), vehicle characteristics (vehicle type and vehicle age), roadway characteristics variables (road alignment and median type), work zone information (work zone speed limit and traffic control type), and crash dependent variables (crash type, contributing circumstances, vehicle pre-crash actions, and safety equipment use). Some attributes are further classified into different variables to indicate the existence of a specific condition. The definition together with the code for each variable is presented in Table 2. These variables are binary or dummy variables representing the existence of a given condition.

Table 2 Description of variables used in the model

Attribute	Variable	Description
Night time	Night	=0 if daytime (6:00-20:00); =1 otherwise
Day of week	Day	=0 if weekday; =1 if weekend
Light condition	Light	=0 if good condition; =1 if poor condition (dawn, dusk, dark)
Weather condition	Weather	=0 if good condition (clear); =1 if unfavorable condition (rain, snow, etc.)
Surface condition	Surface	=0 if good condition (dry); =1 if poor condition (wet, snowy, icy, etc.)
Driver age	Middle	=1 (25 ≤ driver's age < 65); =0 otherwise
	Young	=1 (driver's age < 25); =0 otherwise
	Old	=1 (driver's age ≥ 65); =0 otherwise
Driver gender	Gender	=0 if male; =1 if female
Out-of-state driver	State	=0 if in state driver; =1 if out-of-state driver
Driver under influence	DUI	=0 if apparently normal; =1 if under influence (alcohol, drug, sleep, etc.)
Vehicle type	Car	=1 if passenger car (car, van, SUV, pickup); =0 otherwise
	Light	=1 if light vehicle (motorcycle, moped, etc); =0 otherwise
	Heavy	=1 if truck or bus; =0 otherwise
Vehicle age	VehAge	=0 if number of years since vehicle was built ≤ 10; =1 otherwise
Road alignment	Alignment	=0 if straight; =1 if curve
Road median	Nomedian	=1 if no median; =0 otherwise
	Curb	=1 if curbed, grass, painted median; =0 otherwise
	Barrier	=1 if barrier median; =0 otherwise
Work zone speed limit	Limit	=0 if speed limit ≤ 40 (mph); =1 speed limit > 40 (mph)
Traffic control type	Nocontrol	=1 if no control; =0 otherwise
	Humancontrol	=1 if human control (police, flagman etc.); =0 otherwise
	Signalsign	=1 if signal, sign, flashing, etc.; =0 otherwise
	Lanemark	=1 if lane markings; =0 otherwise
	Channelization	=1 if channelization; =0 otherwise
Crash type	Overturn	=1 if overturned; =0 otherwise
	Fixedobj	=1 if fixed objected; =0 otherwise
	Non-fixed	=1 if non-fixed object (animal, pedestrian, etc.); =0 otherwise
	Othertype	=1 if other crash types; =0 otherwise
Contributing circumstances	Unsafespeed	=1 if unsafe speed; =0 otherwise
	Inattention	=1 if driver inattention; =0 otherwise
	Improper	=1 if improper action or failed to follow regulations; =0 otherwise
	Close	=1 if following too closely; =0 otherwise
	Othererror	=1 if other driver errors (vehicle, road, etc.); =0 otherwise
Pre-crash action	Gostraight	=1 if going straight ahead; =0 otherwise
	Maketurn	=1 if making turn; =0 otherwise
	Slowmove	=1 if low speed manipulation (slow moving, parking, etc.); =0 otherwise
	Interaction	=1 if vehicle interaction (changing lanes, merging, etc.); =0 otherwise
	Otheraction	=1 if other actions; =0 otherwise
Safety equipment use	Safetyequ	=1 if safety equipment (airbag, belt, etc) is used; =0 otherwise

METHODOLOGY

Injury severity of a traffic crash in New Jersey is described by victims' physical conditions such as fatal, incapacitated, moderate injury, complaint of pain, and no injury (NJDOT, 2012). These physical conditions can be considered as a discrete and ordinal response variable (i.e. outcome) of the crash. Given the discrete natural order of the outcome of an injury, the ordered logit (OL) or ordered probit (OP) regression models have been widely employed in traffic safety analysis to describe its link associated with a list of exogenous factors and to capture the qualitative difference among the categories of crash severity. In this study, the OP regression model is used for analysis of drivers' injury severity.

Assume there is an unobserved latent continuous metric y_i^* underlying the observed level of severity y_i in the i^{th} crash. y_i^* is assumed to depends linearly on the exogenous factors X_i plus a random error term ε_i:

$$y_i^* = X_i^{'}\beta + \varepsilon_i \quad (1)$$

where y_i^* denotes the latent variable measuring the injury severity of the i^{th} driver (victim) involved in a crash; X_i is a $k \times 1$ vector of observed non-random explanatory variables; β is a $k \times 1$ vector of unknown parameters; and ε_i is the random error term.

The latent variable y_i^* is mapped to the observed variable y_i according to the following scheme:

$$y_i = j \text{ if } \tau_{j-1} < y_i^* \le \tau_j \quad \text{for } j = 1 \text{ to } J \quad (2)$$

where j is the observed level of severity of the i^{th} victim; y_i^* is dissected by $J-1$ thresholds into J partitions; τ_j's are constant and unknown threshold parameters to define partitions, denoted as $\tau_{j-1} < \tau_j$, $\tau_0 = -\infty$, and $\tau_J = +\infty$. The partitions are not in general equally spaced.

Defining crash severity of five levels according to the drivers' physical conditions in New Jersey crash records, equation (2) can be represented by the following decision model:

$$y_i = \begin{cases} 1 & if\ \tau_0 < y_i^* \le \tau_1 \quad \text{(victim's physical condition = no injury)} \\ 2 & if\ \tau_1 < y_i^* \le \tau_2 \quad \text{(victim's physical condition = complaint of pain)} \\ 3 & if\ \tau_2 < y_i^* \le \tau_3 \quad \text{(victim's physical condition = moderate injury)} \\ 4 & if\ \tau_3 < y_i^* \le \tau_4 \quad \text{(victim's physical condition = incapacitated)} \\ 5 & if\ \tau_4 < y_i^* \le \tau_5 \quad \text{(victim's physical condition = fatal)} \end{cases} \quad (3)$$

Use above equation (3) we can determine the cumulative probability of y_i as equation (4):

$$\Pr(y_i \le j) = \Pr(y_i^* \le \tau_j) = \Pr(X_i^{'}\beta + \varepsilon_i \le \tau_j) = \Pr(\varepsilon_i \le \tau_j - X_i^{'}\beta) = F(\tau_j - X_i^{'}\beta) \quad (4)$$

where F is the cumulative distribution function (CDF) of the unobserved error term ε_i.

Based on equation (4), the probability that the i^{th} victim suffered injury severity level of j can be described by equation (5):

$$\Pr(y_i = j \mid X_i) = F(\tau_j - X_i^{'}\beta) - F(\tau_{j-1} - X_i^{'}\beta) \quad (5)$$

Given the assumption that the error term ε_i in equation (1) is independently distributed according to standard normal distribution $\varepsilon_i \sim N(0,1)$, then equation (1) represents the OP model structure and the probability equation (5) can be rewritten as:

$$\Pr(y_i = j \mid X_i) = \Phi(\tau_j - X_i^{'}\beta) - \Phi(\tau_{j-1} - X_i^{'}\beta) \tag{6}$$

where Φ is the CDF of the standard normal distribution.

Specifically, the probability that the victim is not injured is:

$$\Pr(y_i = 1 \mid X_i) = \Phi(\tau_1 - X_i^{'}\beta) \tag{7}$$

The probability that the victim is fatal is:

$$\Pr(y_i = 5 \mid X_i) = 1 - \Phi(\tau_4 - X_i^{'}\beta) \tag{8}$$

We are concerned with how changes in the independent variables X_i translate into the probability of observing a particular level of severity. Equation (7) and (8) indicate that a positive coefficient β_k decreases $\Pr(y_i = 1 \mid X_i)$ and increases $\Pr(y_i = 5 \mid X_i)$, respectively. In other words, it can be said unambiguously that an increase in the variable will reduce the probability of being a non-injury crash whereas increase the probability of being a fatal crash. The effect of an increase in the value of x_{ik} on the other estimated probabilities of falling in the intermediate levels of severity $(j = 2, 3, \text{or } 4)$ can be in either direction. Therefore, the marginal effect of increasing one unit of a single variable x_{ik} is calculated while the remaining ones are held constant. It can be calculated as the partial derivative of the conditional probability of injury severity with respect to variable x_{ik} using equation (9):

$$\frac{\partial \Pr(y_i = j \mid X_i)}{\partial x_{ik}} = \frac{\partial \Phi(\tau_j - X_i^{'}\beta) - \partial \Phi(\tau_{j-1} - X_i^{'}\beta)}{\partial x_{ik}} = -[\Phi(\tau_j - X_i^{'}\beta) - \Phi(\tau_{j-1} - X_i^{'}\beta)]\beta_k \tag{9}$$

To estimate the unknown parameters of β and thresholds τ_j's for the OP model, we use the method of maximum likelihood estimation (MLE). Given the victims (drivers) $(i = 1, 2, ..., N)$ are the basic units of analysis, the log-likelihood of the samples is given by the following equation:

$$\ln L(\beta, \tau) = \sum_{i=1}^{N} \sum_{j=1}^{J} \varpi_{ij} \ln \Pr(y_i = j \mid X_i) \tag{10}$$

where ϖ_{ij} is one if the observed value of y_i falls in the j^{th} level of severity, and zero otherwise. Estimations of the parameters are obtained by maximizing equation (10).

RESULTS AND DISCUSSION

OP Modeling Results

The dataset that combines driver, vehicle and crash attributes is constructed using software *R*. The OP model was developed in software *STATA*. Initially, all the variables were incorporated in the OP model. The backward stepwise model selection procedure was implemented to select variables that are used in the final model. Table 3 presents the final modeling results. The likelihood ratio (LR) chi-square of 313.65 with a p-value of 0.000 suggests that the developed OP model as a whole is statistically significant, as compared to the null model with no predictors. The pseudo-R-squared of 0.1066 was obtained. The overall goodness-of-fit suggests that the added variables can significantly affect the driver injury severity. The effect of each variable is discussed in next section.

Table 3 Parameter estimates of ordered probit model

Variable	Coefficient	Std. Err.	z-statistic	P>|z|	95% C.I.
Female	0.2854	0.0663	4.3000	0.0000	(0.1554, 0.4154)
Out-of-state driver	-0.1372	0.0727	-1.8900	0.0590	(-0.2796, 0.0052)
DUI	0.5502	0.0888	6.1900	0.0000	(0.3761, 0.7243)
Light vehicle	0.7662	0.1909	4.0100	0.0000	(0.3921, 1.1403)
Heavy vehicle	0.2443	0.1210	2.0200	0.0430	(0.0072, 0.4814)
Old vehicle	0.1272	0.0693	1.8300	0.0670	(-0.0087, 0.2631)
Curve	-0.2013	0.0993	-2.0300	0.0430	(-0.3960, -0.0066)
High speed limit	0.7578	0.2242	3.3800	0.0010	(0.3184, 1.1972)
Non-fixed object	-0.7029	0.0964	-7.3000	0.0000	(-0.8918, -0.5141)
Overturn	0.7327	0.1138	6.4400	0.0000	(0.5097, 0.9557)
Unsafe speed	0.3761	0.1741	2.1600	0.0310	(0.0349, 0.7173)
Inattention	0.5098	0.1679	3.0400	0.0020	(0.1807, 0.8388)
Improper actions	0.7497	0.2182	3.4400	0.0010	(0.3221, 1.1774)
Other circumstances	0.3454	0.1669	2.0700	0.0380	(0.0183, 0.6724)
/cut1	2.0666	0.2798	-------	-------	(1.5182, 2.6151)
/cut2	2.7872	0.2822	-------	-------	(2.2341, 3.3403)
/cut3	4.1425	0.3079	-------	-------	(3.5391, 4.7460)
/cut4	4.5943	0.3457	-------	-------	(3.9167, 5.2719)

Note: Stepwise model selection was implemented based a threshold value of p-value=0.10.

Marginal Effects

Fourteen variables reflecting driver characteristics, work zone conditions, vehicle characteristics, crash type, and different contributing circumstances were found to significantly affect injury severity of drivers involved in single-vehicle crashes in freeway construction work zones. Table 4 presents the marginal effects of each variable on driver injury severity levels. The results are interpreted and discussed in the following sub-sections.

Table 4 Marginal effects of variables

Variable	j=1	j=2	j=3	j=4	j=5
Female	-0.0768	0.0453	0.0300	0.0011	0.0003
Out-of-state driver	0.0345	-0.0212	-0.0128	-0.0004	-0.0001
DUI	-0.1684	0.0896	0.0741	0.0035	0.0013
Light vehicle	-0.2570	0.1203	0.1258	0.0077	0.0032
Heavy vehicle	-0.0694	0.0397	0.0282	0.0011	0.0004
Old vehicle	-0.0339	0.0202	0.0131	0.0005	0.0001
Curve	0.0485	-0.0303	-0.0175	-0.0005	-0.0002
High speed limit	-0.1359	0.0918	0.0427	0.0011	0.0003
Non-fixed object	0.1549	-0.0982	-0.0545	-0.0017	-0.0005
Overturn	-0.2403	0.1166	0.1145	0.0066	0.0026
Unsafe speed	-0.1077	0.0610	0.0444	0.0018	0.0006
Inattention	-0.1445	0.0817	0.0594	0.0025	0.0008
Improper actions	-0.2492	0.1185	0.1206	0.0072	0.0029
Other circumstances	-0.0915	0.0544	0.0355	0.0013	0.0004

Road User and Vehicle Characteristics

The modeling results in Table 3 show that driver gender significantly affects the injury severity levels. If the driver is female, she is more likely to be injured than male drivers in freeway construction work zone crashes. As shown in Table 4, their probability of complaint of pain, moderate injury, incapacitating injury, and fatality increased by 4.53 percent, 3.00 percent, 0.11 percent, and 0.03 percent, respectively, when the driver is female.

The marginal effects in Table 4 indicate that out-of-state drivers are less likely to be involved in severe crashes.

Compared to normal drivers, those who under the influence of alcohol, drugs, fatigue, are associated with significantly higher risk of being injured in freeway construction work zone crashes. The probability of complaint of pain, moderate injury, incapacitating injury, and fatality increased by 8.96 percent, 7.41 percent, 0.35 percent, and 0.13 percent, respectively.

Vehicle configurations also have an impact on driver injury risk. If a driver is in a light-duty vehicle such as a motorcycle or scooter, his or her overall risk of being injured is 25.70 percent higher than the drivers of passenger cars. This is because a light-duty vehicle driver is less protected than those in cars. Interestingly, if a heavy vehicle as a truck had a single-vehicle crash at a freeway construction work zone, drivers' injury severity also tends to increase, as the marginal effects are negative for complaint of pain and worse. This might be attributable to the unique crash type of these heavy vehicles. Examination of the crash records shows that 11 percent of crashes involved heavy vehicles were overturned type crashes. This is twice more than that of crashes involving other types of vehicles.

In addition to vehicle type, vehicle age also affect the level of drivers' injury severity. Drivers of aged vehicles (age>10 years) are associated with a higher risk of injury in crashes in freeway construction work zones.

Work Zone Characteristics

The negative coefficient of variable 'Curve' in Table 3 suggests that crashes occurred at curved segments are more likely to be non-injury crashes. Specifically, the marginal effects presented in Table 4 indicate that the probability of being a property-damage only (PDO) crash increased by 4.85 percent if a single-vehicle crash occurred in the construction work zone located at a curved segment. In contrast, the probabilities of complaint of pain, moderate injury, incapacitating injury, and fatality decreased by 3.03 percent, 1.75 percent, 0.05 percent, and 0.02 percent, respectively. This might be attributable to reduced speed at curved segments. As many studies (Li and Bai, 2009; Akepati and Dissanayake, 2011b; Weng and Meng, 2011) have shown, the marginal effects associated with speed limit variable confirmed that a high speed limit increases driver injury risk in a freeway construction work zone crash. In particular, if the speed limit is greater than 40 mph, the results in Table 4 show that the probability of complaint of pain, moderate injury, incapacitating injury, and fatality increased by 9.18 percent, 4.27 percent, 0.11 percent, and 0.03 percent, respectively. Thus, speed control at these work zones is very important in reducing severity of motor vehicle crashes.

Crash Characteristics

Different crash types have different effects on driver injury risk. As shown in Table 4, the non-fixed-object crash has the lowest impact on driver injury risk compared to fixed-object crashes. In contrast, the overturn crashes significantly increase severity. The probability of complaint of pain, moderate injury, incapacitating injury, and fatality increased by 11.66 percent, 11.45 percent, 0.66 percent, and 0.26 percent, respectively, as shown in Table 4. In fact, these crashes were widely recognized as the most harmful events (Weng and Meng, 2011).

If the crash was caused by some apparent contributing circumstances such as unsafe speed, inattention, and other improper behaviors, the probability for the driver being injured increased. Particularly, the actions such as improper lane change, passing, and turning can increase the injury risk by 24.92 percent. Alerting drivers to drive more carefully in work zones is therefore beneficial to reduce injury severity.

CONCLUSIONS

This study examined the injury severity for drivers involved in single-vehicle crashes in freeway construction work zones. These single vehicle crashes comprised over 20 percent of the crashes in all freeway work zones in NJ. Unlike the previous studies in the literature that aggregated all work zone crashes data for analysis, this study focused only on driver injury in single-vehicle crashes. Working with these selected type of crashes provides us opportunities to reveal the unique characteristics of driver injury. Potential contributing factors associated with driver characteristics, vehicle features, work zone characteristics and crash characteristics were considered. Ordered probit regression model was developed to quantify the most influential factors that affect driver injury severity levels.

According to the modeling results based on six-year sing-vehicle crashes in work zones in NJ, female drivers and those who drive under influence were found to have higher injury risk. Out-of-state drivers were less likely to be injured when involved in single-vehicle crash in freeway construction work zones. Compared to passenger vehicles, both light vehicles and heavy vehicles were prone to link with higher driver injury. In addition, vehicle age was also found to be positively related to driver injury risk. The injury risk of drivers was higher in single-vehicle crashes occurred in work zones of straight road segments or in work zones with high speed limits since drivers may operate in high speed at these locations. Compared to fixed-object crash, non-fixed-object crash decreased the probability of injury. In contrast, overturn crashes were very severe as the probability of overall driver injury risk was over 24 percent higher than other type of crashes. Erroneous driving behaviors such as driving with unsafe speed, improper actions, and lack of attention also resulted in higher probability of more severe crashes.

There are still some efforts that need to be made considering the constraint of the data sources. This paper only examined the work zone crash records reported by polices. To more reliably examine the levels of injury, it is advised to examine detailed injury information recorded by medical practitioners or hospitals. In addition, incorporating detailed work zone information in the model should be considered. To highlight the differences between work zone and non-work zone crashes, a study that compares a set of work zone crashes with a group of non-work zone crashes on similar stretches of roadways is more powerful and persuasive and will be conduct in the following work.

ACKNOWLEDGEMENTS

The contents of this paper reflect views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents of the paper do not necessarily reflect the official views or policies of the agencies.

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