SEVERITY OF PEDESTRIAN-VEHICLE CRASHES IN SOUTH KOREA

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ABSTRACT

This paper examines the factors determining the severity of pedestrian-vehicle crashes in South Korea. Three levels of severity are examined (fatal, severe and minor) using 2006 data from the official crash database maintained by the Korean National Police Agency. A multinomial logit model predicting crash severity conditional on crash occurrence is estimated using the method of maximum likelihood. Our results show that fatal and serious crashes are mostly associated with collisions involving drunk drivers, pedestrians over the age of 65, female pedestrian, pedestrians hit in the middle of the road such as crosswalk and traffic lane, male drivers under the age of 65, pedestrian hit on high speed roads such as freeways, provincial and national highways, inclement weather conditions such as rain and fog, collisions at night, pedestrian hit on road links, crashes in tunnels and on bridges, pedestrian hit on wider roads and pedestrian hit by heavy vehicle.

Keywords: Road safety, multinomial logit analysis, crash severity, pedestrian safety, South Korea.

INTRODUCTION

Motor vehicle crashes are a leading cause of deaths and serious injuries in many developed and developing countries. In South Korea, for example, there were 14,173 traffic fatalities in 1990 (Lee, 2008). Although the road toll has since fallen significantly to 6,563 in 2004 (see Figure 1), South Korea still has one of the highest fatality rates in OECD countries. In 2005, Korea had a fatality rate of 13.2 per 100,000 people, 3.4 per 10,000 registered vehicles and 1.9 per 100 million vehicle-km compared to the OECD median of 9.5, 1.4 and 0.9 respectively.

One of the major differences between South Korea and other OECD countries is the relatively high share of pedestrian fatalities in South Korea (39%) compared to an average of 17% for OECD countries (Lee, 2008). Pedestrian safety is therefore is significant traffic safety issue in South Korea in particular and understanding the factors contributing to the severity of pedestrian crashes will provide policy makers, engineers, and enforcement officers with evidence based recommendations to reduce the severity of pedestrian-vehicle collisions (Tay & Choi, 2008).

The purpose of this study is to determine the factors that contribute to the severity of pedestrian-vehicle crashes in South Korea. Using 2006 police-reported crash data, a multinomial logit model is calibrated to relate crash severity to a number of factors, including roadway environment, traffic control devices and weather conditions as well as pedestrian, driver and vehicle characteristics. The results of this study will provide engineers, policy makers and traffic enforcement agencies with valuable recommendations to reduce the severity of vehicle-pedestrian collisions in South Korea and to provide useful comparisons to previous studies conducted in Korea and around the world.

METHODOLOGY

The severity of pedestrian injury in pedestrian–vehicle collisions is normally classified into discrete categories which describe the injury level of the most severely injured road user involved in the crash. Although ordered response models are the most appropriate models to use in modeling crash severity due to the ordinal nature of the dependent variable, some researchers have instead chosen to use unordered response models, such as the multinomial logit model, to allow the independent variables to have a non-monotonic effect on the dependent variable (Shankar & Mannering, 1996). In this study, the multinomial logit model (MNL) will be used to increase the flexibility in modeling and to complement previous research using the ordinal logit model (Tay & Choi, 2008).

In the MNL, the probability of pedestrian n being injured with severity outcome i is written as:

$$P_n(i) = P\,(U_{ni} \geq U_{nj})$$

where U_{ni} is a function determining the severity, and i is a set of I possible mutually exclusive severity categories. If we assume U_{ni} has a linear-in-parameters form, it can be expressed as:

$$U_{ni} = \beta_i X_{ni} + \varepsilon_{ni}$$

where βi is a vector of parameters to be estimated, X_{ni} is a vector of explanatory variables and ε_{ni} is a random component which is assumed to be distributed with a type 1 extreme value distribution. This assumption leads to the multinomial logit model as expressed in the following:

$$Pn(i) = \frac{e^{\beta_i x_{ni}}}{\sum_{i=1}^{I} e^{\beta_i x_{ni}}}, i = 1,\ldots\ldots, I$$

The parameters of the multinomial logistic regression model are calibrated using the Statistical Package for Social Sciences (SPSS).

DATA

Data on traffic collisions in 2006 in South Korea were provided by the Korean National Police Agency. For the analysis of vehicle-pedestrian crash severity level, only collisions that involved at least one pedestrian were included in the analysis. Data included 45,201 pedestrian collisions involving 48,381 pedestrians. The severity of a crash is determined by the road user (usually the pedestrian) with the highest injury severity. In the police database, injury severity was recorded using 4 categories; namely, fatal injury, severe injury, minor injury and bruise. Since there is little difference between the two lowest severity levels, they are combined into one category. The database also contains information on the time and location of the crash, drivers' and pedestrian characteristics, roadway attributes, weather and environmental information and vehicle types.

The factors examined in the model are shown in Table 1. Among the pedestrians injured in a crash, 4.9% were classified by the police as fatal, 55.8% were classified as severe (requiring hospitalization), and 39.3% were classified as minor. It should be noted that in the estimation model, one of the severity categories has to be omitted from the model and used as a reference or base case. In this study, the minor injury case will be used as reference and two sets of results for fatal and serious injury will be estimated.

Also, note that most of the contributing factors are recorded in categories. Therefore, several dichotomous variables will be created to represent each contributing factor. Again, one of the dichotomous variables for each contributing factor has to be omitted from the multinomial logit model and used as the reference or base case. Note that the choice of the base case is arbitrary and will not affect the estimation results if all the other categories are included in the model. Therefore, all dichotomous variables for a factor will be retained in the model for ease and consistency in interpreting the results even though some may not be statistically significant.

RESULTS AND DISCUSSION

Table 1 presents the estimation results of multinomial logit model. Note that the table has two parts: a set of results for fatal injury and another set of results for severe injury. In this study, the minor injury category was selected as a base case for the dependent variable. The estimated coefficients therefore show the relative effects of a contributing factor on a fatal or serious injury crash compared to a minor injury crash. Also note that some variables that are not statistically significant are retained in the model to facilitate interpretation of the results. Although most researchers choose to retain only significant variables in the final model, we have followed the convention used by some researchers to retain all categorical variables from the same contributing factor as long as at least one of the categories are statistically significant (Kockelman & Kweon, 2002; Tay et al, 2009; Tay & Rifaat, 2007). To compensate for the reduction in efficiency, we choose to use a more generous confidence level of 90% instead of the traditional 95%.

Table 1: Multinomial Logit Estimates of Pedestrian Crash Severity

Number of Observations			48, 381	
Log-likelihood			70253.336	
Restricted Log-likelihood			77253.717	
Chi-Square			7000.381	
P-value			< 0.0001	
Base Case: Minor Crash	**Serious Crash**		**Fatal Crash**	
Variables	**Beta**	**P-value**	**Beta**	**P-value**
Intercept	-3.610	< 0.001	0.089	0.886
Driver Sex (Ref: Female)				
Not known	-0.281	0.195	-0.331	< 0.001
Male	0.424	< 0.001	0.004	0.881
Driver Age (Ref: 26-65 years)				
Under 25	-0.023	0.785	0.001	0.992
Over 65	-0.554	< 0.001	-0.136	0.013
Drunk Driver (Ref: No)				
Yes	-0.185	0.034	0.140	0.001
Pedestrian Sex (Ref: Female)				
Not known	23.510	-	-0.051	-
Male	0.036	0.463	-0.156	< 0.001
Pedestrian Age (Ref 26-65 yrs)				
0 to 5	-0.150	0.240	-0.490	< 0.001
6 to 15	-1.106	< 0.001	-0.367	< 0.001

16 to 25	-1.414	< 0.001	-0.418	< 0.001
Over 65	1.923	< 0.001	0.849	< 0.001
Location (Ref: Sidewalk)				
Crosswalk	0.748	< 0.001	0.303	< 0.001
Shoulder	-0.052	0.702	-0.289	< 0.001
Other	-0.062	0.634	-0.155	< 0.001
Traffic Lane	0.305	0.019	-0.044	0.345
Road Class (Ref City Road)				
Other	0.112	0.878	0.263	0.671
County Road	0.427	< 0.001	0.171	0.001
Freeway	2.665	< 0.001	0.596	0.018
Metropolitan City Road	0.083	0.908	0.251	0.684
National Road	1.221	< 0.001	0.287	< 0.001
Provincial Road	0.853	< 0.001	0.232	< 0.001
Road Segment (Ref: Other)				
Intersection	-0.028	0.831	0.099	0.055
Intersection Approach	-0.220	0.081	-0.006	0.906
Link	0.182	0.098	0.043	0.286
Link crosswalk	-0.112	0.370	0.057	0.226
Link crosswalk Vicinity	0.028	0.864	0.185	0.004
Bridge	0.180	0.509	-0.032	0.811
Tunnel	0.611	0.485	0.406	0.400
Road Width (Ref: 3m or Less)				
Other	0.010	0.943	0.105	0.027
6m or less	-0.090	0.221	0.006	0.834
9m or less	0.048	0.568	0.069	0.048
13m or less	-0.002	0.987	0.188	< 0.001
20m or less	0.179	0.089	0.192	< 0.001
20m or less	0.722	< 0.001	0.313	< 0.001
Weather (Ref: Dry)				
Cloud	0.397	< 0.001	0.073	0.087
Other	-0.386	0.242	-0.012	0.913
Fog	1.289	< 0.001	0.568	0.040
Rain	-0.097	0.783	0.248	0.081
Snow	0.272	< 0.001	0.153	< 0.001

Time of the day (Ref: Off Peak)				
Morning Peak	0.258	0.006	0.156	< 0.001
Afternoon Peak	0.667	< 0.001	0.097	< 0.001
Night	1.008	< 0.001	0.149	< 0.001
Lane Number (Ref: Lane 1)				
Other	-0.408	< 0.001	-0.137	< 0.001
Lane 2	0.359	< 0.001	0.094	0.002
Lane 3	0.312	0.01	0.076	0.081
Lane 4	0.176	0.133	0.047	0.373
Lane 5 and Outside	0.279	0.048	0.180	0.011
Car Type (Ref: Car)				
Motor Bike	-1.380	< 0.001	-0.176	< 0.001
Other	1.158	< 0.001	0.118	0.047
Special Vehicle	1.909	< 0.001	0.715	0.001
Truck	0.808	< 0.001	0.276	< 0.001
Van	0.630	< 0.001	0.108	0.003
Region (Ref: WoolSan)				
ChoongBook	-0.110	0.882	-0.011	0.986
ChoongNam	0.281	0.702	0.120	0.847
DaeGu	-0.477	0.013	-0.253	0.001
Dajeon	-0.325	0.137	-0.330	< 0.001
GangWon	-0.323	0.661	-0.148	0.812
GyungBook	-0.173	0.813	-0.041	0.947
GyungNam	0.334	0.649	0.657	0.290
Incheon	-0.832	< 0.001	-0.344	< 0.001
Jeju	-1.044	0.163	-0.490	0.432
JunBook	-0.400	0.587	-0.342	0.582
JunNam	-0.515	0.483	-0.407	0.513
Kwangju	-0.646	0.01	-0.960	< 0.001
KyungKi	-0.381	0.602	0.001	0.999
Pusan	-0.407	0.030	-0.013	0.863
Seoul	-1.058	< 0.001	-0.582	< 0.001

Driver's Characteristics

Our study shows that, compared with female drivers, male drivers are more likely to be involved in severe injury crash and this result is statistically significant. Similarly, the results from Table 1 indicate that male drivers are more likely to get involved in fatal injury than female driver although this latter variable is not statistically significant. Similar results on the effects of driver gender were reported by other researchers for other types of crashes (Tay & Choi, 2008; Valent et al, 2002; Li et al, 1998; Laapotti & Keskinen, 1998). The difference in higher risk of severe and fatal collisions between genders may be explained by behavioral differences between the sexes as women are generally less likely to be high risk-taker (Tay et al, 2003; Lewis et al, 2007; O'Brien et al, 2004).

Considering drivers' age, Table 1 shows that drivers in the 26-65 age group are more likely to be involved in severe and fatal injury crashes compared to drivers who are older than 65. Both of these findings are statistically significant. On the other hand, both the younger age categories have no statistically significant effect on the severity of collisions. Again, these results are consistent with findings from previous studies (Tay & Choi, 2008; Valent et al, 2002).

In our study, intoxicated drivers are shown to have higher chances of fatal injury. When a vehicle driver is intoxicated, the probability of fatal injury increases drastically. Noland and Quddus (2004) reported that alcohol consumption has a significant effect on collision severity. Moreover, Oxley et al (2006) and Wootton et al (2006) showed that pedestrians who are under the influence of alcohol are shown to engage in more risky road-crossing behavior.

Pedestrian Characteristics

Relative to female pedestrians, male pedestrians were found to be significantly less likely to be involved in fatal collisions. Note that this result refers to the pedestrian who is hit and therefore different from conventional wisdom that male drivers are involved in more fatal crashes than female drivers. Male pedestrians are found to be more likely to survive a crash with a motor vehicle than female pedestrians. This result is consistent with the findings from previous studies (Tay & Choi, 2008).

Consistent with previous studies (Tay & Choi, 2008; Oh et al, 2005, 2007; Youn et al, 2005), our study reveals that pedestrians aged 65 and over are more likely to be severely and fatally injured as compared to pedestrians in the age group of 26-65 years. These results are also statistically significant. On the other hand, the results reported in Table 1 showed that pedestrians aged 25 or younger are less likely to be severely and fatally injured. Similar findings are reported by Vorko-Jovic et al (2006) and Maring et al (1990). Older age groups are more vulnerable and the probability of survival is lower as compared to younger age groups due to various medical conditions (Vorko-Jovic, 2006).

In comparison with pedestrians who were hit on sidewalks, pedestrians who were hit in traffic lane and on crosswalk are more likely to have severe injuries. Additionally, collisions involving pedestrians that occurred on crosswalks are more likely to result in fatality. These findings are expected and are explained by the fact that crosswalk and traffic lanes are the conflict points of pedestrian-vehicle interactions. Also, since the pedestrians are hit in the traffic stream, the impact speed is also expected to be higher, resulting in more severe injuries (Tay & Choi, 2008).

Roadway Characteristics

Consistent with previous study (Tay & Choi, 2008), this study showed that compared to city roads, crashes on high speed roads such as freeways, national roads and provincial roads were likely to be more severe (fatal or serious injury crashes), a finding that is consistent with previous studies (Vorko-Jovic et al, 2006). Also, roads located outside the urban center do not often have sidewalks, separate paths for pedestrians, or pedestrian crossing which placed the pedestrian at higher risk.

Our study showed that compared to other roads, crashes occurring in intersections and link crosswalks had a higher probability of resulting in fatality while crashes occurring at intersection approach and on links had a higher probability of resulting in severe injuries. Klop and Khattack (1999) found similar results in pedestrian collisions occurring on link roads. The authors also suggested that these collisions are more prone to fatal and severe injuries.

As expected, our results showed that the probability of pedestrians being fatally injured increased with an increase in the road width. Compared with roads with a width or 3m or less, pedestrians on roads with wider widths (9m or more) have a higher probability of being fatally injured. Additionally, pedestrian on roads having a width of 13 m or more have a higher probability of being seriously injured compared to the reference case. These findings might be explained by the fact that wider roads are also associated with higher speeds as well as longer walking distance.

Our study showed that compared to lane number 1 (curbside) on the roads, the probabilities of pedestrians suffering severe and fatal injuries increased on the outer lanes. These findings are consistent with previous study (Tay & Choi, 2008) and are simply attributed to the fact that, similar to road width, number of lanes is usually associated with operating higher speeds which, as reported in previous studies, results in high fatality and severe injury (Vorko-Jovic et al, 2006). Moreover, the speed of vehicles on the outside lanes are usually faster than those in the inside lanes.

Weather condition

While most pedestrian-vehicle collisions occurred on clear days, our study found that inclement weather conditions (fog, cloud, snow, etc.) are significantly associated with higher pedestrian injury severity. Klop and Khattak (1999) also showed that fog increases injury severity. The effect of bad weather on injury severity is probably due to the reductions in visibility as well as the reduction in vehicular traction. In other words, foul weather may lead to more severe collisions since it can distract and/or reduce perception of pedestrians and drivers as well as their ability to respond, i.e. brake, steering or take an evasive maneuver at incidents. Kim et al (2007) also reported that foul weather makes roads less skid resistant which might result in reduced braking and steering capability, greater impact speeds and possibly worse impact angles; leading therefore to more severe and fatal collisions.

Time of the Day

The results from our study shows that pedestrian-vehicle collisions occurring during night time are more likely to be associated with severe or fatal injuries compared to collisions occurring in daylight. In addition to higher speed, lighting condition is directly related to visibility which is shown in various studies to be positively correlated with collisions severity. Interestingly, relative to daytime off peak hours, collisions during peak hours were found to be more severe (both serious injury and fatality). These findings are consistent with Vorko-Jovic et al (2006) and might be attributed to stress and fatigue.

Vehicle Type

In comparison with car, vehicles with greater mass, such as special vehicles, trucks and van, were found to be associated with a higher probability for severe and fatal injury. On the other hand, collisions with motorcycles tend to produce injuries of lower severity compared to collision with cars. These findings are expected since vehicle mass is related to momentum and energy, and thus damage. These findings are consistent with previous studies on pedestrian collisions (Lee et al, 2003) and motorcycle collisions (McCarthy and Gilbert, 1996). In another study, Maki et al (2003) also showed that vehicles with a higher hood, whereby the grill section hits the middle or upper body rather than the feet, might cause greater injuries.

Region

Compared to the police region of Woolsan, vehicle-pedestrian crashes occurring in DaeGu, Incheon, Kwangju, Pusan and Seoul are less likely to result in serious injuries. Also, crashes occurring in DaeGu, Daejon, Incheon, Kwangju and Seoul are less likely to result in fatality. In general, these regions have a higher concentration of urban population. Nevertheless, more research will be required to know and understand the underlying influences in these areas.

CONCLUSION AND RECOMMENDATIONS

Using the official collision data for 2006 from South Korea, this study identified the factors associated with injury severity of pedestrian–vehicle collisions. A multinomial logit model predicting injury severity conditional on crash occurrence is calibrated using the method of maximum likelihood to examine the relationship between crash severity and a number of explanatory variables including driver's gender, age and alcohol intoxication, pedestrian's gender, age and location, roadway classification, roadway segment, road width, number of lanes, weather conditions, time of day, vehicle type and police region.

The results of the study showed that the factors that significantly increased the probability of fatal injury to pedestrians are: drivers' sex, age and alcohol intoxication; pedestrians' age and sex; pedestrians' location on crosswalk, intersections, shoulder, outer (faster) lanes, freeways, provincial and national highways; wider roads especially wider than 9m; inclement weather conditions like cloud, fog, snow and rain; time of the day such as night time and peak hours; and vehicle type and size.

Additionally, the results of the study also showed the factors that significantly increased the probability of severe injury to pedestrians are: drivers' sex, age and alcohol intoxication; pedestrians' sex, and age; pedestrians' location on crosswalk, traffic lane, outer (faster) lanes, freeways, provincial and national highways; wider roads especially wider than 13m, inclement weather conditions like cloud, fog and snow; time of the day such as night time and peak hours; and larger vehicles.

In terms of traffic enforcement, it is recommended that enforcement efforts be targeted at: drivers who are male, younger (under 65) and drunk; pedestrians who are female and older (over 65); locations like crosswalks and intersections; roadways that have wider width; roadways that have higher speed such as freeway, provincial and national roads; and when the weather is not clear and dry.

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