Injury Severity of Pedestrian Crashes in Singapore

Yue Ying Wang[1], Md. Mazharul Haque[2], Hoong Chor Chin[3], Jelphine Goh Jie Yun[4]

[1] Research Fellow, Department of Civil & Environmental Engineering, National University of Singapore

[2] Research Fellow, Centre for Accident Research and Road Safety (CARRS-Q), Faculty of Health and Civil Engineering and Built Environment, Science and Engineering Faculty, Queensland University of Technology

[3] Associate Professor, Department of Civil & Environmental Engineering, National University of Singapore

[4] Former student, Department of Civil & Environmental Engineering, National University of Singapore

Email for correspondence: sophiawyy@nus.edu.sg

Abstract

Singapore is a highly urbanized city-state country where walking is an important mode of travel. Pedestrians form about 25% of road fatalities every year, making them one of the most vulnerable road user groups in Singapore. Engineering measures like provision of overhead pedestrian crossings and raised zebra crossings tend to address pedestrian safety in general, but there may be occasions where pedestrians are particularly vulnerable so that targeted interventions are more appropriate. The objective of this study is to identify factors and situations that affect the injury severity of pedestrians involved in traffic crashes. Six years of crash data from 2003 to 2008 containing around four thousands pedestrian crashes at roadway segments were analyzed. Injury severity of pedestrians—recorded as slight injury, major injury and fatal—were modeled as a function of roadway characteristics, traffic features, environmental factors and pedestrian demographics by an ordered probit model. Results suggest that the injury severity of pedestrians involved in crashes during night time is higher indicating that pedestrian visibility during night is a key issue in pedestrian safety. The likelihood of fatal or serious injuries is higher for crashes on roads with high speed limit, center and median lane of multi-lane roads, school zones, roads with two-way divided traffic type, and when pedestrians cross the roads. Elderly pedestrians appear to be involved in fatal and serious injury crashes more when they attempt to cross the road without using nearby crossing facilities. Specific countermeasures are recommended based on the findings of this study.

1. Introduction

Singapore is a highly urbanized city-state island country with a population of about 5.3 million (SINGSTATS 2013). Walking is the primary form of mobility in Singapore. A recent study has reported that more than one-fifth of total daily trips in Singapore are solely achieved by walking (LTA 2011). In addition, walking is the supplementary mode to all motorized journeys made by public transports every day which accommodate about 50% of daily motorized journeys in Singapore (LTA 2009). Although Singapore has a comparatively lower road traffic death rate of 4.8 per 100,000 population (WHO 2007), pedestrian safety is still a major concern. Recent statistics show that pedestrians are the second most vulnerable group of road users, after motorcyclists, making up approximately 25% of total fatalities across all road users (Singapore Police Force 2013).

Research on pedestrian-vehicle crashes has revealed a magnitude of risk factors affecting the injury severity of pedestrians. These factors can be generally categorized into

demographic characteristics of pedestrian and driver, vehicle attributes, environmental conditions, roadway features and crash characteristics. Some common factors, such as the age of pedestrian (Al-Ghamdi 2002, Roudsari et al. 2004, Lee and Abdel-Aty 2005), vehicular speed (Roudsari et al. 2004, Lee and Abdel-Aty 2005), and vehicle type (Ballesteros et al. 2004, Roudsari et al. 2004) have often been identified to be highly associated with more severe injury of pedestrians.

Factors that are specific and unique to the pedestrian injury severity mostly depend on the circumstances of the study and type of dataset used for the analysis. For instance, in a study (Mohamed et al. 2013) using crash data from New York City (2002-2006) and the city of Montreal, Canada (2003-2006), location type, driver age, driver alcohol involvement, lighting conditions, and several built environment characteristics were found to be significantly associated with fatal crashes. Analyzing the pedestrian crashes in Hong Kong, Sze and Wong (2007) revealed a number of circumstances leading to a higher risk of mortality and severe injury, including on road sections with a speed limit above 50km/h, at a crossing or within 15m of a crosswalk, a signalized intersection, and roads with two or more lanes. The study also reported that the injury severity of a pedestrian was lower if the crash involved a male pedestrian aged below 15, or a pedestrian casualty occurred on an overcrowded or obstructed footpath, in day time and road section with severe or moderate congestion. By contrast, in a city of developing countries, such as Ghana, risk factors associated with pedestrian fatality included being hit by heavy vehicles, speeding and roadside activities, such as street hawking, jaywalking and nighttime walking (Damsere-Derry et al. 2010). It is also noticeable that pedestrian injury and fatality rates are considerably higher in developing countries than in developed economies (WTO 2013). Even within developed countries or cities, differences in road infrastructures, traffic conditions, pedestrians' and drivers' behavioural patterns can result in a different set of significant factors associated with the injury severity of pedestrians.

The changes in Singapore particularly in population demography and road infrastructures in the past few years might have an influence on the recent high injury records of pedestrians. The elderly population (aged 65 years and over) constitute about 10% of total population as of 2012 and the Old-Age Support Ratio, the ratio of resident aged 20-64 years to elderly residents has been trended downwards with a further drop from 7.2 in 2011 to 6.7 in 2012 (SINGSTATS 2013). The growth of elderly residents among the whole population is posing a significant safety concern particularly for pedestrians presumably because the older demographic have slowly reactive and cognitive skills. The changes of roadway characteristics and traffic conditions of Singapore might also have an impact on pedestrian safety. For the last 15 years, the increase in the total length and width of road has been approximately 1 per cent a year. Today, there are 9,046 lane-km of roads, which takes up to about 12% of land in Singapore (Ministry of Transport, 2012). The expansion of road network and its coordination with the existing road networks might have an influence on the crash risk and exposure of pedestrians which has not been examined yet. Although the safety of drivers has been improved significantly through embedding intelligent technologies and incorporating effective safety measures and strategies, the safety of pedestrians has received less attention. Considering a road transport network consisting of a densely populated urban environment with a considerable amount of elderly citizens, a study on risk factors contributing to fatality and serious injury of pedestrians in Singapore becomes important and might be appealing for other similar cities.

The objective of this study is to identify factors and situations that affect the injury severity of pedestrians involved in road traffic crashes in Singapore. To measure the relationships between injury severity of pedestrian and potential contributory factors, an ordered probit model has been employed in this study. Six years of road traffic crash data from 2003 to 2008 containing around four thousands pedestrian crashes are available for analysis. In addition to the injury severity, the dataset contained a wide range of factors including roadway characteristics, traffic features, environmental factors, driver and pedestrian

demographics and vehicle attributes. An emphasis is given to the contributory factors and situations that might be unique to the road traffic environment in Singapore. Based on the findings, the paper discusses potential countermeasures and safety measures to improve pedestrian safety of Singapore and the measures that may be widely applied to other similar urban cities with dense population.

2. Methodology

Researchers over the years have employed various statistical techniques to model pedestrian injury severity that is usually classified as either nominal or ordinal variable. The multinomial logit model (Kim et al. 2008, Damsere-Derry et al. 2010, Rifaat et al. 2011) and the ordered logit or probit model (Quddus et al. 2002, Lee and Abdel-Aty 2005, Mohamed et al. 2013) are two approaches generally applied to examine the injury severity of pedestrian casualties. A multinomial model assumes injury severity is categorical in nature, while an ordered model assumes injury severity categories are ordered. The ordinal nature of injury severities has made an ordered model more appropriate than the multinomial model, and thus an ordered model is applied in this study. In particular, an ordered probit model is employed to understand how variations in the road characteristics, environmental factors, vehicle characteristics, potential causal factors, driver demographics and pedestrian attributes can lead to variations in different levels of injury severity to the pedestrian.

The ordered probit model, according to Long and Freese (2003), is often presented as a latent variable model. For this study, y_i denotes the observed injury severity of ith pedestrian, y_i^* denotes the latent (unobserved) injury severity measure ranging from $-\infty$ to $+\infty$ and μ_j $(j=1,2)$ are the thresholds for injury severity. In this study, pedestrian injury severity y_i^* is grouped into three categories (i.e. slightly injured, seriously injured and fatal), so the range of values is divided into three intervals, each corresponding to a different level of injury severity. The observed level of injury severity can be determined from the ordered probit model as follows,

$$y_i = \begin{cases} 1 & \text{(slightly injured)} & \text{if } -\infty \leq y_i^* < \mu_1 \\ 2 & \text{(seriously injured)} & \text{if } \mu_1 \leq y_i^* < \mu_2 \\ 3 & \text{(fatal)} & \text{if } \mu_2 \leq y_i^* < +\infty \end{cases} \quad (1)$$

where the threshold values μ_1, μ_2 are unknown parameters to be estimated. When the latent y_i^* crosses a threshold, the observed level of injury severity will change. The latent pedestrian injury severity y_i^* for the ith pedestrian is expressed by the following linear equation,

$$y_i^* = X_i \beta + \varepsilon_i \quad (2)$$

where X_i is a $(k \times 1)$ vector of explanatory variables, β is a $(k \times 1)$ vector of regression coefficients that is to be estimated and ε_i is the random error term that indicates the effect of all unobserved factors on y_i^* and is assumed to be normally distributed with zero mean and unit variance.

In Equation (2), if there is a unit change in X_k, y_i^* is expected to change by β_k units, assuming all the other variables constant. If σ_{y^*} is the unconditional standard deviation of the

unobserved y_i^*, then the y_i^* standardized coefficient for X_k is

$$\beta_k^{Sy^*} = \frac{\beta_k}{\sigma_{y^*}} \tag{3}$$

which means that for a unit change in X_k, y_i^* is expected to change by $\beta_k^{Sy^*}$ standard deviations. To estimate values of the thresholds μ and unknown coefficients β such that it maximizes the probability of obtaining the observed set of data, the maximum likelihood method is used (Long and Freese 2003).

Predicted probabilities are used for interpretation as it allows for better understanding of the marginal impacts of the explanatory variables on injury severities. The probability of pedestrian injury severity j for the ith observation can be computed as follows,

$$P(y_i = j) = P\left(\mu_{j-1} < y_i^* \le \mu_j\right) = \phi\left(\mu_j - X_i\beta\right) - \phi\left(\mu_{j-1} - X_i\beta\right) \tag{4}$$

where $\phi(\ )$ is the cumulative standard normal distribution. The results of this study are mainly discussed using predicted probabilities estimated by Equation (4) and presented in section 4.

3. Dataset for analysis

The road traffic crash data were obtained from the National Road Crash database which is recorded and maintained by the Singapore Traffic Police (Singapore Police Force 2010). During these six years, there were total 5044 pedestrian crashes, of which 3975 cases occurred at roadway segments away from intersections and the rest 1069 crashes occurred at intersections. The analysis of this study is restricted to the pedestrian crashes occurring on the roadway segments, leaving the intersection crashes for another study. The dependent variable of interest is the injury severity of pedestrian, which was classified into three ordinal levels: (a) fatal, (b) seriously injured and (c) slightly injured. According to Singapore Traffic Police, a casualty is considered fatal if the person is killed within 30 days of the crash. A serious injury is defined if a person suffers fracture, concussion, internal lesions, crushing, severe cuts and laceration and severe general shock requiring hospitalization or other forms of bodily pain requiring at least 7 days of medical leave. A person is considered to be slightly injured if he/she suffers from other forms of injury which requires conveyance from the crash scene to hospital by an ambulance or if conveyance to hospital or outpatient centres is by other transport modes, the medical treatment requires medical leave of at least 3 days. Following this definition, 5.5% pedestrians were classified as injured fatal, 3.1% were seriously injured and the rest 91.4% were slightly injured.

In addition to the injury severity level of pedestrian, the crash dataset included numerous variables such as crash occurrence data, crash type, road names, direction of travel, number of affected vehicles, various geometric features, a number of traffic factors, and several environmental conditions. From these, a total of 18 variables were initially hypothesized to have some association with the injury severity level of pedestrians. As shown in Table 1, these variables include environmental factors, roadway characteristics, pedestrian attributes, driver characteristics, vehicle types, and specific cause factors. The definitions of the variables, together with each variable's mean and standard deviation, are presented in Table 1. The majority of the variables included in the analysis are categorical dummy variables that simply indicate the existence of a certain condition, except for the pedestrian and driver age which are continuous variable.

Table 1 Summary statistics of explanatory variables included in the model

Explanatory Variables	Description of Variables	Mean	St. Dev
Environmental factors			
Night Time Indicator	If crash occurred from 1900 to 0700=1, otherwise=0	0.339	0.473
Wet	If crash on wet surface=1, otherwise=0	0.089	0.285
Rainy	If crash on rainy day=1, otherwise=0	0.065	0.247
Roadway characteristics			
Type of Traffic			
One-way	If crash is on one-way road=1, otherwise=0	0.204	0.403
Two-way Divided	If crash is on two-way divided road=1, otherwise=0	0.457	0.498
Two-way Undivided	If crash is on two-way undivided road=1, otherwise=0	0.273	0.445
Slip Road	If crash is on slip road=1, otherwise=0	0.066	0.248
Lane Position			
Single Lane	If crash is on single lane=1, otherwise=0	0.261	0.439
Curb Lane	If crash is on curb lane=1, otherwise=0	0.226	0.418
Centre Lane	If crash is on centre lane=1, otherwise=0	0.121	0.326
Median Lane	If crash is on right lane=1, otherwise=0	0.288	0.453
Other Lanes	If crash is on other lane=1, otherwise=0	0.104	0.306
Speed Limit			
<50km/h	If crash occurred on road with speed limit<50km/h=1, otherwise=0	0.093	0.291
50km/h	If crash occurred on road with speed limit of 50km/h=1, otherwise=0	0.811	0.392
>50km/h	If crash occurred on road with speed limit>50km/h=1, otherwise=0	0.096	0.295
School Zone	If crash occurred at school zone=1, otherwise=0	0.030	0.172
Pedestrian attributes			
Pedestrian Gender	If pedestrian is female=1, otherwise=0	0.421	0.494
Pedestrian Age	Continuous	37.013	22.238
Pedestrian Movement Type			
On Footpath	If pedestrian walking on the foot path during crash=1, otherwise=0	0.024	0.153
On Road	If pedestrian walking along traffic during crash=1, otherwise=0	0.373	0.484
Crossing Road	If pedestrian crossing the road=1, otherwise=0	0.603	0.489
Pedestrian with Company	If pedestrian is with company=1, otherwise=0	0.190	0.392
Driver attributes			
Driver Gender	If driver is female=1, otherwise=0	0.104	0.305
Driver Age	Continuous	41.520	12.978
Driver Nationality	If driver is non-Singaporean=1, otherwise=0	0.117	0.322
Vehicle characteristics			
Vehicle Type			
Two-wheel Vehicle	If vehicle is a two-wheel=1, otherwise=0	0.192	0.394

Explanatory Variables	Description of Variables	Mean	St. Dev
Light Vehicle	If vehicle is a light vehicle=1, otherwise=0	0.645	0.479
Heavy Vehicle	If vehicle is a heavy vehicle=1, otherwise=0	0.164	0.370
Vehicle Registration Type	If vehicle registered other than Singapore=1, otherwise=0	0.061	0.240
Specific cause factors			
Causes Attributed to Pedestrians	If crash is caused due to pedestrians=1, otherwise=0	0.554	0.497
Crossing heedless	If crash is caused due to crossing heedless=1, otherwise=0	0.244	0.430
Failing to use pedestrian crossing	If crash is caused due to failing to use pedestrian crossing=1, otherwise=0	0.106	0.307
Crossing with red man lighted	If crash is caused due to crossing when red man lighted=1, otherwise=0	0.058	0.233
Crossing in front/ behind vehicle	If crash is caused by crossing in front of or behind a vehicle with obstructed view=1, otherwise=0	0.085	0.279
Other causes	If pedestrian is not at fault=1, otherwise=0	0.061	0.240
Cause of Crash (Driver)	If crash is caused due to driver=1, otherwise=0	0.859	0.348
Failing to keep a proper lookout	If driver fails to ensure a proper lookout of vehicles in traffic stream=1, otherwise=0	0.682	0.466
Failing to give way at zebra crossing	If driver fails to give way to pedestrian at zebra crossing=1, otherwise=0	0.027	0.161
Failing to have proper control	If driver fails to have proper control=1, otherwise=0	0.038	0.191
Others causes	For other reasons from drivers=1, otherwise=0	0.112	0.315

4. Results and discussions

The ordered probit model estimates of significant parameters along with unstandardized and standardized coefficient estimates are presented in Table 2. The best-fit or parsimonious model was obtained by following a backward stepwise method. The likelihood ratio statistic for the model is 366.15, which is well above the critical value at 5% significant level. Moreover, the McFadden pseudo-R^2 of 0.132 also indicates a reasonable level of fit. The parsimonious model has identified 12 significant variables including night time crash occurrence, type of traffic, lane position, occurrence of a crash in school zone, posted speed limit, pedestrian age, pedestrian movement type, driver's gender, vehicle type, vehicle registration type, specific causal factors of pedestrians like crossing heedlessly and without using any crossing facility, and specific causal factors of drivers like failing to have proper control and failing to keep a proper lookout. From the calibrated model, the effect of a significant explanatory variable on pedestrian injury severity was estimated using the predicted probability change following Equation (4) and is shown in Table 3. A detailed discussion on the effects of key significant factors on pedestrian injury severity is provided in the following sub-sections.

Table 2 Ordered probit estimates of significant variables for injury level of pedestrian crash

Explanatory Variables	Coefficient Estimate	Standard Deviation	Standardized Estimate $\beta_k^{Sy^*}$	z-statistic	p-value	Confidence Interval	
Night Time Indicator	0.331	0.064	0.287	5.210	<0.001	0.207	0.456
Type of Traffic							
One-way	-0.103	0.108	-0.090	-0.960	0.338	-0.315	0.108
Two-way Divided	0.202	0.093	0.175	2.170	0.030	0.019	0.385
Slip Road	0.110	0.143	0.095	0.770	0.443	-0.170	0.389
Lane Position							
Single Lane	-0.054	0.110	-0.046	-0.490	0.626	-0.269	0.162
Centre Lane	0.329	0.102	0.285	3.230	0.001	0.130	0.529
Median Lane	0.217	0.085	0.188	2.550	0.011	0.050	0.383
Other Lanes	0.027	0.127	0.024	0.220	0.829	-0.222	0.277
School Zone	0.380	0.185	0.329	2.050	0.040	0.017	0.743
Speed Limit							
<50km/h	0.043	0.129	0.037	0.330	0.739	-0.210	0.296
>50km/h	0.433	0.089	0.375	4.880	<0.001	0.259	0.606
Pedestrian Age	0.017	0.001	0.015	12.180	<0.001	0.014	0.020
Pedestrian Movement Type							
Crossing Road	0.265	0.069	0.230	3.830	<0.001	0.129	0.400
Driver's Gender	-0.258	0.122	-0.224	-2.120	0.034	-0.497	-0.019
Vehicle Type							
Two-wheel Vehicle	-0.204	0.087	-0.177	-2.340	0.019	-0.376	-0.033
Heavy Vehicle	0.477	0.079	0.413	6.020	<0.001	0.322	0.632
Vehicle Registration Type	-0.700	0.190	-0.606	-3.680	<0.001	-1.072	-0.328
Cause of Crash (Pedestrian)							
Crossing heedless	0.164	0.073	0.142	2.240	0.025	0.020	0.308
Failing to use pedestrian crossing	0.204	0.095	0.177	2.140	0.033	0.017	0.391
Cause of Crash (Driver)							
Failing to keep a proper lookout	0.150	0.077	0.130	1.970	0.049	0.000	0.301
Failing to have proper control	0.314	0.165	0.272	1.910	0.057	-0.009	0.636
μ_1	2.857	0.147				2.568	3.146
μ_2	3.135	0.150				2.842	3.428
Number of observations		3975					
Log-likelihood at zero		-1384.096					
Log-likelihood at convergence		-1201.021					
Pseudo-R^2		0.132					
LR chi-square(19)		366.150					
Prob> chi-square		0.000					

Table 3 Pedestrian injury severity probabilities

Explanatory Variables	Estimated Probability			Percent change relative to reference case (%)		
	Fatal	Seriously Injured	Slightly Injured	Fatal	Seriously Injured	Slightly Injured
Reference Case	0.006	0.007	0.987			
Night Time Indicator	0.015	0.014	0.971	144.26	105.80	-1.63
Type of Traffic						
One-way	0.005	0.005	0.990	-24.59	-21.74	0.31
Two-way Divided	0.011	0.011	0.979	75.41	56.52	-0.86
Slip Road	0.008	0.009	0.983	36.07	27.54	-0.43
Lane Position						
Single Lane	0.005	0.006	0.989	-13.11	-11.59	0.17
Centre Lane	0.015	0.014	0.971	142.62	104.35	-1.61
Median Lane	0.011	0.011	0.978	81.97	62.32	-0.94
Other Lanes	0.007	0.007	0.986	8.20	5.80	-0.10
School Zone	0.017	0.016	0.968	175.41	126.09	-1.98
Speed Limit						
<50km/h	0.007	0.008	0.986	13.11	10.14	-0.15
>50km/h	0.019	0.017	0.964	214.75	150.72	-2.38
Pedestrian Age						
15 yrs old	0.002	0.003	0.995	-67.21	-60.87	0.85
25 yrs old	0.003	0.004	0.993	-44.26	-39.13	0.56
35 yrs old	0.006	0.006	0.988	-8.20	-8.70	0.11
65 yrs old	0.021	0.019	0.960	249.18	172.46	-2.76
75 yrs old	0.032	0.026	0.943	419.67	271.01	-4.49
Pedestrian Movement Type						
Crossing Road	0.013	0.012	0.975	106.56	79.71	-1.21
Driver's Gender	0.003	0.004	0.994	-52.46	-47.83	0.66
Vehicle Type						
Two-wheel Vehicle	0.003	0.004	0.993	-44.26	-39.13	0.56
Heavy Vehicle	0.021	0.019	0.960	249.18	172.46	-2.76
Vehicle Registration Type	0.001	0.001	0.998	-88.52	-85.51	1.14
Cause of Crash (Pedestrian)						
Crossing heedless	0.010	0.010	0.980	57.38	44.93	-0.67
Failing to use Available pedestrian crossing	0.011	0.011	0.978	75.41	57.97	-0.87
Cause of Crash (Driver)						
Failing to keep a proper lookout	0.007	0.008	0.985	21.31	17.39	-0.25
Failing to have proper control	0.014	0.014	0.972	134.43	98.55	-1.51

4.1 Night-time crash occurrence

The time of crash is a significant factor ($p < 0.001$) in the injury severity model and the risk of fatal injury increases by 144% at night, relative to day time. There might be two possible reasons for this. First, the speed of traffic is generally higher during night time due to lighter traffic flows (Rifaat, Tay et al. 2011). Due to insufficient time left for driver to react, a pedestrian is likely to be severely injured if a crash occurs during night. Second, reduced visibility of pedestrians during night might be a contributing factor of fatal and serious injury

pedestrian crashes as found by other studies (e.g., Lee and Abdel-Aty 2005, Mohamed et al. 2013). Lamp posts along the roadways in Singapore are generally well designed following international standards and streets are generally well lighted with sodium lights. To further examine whether there is any association between pedestrian injuries at night and street lighting condition, a contingency table analysis—not reported here—has been conducted. However, the association has not been statistically significant. It implies that the reduced visibility of a pedestrian under sodium lights and interactions with high speed traffic might be a significant factor for severe injuries of pedestrians.

4.2 Type of traffic

The two-way divided traffic type has been found to be significantly affecting the injury severity of pedestrians involved in road traffic crashes. Probabilities of a pedestrian involved in fatality and serious injury on two-way divided roads are respectively about 75% and 57% higher than those along two-way undivided roads. In general, two-way divided roads have better geometric design than two-way undivided roads and provide a more comfortable environment of driving mainly due to having a separated opposing traffic. Since the speed limit is generally higher and motorists tend to speed along divided roads compare to undivided roads (Kim et al. 2008), it is not surprising that the probability of more severe injury to pedestrians is higher on two-way divided roads.

4.3 Lane position

The lane position on which the crash occurred has been found to be significant. Relative to the curb lane of multi-lane roads, centre and median lanes are associated with severe injuries. Probabilities of fatal and serious injury have been increased respectively by 143% and 104% on centre lanes, and the corresponding probabilities are increased respectively by 82% and 62% on median lane. Compared to curb lane, vehicle speeds are relatively higher on centre lanes and median lane, which might result in a higher injury severity.

4.4 School zone

A pedestrian crash along roads around school zones has been found to have significant and positive association with injury severity. The probability of fatal and serious injuries is respectively 175% and 126% higher if a crash occurs on school zone compared to other areas. Further analysis, not reported here, show that children aged between 10 and 14 years is the most vulnerable group of pedestrians to be injured on roadways around school zones.

4.5 Speed limit

Pedestrians have been found to be severely injured when they are involved in a collision on roads with high speed limit, e.g., over 50 km/h. The injury severity for fatality multiplies by two times when a pedestrian crash occurs on roads with speed limit greater than 50 km/h compared to roads with a speed limit of 50 km/h. Similarly the probability of serious injuries increases by 1.5 times on high speed roads. Many other researchers (e.g., Jensen 1999, Lefler and Gabler 2004, Lee and Abdel-Aty 2005, Sze and Wong 2007) have also reported similar increase of injury severity of pedestrians along high speed roads in various jurisdictions.

4.6 Pedestrian age

The injury severity of pedestrians is found to increase with the age of pedestrians involved in road traffic crashes. To better understand the relationship between injury severity and pedestrian age, changes in probabilities of fatal and serious injuries from the reference case have been plotted across 5 years age intervals and presented in Figure 1. It appears that probabilities of both fatal and serious injuries increase drastically for elderly pedestrians. While there is a marginal difference between changes in probabilities of fatal and serious

injuries up to age of 50 years, the corresponding difference starts to increase for pedestrians older than 50 years and the difference is notably greater for elderly pedestrians (65 years and above). In general, the crash risk of elderly pedestrians is higher due to their reduced physical and cognitive abilities. The higher injury severity of elderly pedestrians is also expected because they are less able to withstand collision impacts because of their frailty, and therefore even a minor crash can result in severe injuries to elderly pedestrians.

Figure 1 Relationship between changes in probabilities of fatal and serious injuries and pedestrian age
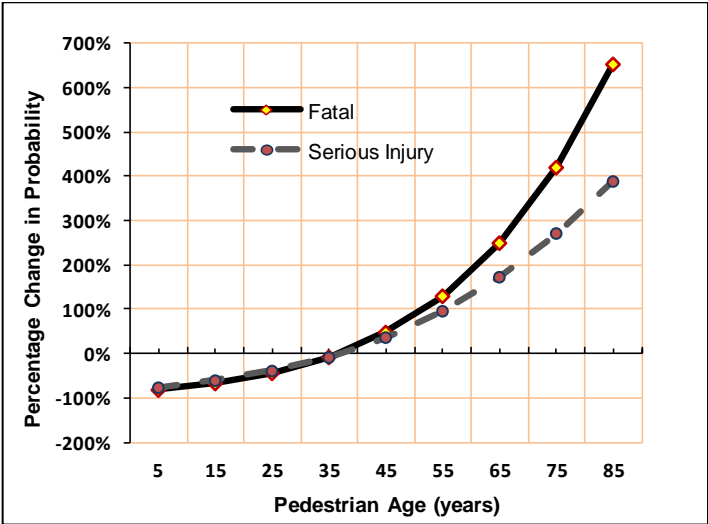
Figure 2 Percentages of fatal and serious injuries among elderly (65 years and above) and other (15-64 years) pedestrians during different crossing types
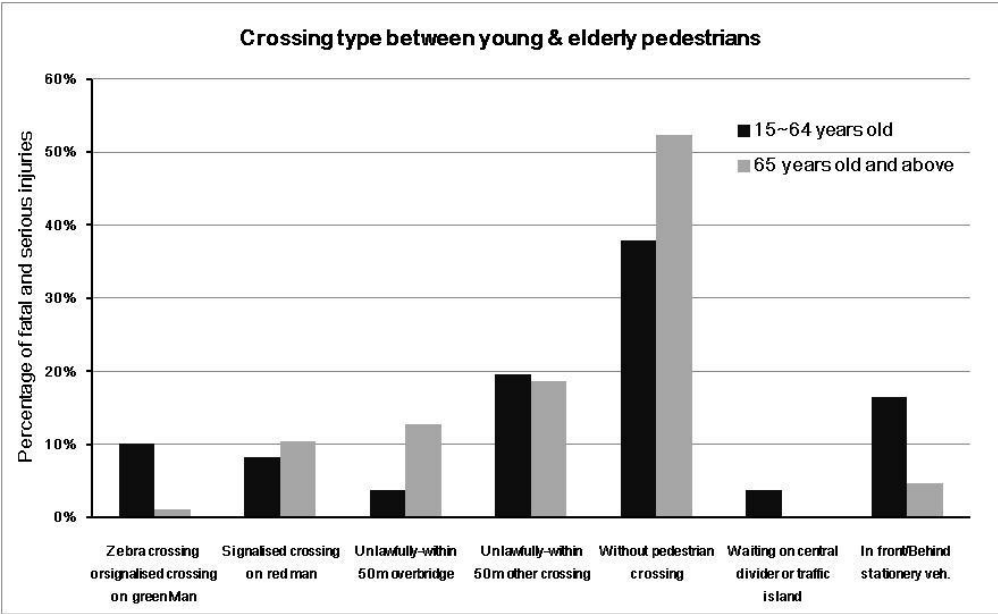
4.7 Pedestrian movement type

Relative to walking along the road or footpath, the probability of fatal and serious injury is respectively about 107% and 80% higher when pedestrians involved in crashes during

crossing the road. To better understand the circumstances and situations of pedestrian injuries during crossing and examine whether there is any peculiarity among elderly pedestrians, fatal and serious injury crashes are compared between elderly pedestrians and others across crossing types. Figure 2 shows the distribution of serious and fatal injury crashes among elderly (65 years and above) and other pedestrians (15 to 64 years) during different crossing types. Clearly elderly pedestrians are more involved in fatal and serious injury crashes when they attempts to cross without any pedestrian crossing facility. Elderly pedestrians seem to be more involved in severe injury crashes when attempt to cross the road unlawfully within 50m of an over-bridge crossing facility. In summary, crossing without any pedestrian crossing and unlawfully within 50m of a designated crossing facility are responsible for severe injuries of many pedestrian crashes in general but with a greater percentage for elderly pedestrians.

4.8 Driver's gender

Among driver's demographic factors, such as driver's nationality, age and gender, only the driver's gender is significantly associated (p=0.034) with injury severity of pedestrians. Relative to male drivers, the female driver is less likely to be involved in serious injury and fatal pedestrian crashes respectively by 48% and 53%. Female drivers generally exhibit less risk taking behaviors than males, and hence might less likely to be involved in fatal crashes (Rifaat et al. 2011).

4.9 Vehicle type

The injury severity of pedestrians is higher when a collision involves a heavy vehicle and less when it involves a two-wheeler. In particular, the probability of fatal and serious injury is respectively 2.5 and 1.7 times higher when a pedestrian is struck by heavy vehicles, such as buses and trucks, relative to cars. Paulozzi (2005) has also reported that the risk of a pedestrian being killed in a road crash is eight times higher if a bus is involved compared to a passenger car. For any given speed, the greater the vehicle mass, the greater the force of impact is on a pedestrian during the collision, causing higher injury severity. Moreover, heavy vehicles having larger impact areas compared to passenger cars further increase the likelihood of severe injuries to the pedestrians involved in crashes (Lefler and Gabler 2004, Lee and Abdel-aty 2005).

4.10 Vehicle registration type

Interestingly, the type registration of the vehicle involved in collisions with pedestrians has been found to have a significant association with the injury severity of pedestrians. Relative to Singapore registered vehicle, the foreign registered vehicles are less likely to be involved in fatal and serious injury pedestrian crashes. Foreign registered vehicles in Singapore are mostly motorcycles as a large number of motorcyclists enter Singapore from Malaysia to work on a daily basis (Haque et al. 2009, Quddus et al. 2002). In the dataset, about 47% (115 out of 243) foreign registered vehicles involved in pedestrian-vehicle crashes were two-wheelers while the counterpart for Singapore registered vehicles is only 17% (647 out of 3732). Since a collision between a motorcycle and pedestrian is likely to be less severe than that between a light vehicle or heavy vehicle and pedestrian, it is likely that the injury severity of pedestrians is lower for crashes associated with foreign registered vehicle.

4.11 Specific causes

The parsimonious model has successfully identified few specific causes that are significant in influencing the injury severity of pedestrians. The significant specific causes of pedestrians include crossing heedless and failing to use available pedestrian crossing, resulting in corresponding increases in probability of fatality respectively about 57% and 75%, and in

probability of serious injuries about 45% and 58%.The specific causes of failing to use available pedestrian crossing and crossing heedless coincide with the earlier discussion on the factor of pedestrian movement type where crossing the road has been a significant contributor of fatal and serious injury pedestrian crashes. Among the drivers, the specific causes like failing to keep a proper lookout and failing to have proper control of vehicles increase the injury severity of pedestrians.

5. Conclusions and recommendations

This study has investigated the contributing factors and situations that influence the injury severity of pedestrians involved in crashes using the ordered probit model. While some findings related to pedestrian injuries are reinforcement of previous research, this study also brought in new insights into the factors that are particularly associated with the severity of pedestrian injury in an urban city-state country like Singapore. Although the road safety situations are well managed and various initiatives have been taken to ensure safety of pedestrians in Singapore (see Haque et al. 2013 for details), findings of this study ought to raise more awareness among road safety professionals to look into the matter in greater details. The new insights from this study should prompt the authorities to establish more effective targeted countermeasures and traffic management scheme by prioritizing the road users from safety perspective.

This study has identified that night time visibility of pedestrians represents a significant safety concern for the injury severity of pedestrians involved in crashes away from intersections. The injury severity of pedestrian in a pedestrian-vehicle crash may serve as an indirect indicator of the risk of crashes. In general, the injury severity of pedestrians in a vehicle-pedestrian crash could possibly be reduced if the drivers have chance to react earlier to stop the vehicle in time or slacken the speed. For instance, in a crash involving severe or fatal injury to pedestrians at night, it is likely that the driver does not have sufficient time to react due to poor visibility or speeding behaviour. The Land Transport Authority in Singapore checks street lightings along public roads across the island every 2 months. Despite having an established lighting standard with well-managed street lighting conditions, pedestrians remained vulnerable to more severe crashes during night time when speeding drivers may not be able to perceive pedestrians in time and make prompt reactions. It may also imply that street lighting standards may need to be revised for better pedestrian safety especially in the aspect of visibility and luminance requirement. Authorities should also look into ways either to increase the luminance of street lightings or to reduce the pedestrian exposure along the roads with high-risk pedestrian crashes.

Elderly (65 years and above) pedestrians have been identified to be severely injured when they are involved in a crash, particularly while attempting to cross the road without using any crossing facility. Singapore has recently adopted various crossing facilities for pedestrians such as elderly pedestrian signal to allow extended green time for elderly, intelligent road studs to warn motorists about the presence of pedestrians on the crossing facility during night and countdown timers to allow pedestrians to know the time of the green cycle they have (Haque et al. 2013). These facilities may be deemed inefficient if the elderly pedestrians do not use them. Therefore, authorities should look into how to encourage pedestrians to cross roads at crossing facilities. In addition, public educational programs and awareness campaigns should target elderly pedestrians to make them aware of the new features on crossing facilities and encourage them to use these. Elderly pedestrians need to be encouraged to wear appropriate clothing to improve visibility at night. The reflective clothing will increase the visual contrast of pedestrians (e.g., Luoma et al., 1996) and thus likely to reduce overall crash involvements as well as injury severity if visible clothing trigger the crash avoidance action of motorists earlier. In addition, this study has identified that elderly pedestrians are more likely to be involved in fatal and serious injury crashes while crossing

the road unlawfully within 50m of pedestrian overhead bridge. Elderly pedestrians might have difficulties in climbing up and down on a pedestrian overhead bridge. Therefore, it is recommended that the crossing facilities for pedestrians near residential areas be made friendlier to elderly people, perhaps with the provision of ramps instead of staircases, or with elevators.

The injury severity of children has been found to be higher along roads around school zones. Strict speed enforcement along roads around school zones might help to reduce the injury severity of school children. Currently, the 'Enhance School Zone' initiative has been introduced in several schools with the installation of various safety measures such as road humps, speed regulating strips, raised pedestrian crossing and red-colored pavement surface on roads around school zones of few schools. In addition to extending this initiative to more school zones, educational programs and safety campaigns should be organized regularly for schoolchildren to educate them on the proper use of pedestrian crossings. Motorists on the other hand should be encouraged to be more tolerant to schoolchildren and this should be strictly monitored by the school authority.

The Singapore Traffic Police in collaboration with other agencies organize safety campaigns and public education outreach programs every year particularly to spread road safety messages to vulnerable road users (Haque, 2011). For example, the recent road safety campaign—the 2013 Road Safety Month—organized by the Singapore Road Safety Council and Traffic Police intends to reach out four road user groups including elderly pedestrians, students, heavy vehicle drivers and motorcyclists (CNA, 2013). These safety campaigns could use the findings of this study to raise awareness among pedestrians including elderly and school kids.

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