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Factors affecting the injury severity of out-of-control single-vehicle crashes in Singapore

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ABSTRACT

Single-vehicle (SV) crashes are of major concerns because of their high fatality rates. To understand the proneness of high injury severity for vehicle operators brought about by SV crashes without the confounding influence of other road users, this study focuses on those SV crashes without colliding with pedestrians, which are defined as out-of-control SV crashes given the general consequence of involved vehicles. Moreover, to compare the influence of contributory factors (including driver-vehicle/rider-vehicle, roadway, and environmental characteristics) by vehicle types, the injury severity for riders of motorized two-wheelers and drivers of other motorized vehicles are investigated separately using two disaggregated ordered probit models. The results show that for both riders and drivers, variables such as age (65 and above), drink driving, error type of failing to have proper control, driving maneuvers of left and right turns as well as driving after midnight are associated with more severe injuries whereas factors such as wet, oily or sandy surfaces are related to less severe injury. Four other variables, i.e., foreign vehicle registration, probation or expired license, high speed-limit roads, and type of median lane, have different influences on riders and drivers on injury severity. Additionally, factors such as road traffic type and nationality are only found to significantly influence only riders and drivers respectively. The results shed light on both the similar and different causes of high injury severity for riders and drivers involved in out-of-control SV crashes. Based on the findings, targeted countermeasures may be introduced from multiple perspectives such as driver education and policy development to improve non-traffic-interactive safety.

1. Introduction

Single-vehicle (SV) crashes are of major concerns especially when they result in injuries. A number of studies have indicated that SV crashes account for a large proportion of all fatal crashes and the fatality rate of the vehicle operators are also higher compared to other types of crashes (Kim et al., 2013; Lang et al., 1996; Renski et al., 1999; Wu et al., 2016a). In Singapore, the odds of fatal injuries for vehicle operators during SV crashes is 1.7 times that during two-vehicle crashes (Rifaat and Chin, 2005). Thus, it is imperative to further investigate SV crashes and identify the factors contributing to the injury severity.

SV crashes can be classified into two categories based on the consequences: those that collide with pedestrians and those that do not collide with other road users. Different from the former type of crashes, the primary causation of the latter type, e.g. self-skidding or hitting-stationary-object crashes, is simply contributed to the riders/drivers themselves and the influence from roadway and environmental characteristics. To observe those relationships without potential confounding effects brought by pedestrians, we only focus on the latter type of SV crashes. Given the general consequence of involved vehicles, these crashes are defined as out-of-control SV crashes in this study. According to empirical datasets (Quddus et al., 2002; Huang et al., 2008) and the current dataset, out-of-control SV crashes constitute nearly 80% of the total SV crashes in Singapore. Although certain specific types of SV crashes have been studied such as rollover, run-off-road, and collisions with fixed objects, few have analyzed them generally. Moreover, in spite of the possible influence of vehicle types on injury severity of the operators, a limited number of studies have been conducted with this type of crashes in a disaggregated manner.

The objective of this study is to obtain a clearer understanding regarding the high injury severity of vehicle operators brought about by out-of-control SV crashes. Contributory factors including driver-vehicle/rider-vehicle, roadway, and environmental characteristics are investigated and discussed. Moreover, their influence on the injury severity of riders of motorized two-wheelers (denoted as “riders” thereafter) and drivers of other motorized vehicles (denoted as “drivers” thereafter) are analyzed and compared by formulating two disaggregated ordered probit models. This can be particularly insightful

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given the considerable number of motorized two-wheelers involved in this type of crashes.

2. Method

2.1. Data

The data used in the study are based on the national crash records in Singapore from 2012 to 2014, which were established from both the onsite crash reports by either the traffic police or the driver (applied for property-damage-only crashes) and the post-crash validation by investigation officers. The crash records contain four categories of information in general: 1) vehicle-related information about vehicle itself and its operator (including vehicle type, demographics of the operator, degree of injury, etc.); 2) general information regarding the crash (e.g. time of accident, location and other features about the road and environment condition); 3) vehicle passenger information (if there were any that were injured); 4) pedestrian information (if there were any that were injured). In the 3-year period, there were 6427 cases of SV crashes, of which 5199 are out-of-control crashes. Among these, 77 involved non-motorized vehicles such as bicycles and tricycles, which are excluded from the investigation due to the limited sample size. Apart from that, most out-of-control SV crashes were related to motorized vehicles, with 3557 involving motorized two-wheelers including motorcycles and motor-scooters and 1565 involving other motorized vehicles (most of them being four-wheelers) including passenger cars, buses, and trucks. In this study, these two groups of crashes are studied separately in the following sections for comparison.

From the crash records of motorized two-wheelers and other motorized vehicles, a number of relevant data fields are selected for investigation. These include rider-vehicle or driver-vehicle characteristics (such as age, country of vehicle registration), roadway characteristics, (such as lane position and type of road traffic) and environmental characteristics (such as weather and lighting conditions). There may be other factors potentially affecting the injury severity of vehicle operators during out-of-control SV crashes that are not captured in the accident database, such as vehicle weight. These cannot be included in this investigation.

2.2. Ordered probit model

A review of methods used in injury-severity investigations have been undertaken by Christoforou et al., (2010) and Savolainen et al., (2011). This study applies the ordered probit model, relating the injury severity to potential risk factors. The model can be described as

$$y_i^* = \boldsymbol{x}_i^T \boldsymbol{\beta} + \varepsilon_i \tag{1}$$

Where y_i^* is a latent variable measuring the injury severity of i th accident in the observation, $\boldsymbol{x}_i$ is a vector of explanatory variables, $\boldsymbol{\beta}$ is a vector of regression coefficients to be estimated and ε_i is the random error which is assumed to be standard normally distributed.

In this paper, injury severity is grouped into four categories as captured in the crash record, i.e. fatal, serious injury, slight injury, no injury (also known as PDO). The observed injury severity categories y_i are determined by the latent variable y_i^* following the measurement as follows:

$$y_i = \begin{cases} 1\,(No\ injury) & if -\infty \le y_i^* < \mu_1 \\ 2\,(Slight\ injury) & if \mu_1 \le y_i^* < \mu_2 \\ 3\,(Serious\ injury) & if \mu_2 \le y_i^* < \mu_3 \\ 4\,(Fatal) & if \mu_3 \le y_i^* < +\infty \end{cases} \tag{2}$$

where μ_1, μ_2, μ_3 are unknown constants to be estimated.

To prove the statistical significance of conducting separate analysis on riders and drivers, the likelihood ratio test comparing two

Table 1
Distribution of all potential explanatory variables.

Explanatory variables	Rider		Driver	
	Frequency	Percentage	Frequency	Percentage
Rider/driver characteristics				
Age[a,b]				
24 & below	804	22.60%	159	10.16%
25 to 64	2579	72.50%	1289	82.36%
65 & above	174	4.89%	117	7.48%
Gender				
male	3365	94.60%	1352	86.39%
female	192	5.40%	213	13.61%
Race[a]				
Chinese	1513	42.54%	1113	71.12%
Malay	1353	38.04%	212	13.55%
Indian	551	15.49%	137	8.75%
others	140	3.94%	103	6.58%
Nationality[b]				
Singaporean	2305	64.80%	1308	83.58%
Malaysian	1115	31.35%	107	6.84%
others	137	3.85%	150	9.58%
License status[a,b]				
normal	2993	84.14%	1436	91.76%
other status, e.g. expired or probation	564	15.86%	129	8.24%
Drink riding/driving[a,b]				
negative	2733	76.83%	1143	73.04%
positive	116	3.26%	112	7.16%
uncertain	708	19.90%	310	19.81%
At-fault status[a]				
at-fault	2313	65.03%	984	62.88%
not at-fault	1244	34.97%	581	37.12%
Type of error of rider/driver[a,b]				
failing to have proper control	2087	58.67%	775	49.52%
violation of rules	4	0.11%	23	1.47%
distraction	52	1.46%	58	3.71%
carelessness	114	3.20%	93	5.94%
others	72	2.02%	47	3.00%
unknown	1228	34.52%	569	36.36%
Vehicle registration type[a,b]				
registered in Singapore	2771	77.90%	1512	96.61%
registered overseas	786	22.10%	53	3.39%
Vehicle maneuvers before accident[a,b]				
left	874	24.57%	354	22.62%
right	500	14.06%	394	25.18%
straight	398	11.19%	160	10.22%
other complex maneuvers	1785	50.18%	657	41.98%
Vehicle headlight status				
on	2709	76.16%	545	34.82%
off	6	0.17%	22	1.41%
unknown	842	23.67%	998	63.77%
Roadway characteristics				
Roadway traffic type[a]				
one-way road	197	5.54%	94	6.01%
two-way undivided	110	3.09%	97	6.20%
two-way divided	1289	36.24%	777	49.65%
expressway	1435	40.34%	389	24.86%
expressway slip	80	2.25%	34	2.17%
other slip	446	12.54%	174	11.12%
Posted speed limit[a,b]				
< 50km/h	102	2.87%	72	4.60%
50km/h	1275	35.84%	610	38.98%
60km/h	616	17.32%	371	23.71%
70km/h	190	5.34%	137	8.75%
80km/h	562	15.80%	142	9.07%
90km/h	812	22.83%	233	14.89%
road segments	3396	95.47%	1447	92.46%
intersection	161	4.53%	118	7.54%
Lane position[a,b]				
center	1420	39.92%	543	34.70%
Curb (left most)	651	18.30%	230	14.70%
median (right most)	393	11.05%	204	13.04%
single	405	11.39%	192	12.27%
unknown	688	19.34%	278	17.76%
Road surface[a,b]				

(continued on next page)

Table 1 (*continued*)

Explanatory variables	Rider		Driver	
	Frequency	Percentage	Frequency	Percentage
dry	2664	74.89%	1184	75.65%
wet, sandy or oily	857	24.09%	248	15.85%
unknown	36	1.01%	15	0.96%
Environmental characteristics				
Time of accident[a,b]				
early morning (0000-0659)	596	16.76%	378	24.15%
morning peak (0700-0929)	668	18.78%	171	10.93%
daytime off-peak (0930-1659)	1054	29.63%	518	33.10%
afternoon peak (1700-1929)	565	15.88%	180	11.50%
nighttime off-peak (1930-2359)	674	18.95%	200	12.78%
Lighting[a]				
good	1815	51.03%	760	48.56%
poor	6	0.17%	7	0.45%
unknown	1736	48.81%	680	43.45%
Weather[b]				
clear	3056	85.92%	1284	82.04%
inclement	453	12.74%	146	9.33%
unknown	48	1.35%	17	1.09%
Presence of pedestrian[b]				
no	3539	99.49%	1524	97.38%
yes	18	0.51%	41	2.62%
Hitting stationary object[a]				
no	3528	99.18%	1496	95.59%
yes	29	0.82%	69	4.41%

[a] Included in the most parsimonious model for the rider.
[b] Included in the most parsimonious model for the driver.

disaggregated models and the aggregated are performed. According to Washington et al. (2003), the likelihood ratio statistic, χ^2 is defined as

$$\chi^2 = -2[LL(\beta_A) - LL(\beta_R) - LL(\beta_D)] \tag{3}$$

where $LL(\beta_A)$ is the log-likelihood at convergence of the aggregate model estimated with data from all vehicle types, $LL(\beta_R)$ is the log-likelihood at convergence of the model using the rider data only, and $LL(\beta_D)$ is the log-likelihood at convergence of the model using the driver data only.

The likelihood ratio statistic is assumed to follow a χ^2 distribution with the degree of freedom being

$$df = n_R + n_D - n_A \tag{4}$$

where n_A is the number of the estimated parameters in the aggregate model, n_R is the number of parameters estimated in the rider model, and n_D is the number of parameters estimated in the driver model.

After confirming the avoidance of multicollinearity, a potential list of 21 explanatory variables is identified and the frequency of each variable is listed in Table 1. From that, Akaike's Information Criteria (AIC) is applied to find the appropriate variables that yield the most parsimonious model. The procedure follows similar studies conducted previous such as (Haque et al., 2009; Chin and Zhou, 2018). The symbol [a] and [b] noted in Table 1 suggest the variables included in the most parsimonious rider model and driver model respectively. Further, likelihood ratio tests comparing the final models with the null models are conducted to measure the overall goodness of fit.

3. Results and discussions

According to the likelihood ratio test, the log-likelihood values at convergence for the rider model and driver model are −907.843 (54 df) and −976.452 (54 df) respectively, while the corresponding value for the aggregated model is −2040.177 (55 df). Apart from the difference in nature of the two groups, the χ^2 statistic of 311.764 (p-value < 0.001) also suggests that separate analyses for riders and drivers is preferable.

Following the stepwise backward elimination (10% criterion) to minimize AIC, the most parsimonious solutions have 15 explanatory variables for the rider model and 13 explanatory variables for the driver model. These models also provide a good fit based on the likelihood ratio test statistics and pseudo-R^2, as shown in Table 2 and these will be discussed in subsequent sections. For better appreciation, the variables are divided into and discussed in four groups, i.e. rider/driver factors, vehicle factors, roadway factors, and environmental factors. Moreover, to better explain the effects of changes in predictors on the outcome probabilities for ordered probit models, elasticities and marginal effects are presented and these are shown in Table 3.

3.1. Driver characteristics

3.1.1. Age

Age is found to be a significant predictor of injury severity for both riders and drivers in out-of-control SV crashes. More specifically, older riders and drivers are more likely to suffer from more severe injuries. Compared to middle-aged riders and drivers, the probability of being fatally injured is found to be 1.44% and 1.11% higher for their older counterparts. This finding is consistent with a number of similar studies (Shankar and Mannering, 1996; Quddus et al., 2002; Savolainen and Mannering, 2007; Wu et al., 2016a), indicating that factors such as age-related fragility and impairment (e.g. reduced visibility) are also prevalent for vehicle operators in out-of-control SV crashes. The more severe impact for older riders compared to older drivers is also expected due to less protection for motorized two-wheelers.

3.1.2. Race and nationality

In Singapore, the injury severity of riders in out-of-control SV crashes is significantly affected by race whereas the injury severity of drivers is affected by nationality.

The probability of getting fatal injuries for Malay riders is found to be 0.82% lower than that for Chinese riders. Riding is more popular among Malays, particularly for work-related purposes, they tend to be more skillful either through extensive riding experience or under peer influence.

For drivers of minor nationalities (not Singaporean) such as Malaysian and others, the probability of getting fatal injuries in SV crashes is found to be a 0.76% and 0.77% lower than that of Singaporean drivers. One possible explanation of this is that foreign drivers tend to drive more cautiously than local drivers when they are acting by themselves. As mentioned by Wang et al. (2017), foreign drivers are found to generally drive at a lower speed than local drivers in Singapore. This may have resulted in less severe injuries when they are involved in SV out-of-control crashes.

3.1.3. License status

License status is found to be a statistically significant indicator for riders involved in SV out-of-control crashes. The probability of fatal injuries is estimated to be 1.76% higher among riders with "abnormal" license status (e.g. those holding probation or expired license) compared to the rest. As for drivers, such relationship does not appear to be statistically significant (p-value = 0.124). However, since the variable is just outside the 10% significance level and included in the most parsimonious model, it is still discussed here due to its potential importance. It is noteworthy that the influence turns out to be the opposite among drivers compared to riders, resulting in a 0.58% decrease in fatality of drivers. As indicated in Table 4, most of the riders with abnormal license status were riding illegally, with expired or disqualified license. These riders exhibiting deviant behavior are likely to be more reckless and with the tendency to disregard traffic regulations and even personal safety. In comparison, among drivers with abnormal license status, over 60% of them were under probation (i.e., within the first

Table 2
Parameter estimates of significant variables.

Explanatory variables	Rider			Driver		
	Coef.	t-stat.	p-value	Coef.	t-stat.	p-value
Rider/driver-vehicle characteristics						
Age (relative to those who aged between 25 & 64)						
65 & above	0.2756	1.79	0.073	0.2721	2.07	0.039
24 & below	−0.0012	−0.01	0.988	0.0675	0.60	0.548
Race (relative to Chinese)						
Indian	0.0645	0.66	0.508	–	–	–
Malay	−0.2151	−2.79	0.005	–	–	–
others	0.1311	0.77	0.441	–	–	–
Nationality (relative to Singaporean)						
Malaysian	–	–	–	−0.2701	−1.70	0.090
others	–	–	–	−0.2770	−2.41	0.016
License status (relative to normal)						
other status, e.g. expired & probation	0.3367	2.76	0.006	−0.2051	−1.54	0.124
Drink riding/driving (relative to negative)						
unknown	−0.2297	−2.66	0.008	−0.3059	−3.48	0.001
positive	0.3705	1.79	0.074	0.2233	1.26	0.209
At-fault status (relative to at-fault)						
not at-fault	−0.7352	−1.67	0.095	–	–	–
Type of error of rider/driver (relative to failing to have proper control)						
violation of rules	−2.1590	−3.37	0.001	−1.5540	−5.27	< 0.001
distraction	−0.7941	−2.26	0.024	−0.2388	−1.02	0.353
carelessness	−0.3676	−1.96	0.050	−1.0921	−7.32	< 0.001
others	−0.0727	−0.32	0.748	−0.7332	−3.65	< 0.001
unknown	0.4065	0.92	0.357	−0.7861	−10.01	< 0.001
Vehicle registration type (relative to registered in Singapore)						
registered overseas	−0.3858	−3.48	0.001	0.5536	2.39	0.017
Vehicle maneuvers before accident (relative to other complex maneuvers)						
left	0.2830	3.37	0.001	0.2250	2.53	0.011
right	0.3544	3.53	< 0.001	0.3124	3.50	< 0.001
straight	−0.0059	−0.05	0.959	0.4097	3.33	0.001
Roadway characteristics						
Road traffic type (relative to two-way divided)						
one-way	0.1629	1.06	0.288	–	–	–
two-way undivided	0.5426	3.00	0.003	–	–	–
expressway	0.3267	2.41	0.016	–	–	–
expressway slip	0.2723	1.29	0.197	–	–	–
other slip	0.0602	0.53	0.594	–	–	–
Posted speed limit (relative to 50km/h)						
60km/h	0.1168	1.18	0.240	0.2245	2.47	0.013
70km/h	0.3091	2.04	0.042	0.1502	1.19	0.234
80km/h	−0.1023	−0.66	0.512	−0.3203	−2.51	0.012
90km/h	−0.1459	−0.99	0.320	−0.2119	−1.97	0.049
< 50km/h	−0.4201	−2.22	0.027	0.1585	0.90	0.368
Lane position (relative to center)						
curb (left most)	0.0829	0.86	0.389	0.1369	1.35	0.177
median (right most)	0.2749	2.54	0.011	0.1121	1.05	0.296
single	0.1737	1.42	0.157	−0.0268	−0.23	0.820
unknown	−0.0008	−0.01	0.994	0.3867	3.98	0.000
Road surface (relative to dry)						
wet, sandy or oily	−0.2464	−3.09	0.002	−0.5982	−4.78	0.000
unknown	−0.4539	−1.38	0.168	−0.3626	−0.77	0.442
Environmental characteristics						
Time of accident (relative to daytime off-peak)						
early morning (0000-0659)	0.1894	1.78	0.075	0.2461	2.74	0.006
morning peak (0700-0929)	−0.1242	−1.26	0.207	−0.0679	−0.61	0.545
afternoon peak (1700-1929)	−0.1027	−0.99	0.321	−0.0196	−0.18	0.861
nighttime off-peak (1930-2359)	−0.1729	−1.63	0.104	−0.0893	−0.83	0.405
Lighting (relative to good)						
poor	2.0186	3.58	< 0.001	–	–	–
unknown	−0.0302	−0.38	0.702	–	–	–
Weather (relative to clear)						
inclement	–	–	–	0.3611	2.32	0.020
unknown	–	–	–	−0.1176	−0.28	0.779
Presence of pedestrian (relative to no)						
yes	–	–	–	−1.8126	−6.37	< 0.001
Hitting stationary object (relative to no)						
yes	0.6888	1.87	0.061	–	–	–
μ_1	−2.1999			−0.8225		
μ_2	1.9286			2.0532		
μ_3	2.2209			2.3726		
Number of Observations		3557			1565	

(*continued on next page*)

Table 2 (*continued*)

Explanatory variables	Rider			Driver		
	Coef.	t-stat.	p-value	Coef.	t-stat.	p-value
Degree of freedom		44			37	
Log likelihood (null)		−993.622			−1179.897	
Log likelihood (convergence)		−910.584			−980.893	
Likelihood ratio test		$\chi2$ (41) =185.020, p-value < 0.001			$\chi2$ (34) =398.01, p-value < 0.001	
AIC		1909.168			2035.786	
Pseudo-R2		0.092			0.169	

year of obtaining the driver's license). These inexperienced drivers, who may show less flexibility in driving (Crundall et al., 1999), are more likely to drive more cautiously, e.g., driving at lower speeds, so that when involved in SV out-of-control crashes, they tend to suffer less severe injuries. Further studies may be conducted to test the statistical association between the injury severity of drivers and the two-way interaction term involving license status.

3.1.4. Drink riding/driving

Not surprisingly, riding and driving under the influence of alcohol is found to show a higher probability of being severely injured. When involved in SV out-of-control crashes, the riders who were drunk are estimated to increase their probabilities of being fatally injured by 2.29%. This finding is found to be consistent with other studies (Shankar and Mannering, 1996; Quddus et al., 2002; Savolainen and Mannering, 2007). The use of alcohol can cause impairment to judgment and trigger more high-risk riding behaviors such as speeding and risk-taking (Das et al., 2012) as well as poorer response to crash recovery, thus resulting in more severe injuries. However, this association does not appear to be statistically significant for drivers. One possible explanation for that is drink driving may not be a leading reason for the severe injuries of drivers involved in SV out-of-control crashes here in Singapore. As reported by the analyst, the issue of drink driving in Singapore is not nearly as prominent as other Asia-pacific countries such as Vietnam, New Zealand and Australia due to different cultural background and strict regulation (Milnes, 2017). In the future, exploring two-way interaction involving drink driving may be helpful in gaining a clearer understanding of its role in injury severity.

3.1.5. At-fault status

According to the result, the probability of having fatal injuries is estimated to be 2.66% higher when the rider is at-fault in SV crashes compared to when the crash is not inflicted on the rider. Although the responsibility for SV crashes is often assigned to the rider/driver, it is possible that certain crashes may not be self-inflicted sometimes, e.g. under the indirect influence of other vehicles even though there was no collision. Further investigation is being carried out to gain a better understanding of this type of crashes.

3.1.6. Type of error of rider/driver

The type of errors made by the rider/driver in the crash is found to be a significant influence on injury severity of both riders and drivers involved in SV out-of-control crashes. Fig. 1 shows the marginal effects of levels that are significant for both riders and drivers. As shown in Fig. 1, the reference as well as the most common type of error, i.e. failing to have proper control over the vehicle, is associated with the highest probability of rider and driver fatality. Compared to rule violation and carelessness, the probability of fatal injuries when failing to have proper control increases 1.82% and 1.11% for riders and 2.59 and 2.46% for drivers respectively. Different from error types such as violation of rules, and carelessness that occurred mostly due to subjective reasons, failing to have proper control is more likely to be associated with objective disruptions such as vehicle malfunction or breakdown. Under those unexpected circumstances, it may be more difficult or even impossible for riders and drivers to take necessary countermeasures to avoid further injuries. Moreover, according to the magnitude of increase with reference to those subjective errors, drivers tend to suffer higher fatalities than riders when failing to have proper control. This indicative finding suggests that despite riders are known to be more vulnerable than drivers in most cases, it should be noted that there are exceptions given specific error types and crash types.

3.1.7. Vehicle registration type

According to the Land Transport Authority (a statutory board under the Ministry of Transport of Government of Singapore), most long-term residents such as local citizens and permanent residents are not allowed to drive foreign-registered vehicles (including motorcycles) into Singapore. Therefore, foreign-registered vehicles found in Singapore are mostly ridden or driven by foreigners and most of those vehicles are registered in neighboring Malaysia. Intriguingly, the impact of vehicle registration type on injury severity appears to have an opposite effect between the riders and drivers.

The probability of fatal injuries among drivers in foreign-registered vehicles is found to be 3.03% higher than that in local-registered vehicles. This is probably because vehicles registered overseas, especially in Malaysia, may not have been as well-maintained compared to locally registered vehicle. In Singapore, the vehicles are inspected once every one or two years under a strict regime, making vehicles roadworthy. However, such mandatory roadworthiness inspection is not available in Malaysia (Solah et al., 2017). According to Solah et al. (2017), most Malaysian vehicles, especially private-owned ones, are not required to conduct regular inspection after registration. In consequence, vehicle defects that failed to be discovered and remedied in time may give rise to potential safety hazards, leading to more severe injury when involved in crashes.

However, the probability of fatal injuries among riders in foreign-registered vehicles is estimated to be 1.35% lower than that of other vehicles. Most foreign motorcycles come from Malaysia and these are ridden for work-related purposes, i.e., commuting between Malaysia and Singapore, since only work pass holders that are not local residents are allowed to operate the foreign-registered vehicles in Singapore. Consequently, these trips are made on familiar routes and at about the same time of the day with similar traffic conditions. In comparison, local motorcycles may be used for a wider variety of purposes, including delivery and recreation and under varied routes and traffic conditions.

3.1.8. Vehicle maneuvers before crash

Vehicle maneuvers are found to significantly influence injury severity of riders and drivers involved in out-of-control SV crashes. Based on their recorded frequency in this type of crashes, the four maneuver types, ranking from lowest to highest, are driving ahead, turning right (left), turning left (right) and other complex maneuvers such as lane changing for riders (drivers).

Relative to complex maneuvers, riders turning left and turning right is associated with a higher probability of 1.19% and 1.60% respectively. For drivers, the corresponding probabilities are 0.65% and 0.99% higher respectively. The more severe impact among riders is

Table 3
Marginal effects of significant variables.

Explanatory variables	Rider				Driver			
	No injury	Slight injury	Serious injury	Fatal	No injury	Slight injury	Serious injury	Fatal
Rider/driver-vehicle characteristics								
Age (relative to those who aged between 25 & 64)								
65 & above	−0.0109	−0.0126	0.0091	0.0144	−0.0745	0.0564	0.0069	0.0111
24 & below	0.0001	< 0.0001	< 0.0001	< 0.0001	−0.0194	0.0156	0.0015	0.0023
Race (relative to Chinese)								
Indian	−0.0027	−0.0026	0.0021	0.0032	–	–	–	–
Malay	0.0116	0.0024	−0.0058	−0.0082	–	–	–	–
others	−0.0051	−0.0062	0.0044	0.0069	–	–	–	–
Nationality (relative to Singaporean)								
Malaysian	–	–	–	–	0.0808	−0.0679	−0.0053	−0.0076
others	–	–	–	–	0.0829	−0.0698	−0.0054	−0.0077
License status (relative to normal)								
abnormal status	−0.0139	−0.0148	0.0111	0.0176	0.0611	−0.0512	−0.0041	−0.0058
Drink riding/driving (relative to negative)								
unknown	0.0133	0.0006	−0.0058	−0.0080	0.0929	−0.0793	−0.0057	−0.0079
positive	−0.0122	−0.0244	0.0138	0.0229	−0.0601	0.0446	0.0060	0.0095
At-fault status (relative to at-fault)								
not at-fault	0.0477	−0.0027	−0.0185	−0.0266	–	–	–	–
Type of error of rider/driver (relative to failing to have proper control)								
violation of rules	0.5057	−0.4728	−0.0148	−0.0182	0.5036	−0.4578	−0.0200	−0.0259
distraction	0.0998	−0.0725	−0.0119	−0.0154	0.0622	−0.0444	−0.0070	−0.0108
carelessness	0.0340	−0.0216	−0.0082	−0.0111	0.3465	−0.3034	−0.0185	−0.0246
others	0.0053	−0.0009	−0.0017	−0.0025	0.2194	−0.1820	−0.0157	−0.0218
unknown	−0.0203	−0.0159	0.0133	0.0230	0.2378	−0.1992	−0.0162	−0.0224
Vehicle registration type (relative to registered in Singapore)								
registered overseas	0.0241	−0.0011	−0.0095	−0.0135	−0.1383	0.0912	0.0168	0.0303
Vehicle maneuvers before accident (relative to other complex maneuvers)								
left	−0.0133	−0.0068	0.0082	0.0119	−0.0668	0.0557	0.0046	0.0065
right	−0.0156	−0.0112	0.0108	0.0160	−0.0910	0.0743	0.0067	0.0099
straight	0.0004	< 0.0001	−0.0001	−0.0002	−0.1166	0.0927	0.0095	0.0144
Roadway characteristics								
Road traffic type (relative to two-way divided)								
one-way	−0.0097	−0.0001	0.0041	0.0057	–	–	–	–
two-way undivided	−0.0236	−0.0221	0.0176	0.0281	–	–	–	–
expressway	−0.0170	−0.0058	0.0092	0.0136	–	–	–	–
expressway slip	−0.0148	−0.0033	0.0074	0.0108	–	–	–	–
other slip	−0.0039	0.0006	0.0014	0.0019	–	–	–	–
Posted speed limit (relative to 50 km/h)								
60 km/h	−0.0050	−0.0043	0.0037	0.0056	−0.0621	0.0478	0.0056	0.0087
70 km/h	−0.0110	−0.0178	0.0110	0.0178	−0.0424	0.0334	0.0036	0.0054
80 km/h	0.0054	0.0014	−0.0028	−0.0040	0.0993	−0.0865	−0.0055	−0.0073
90 km/h	0.0080	0.0014	−0.0039	−0.0055	0.0645	−0.0552	−0.0039	−0.0054
< 50 km/h	0.0295	−0.0081	−0.0092	−0.0122	−0.0446	0.0350	0.0038	0.0058
Lane position (relative to center)								
curb	−0.0043	−0.0012	0.0023	0.0032	−0.0403	0.0333	0.0029	0.0042
median	−0.0120	−0.0095	0.0086	0.0129	−0.0332	0.0276	0.0023	0.0033
single	−0.0083	−0.0042	0.0051	0.0074	0.0081	−0.0069	−0.0005	−0.0007
unknown	< 0.0001	< 0.0001	< 0.0001	< 0.0001	−0.1075	0.0829	0.0095	0.0151
Road surface (relative to dry)								
wet, sandy or oily	0.0137	0.0018	−0.0064	−0.0090	0.1852	−0.1613	−0.0101	−0.0138
unknown	0.0307	−0.0066	−0.0103	−0.0138	0.1084	−0.0910	−0.0072	−0.0103
Environmental characteristics								
Time of accident (relative to daytime off-peak)								
early morning	−0.0072	−0.0091	0.0064	0.0099	−0.0687	0.0535	0.0060	0.0092
morning peak	0.0064	0.0019	−0.0034	−0.0048	0.0203	−0.0171	−0.0013	−0.0019
afternoon peak	0.0051	0.0018	−0.0029	−0.0041	0.0058	−0.0049	−0.0004	−0.0006
nighttime off-peak	0.0093	0.0017	−0.0046	−0.0064	0.0269	−0.0228	−0.0017	−0.0024
Lighting (relative to good)								
poor	−0.0222	−0.4637	0.0911	0.3949	–	–	–	–
unknown	0.0015	0.0006	−0.0009	−0.0012	–	–	–	–
Weather (relative to clear)								
inclement	–	–	–	–	−0.0958	0.0696	0.0097	0.0165
unknown	–	–	–	–	0.0348	−0.0290	−0.0023	−0.0034
Presence of pedestrian (relative to no)								
yes	–	–	–	–	0.5458	−0.5179	−0.0127	−0.0153
Colliding with stationary object(S) (relative to no)								
yes	−0.0189	−0.0636	0.0286	0.0539	–	–	–	–

Table 4
Detailed distribution of license status.

Detailed status	Rider		Driver	
	Frequency	Percentage	Frequency	Percentage
Expired	530	93.97%	38	29.46%
Disqualified/suspended	24	4.25%	7	5.43%
Under probation	1	0.18%	80	62.01%
Others	9	1.60%	4	3.10%
Total number of "abnormal"	564	100%	129	100%
Total number of "normal"	*2993*		*1436*	

expected due to their general vulnerability. The reason that turning left and right generally appear to be more hazardous may be due to the fact that the lateral skidding due to turning may be more likely to result in rollover, the leading cause of road traffic fatalities (Anarkooli et al., 2017). Moreover, since turning left is usually guided by curves (especially at intersections), drivers and riders are more likely to operate the vehicles at lower speed and less likely to make mistakes than unguided right-turns. This may explain the relatively lower probability of being fatally injured when turning left compared to turning right.

However, among drivers, the most dangerous driving maneuvers is driving ahead instead of turning left or right as it indicates a higher probability of fatal injuries by 1.44%. As suggested by Wu et al. (2016b), compared to driving straight, drivers tend to decelerate when turning to avoid collision with surrounding vehicles. Therefore, the generally higher speed when going straight ahead may presumably result in more severe inpacts when involved in out-of-control SV crashes.

3.2. Roadway characteristics

3.2.1. Road traffic type

The results also show that the road type has a significant influence on injury severity of riders involved in out-of-control crashes. With reference to riding on two-way divided road, the probability of fatal injuries when riding on expressway and two-way undivided road is found to be 1.36% and 2.81% higher respectively. It is intuitive that the riding on high-speed expressways could lead to more severe injuries more intriguing finding is that two-way divided road is safer than undivided road for riders, largely because riders need only focus on traffic in one direction. As suggested by Haque et al. (2012), median separation could restrict possible interactions with traffic from opposing side, which may be able to control the collateral damage given the occurrence of out-of-control crashes. Moreover, large median with planting may serve as buffers for falling riders.

3.2.2. Posted speed limit

Posted speed limit is found to a significantly contributory factor to the injury severity of riders and drivers. Roads with higher-speed limit turn out to be more dangerous to riders, consistent with the aforementioned higher probability of fatal injuries on expressways. Compared to the default speed limit of 50 km/h, riding on roads with speed limit of 70 km/h is expected to result in higher probability of being fatally injured by 1.78%, whereas the probability is 1.22% lower on roads with speed limit of 30 km/h and 40 km/h. On the other hand, for drivers, speed limit of 60 km/h is gives the highest probability of fatal injuries, whereas high speed limits of 80 km/h or 90 km/h is found to produce lower likelihood of fatal injuries. Since serious SV out-of-control crashes tend to be a result of complex maneuvers, the injury severity may be alleviated when driving on roads with high speed limits due to less interactions and less complex maneuvers.

3.2.3. Lane position

Lane position is found to be a significant predictor for both models. For riders, the median lane is estimated to give a higher probability of fatal injuries by 1.29% compared to the reference to case of center lane. The median lane tend to be used by vehicles travelling at higher speeds than other lanes (Haque et al., 2009), more severe injuries are likely in out-of-control crashes. However, such significance is not found for drivers. Instead, crashes occurred at unknown lane are associated with the highest probability of fatal injuries for drivers. It may be reasonable to assume that they are most likely to be run-off-road accidents, which are found to account for the majority of highway fatalities (Gong and Fan, 2017).

3.2.4. Road surface condition

Road surface condition is a significant predictor for severity in out-of-control crashes. The results suggest that compared to dry road surface, the probability of fatal injuries when the surface is wet, oily or sandy is lower by 0.90% and 1.38% for riders and drivers respectively. Riders and drivers may adjust their behavior to compensate for the higher risk when they are travelling on slippery surface. This is consistent with findings in previous studies (Chen and Chen, 2011; Garrido et al., 2014; Chen et al., 2016).

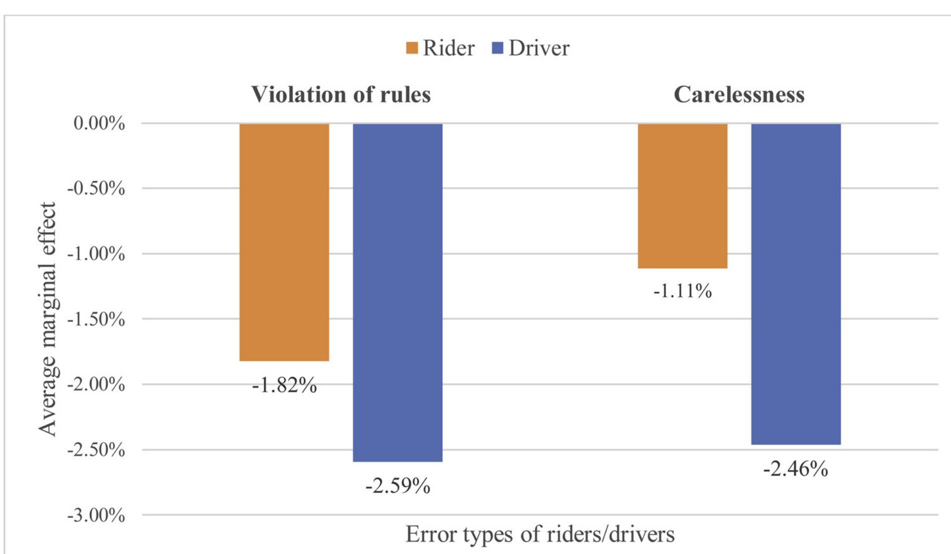

Fig. 1. Average marginal effects of error types (relative to failing to have proper control).

3.3. Environmental characteristics

3.3.1. Time of accident

The time of accident appears to be significantly associated with injury severity of both models. The probability of a fatal injuries when involved in SV out-of-control crashes during early morning hours is estimated to be 0.99% and 0.92% higher compared to during daytime off-peak hours for riders and drivers respectively. This indicates that although the lighting condition after midnight in Singapore is generally good, the riding and driving behaviors may still be compromised due to fatigue or speeding under low flow traffic conditions.

3.3.2. Lighting condition

Lighting condition is found to be significantly influence riders involved in SV out-of-control crashes. In poor lighting conditions, the probability of getting fatal injuries is estimated to be 39.49% higher. The reduced visibility could lead riders to be less able to respond to hazards, leading to higher likelihood of losing control of vehicles. Interestingly this condition is not significant among drivers, largely because vehicles may not be affected by problems of instability as in motorcycles.

3.3.3. Weather

Inclement weather condition is found to significantly exacerbate the injury severity for drivers involved in SV out-of-control crashes by showing higher probability of fatal injuries by 1.65%. Inclement weather, e.g. rain and haze, is generally associated with reduced visibility, which tend to result in misjudgment and risky behaviors such as sharp brakes and rollover. Similar results can also be found in the research with respect to SV crashes conducted by Chen and Chen (2011) and Anarkooli et al. (2017).

3.3.4. Presence of pedestrian

The presence of pedestrians in the vicinity is found to influence injury severity of drivers by indicating lower probability of being fatally injured by 1.53%. This may be because, in the presence of pedestrian, drivers tend to be more careful and alert and less likely to perform risky maneuvers. On the other hand, riders do not seem to exhibit the same precaution.

3.3.5. Colliding with stationary object(s)

Compared to crashes without striking anything, the probability of fatal injuries for riders is estimated to be 5.39% higher when there was striking object(s). This finding is fairly intuitive and consistent with previous studies considering the greater deceleration rate caused by the sudden stoppage (Quddus et al., 2002; Huang et al., 2008). However, such influence is found to be significant for drivers. This finding may be considered consistent with the previous finding regarding the influence of median lane. Due to the buffering effect brought by the body of vehicles and passive safety systems inside, drivers may be more resilient to such impacts compared to motorcycle or motor-scooter riders.

4. Conclusions

This study focuses on out-of-control crashes, a prevailing type of SV crashes in Singapore that has rarely been studied specifically. 18 contributing factors from rider- /driver-vehicle, roadway and environmental characteristics to injury severity of this type of crash are investigated using ordered probit models. The results discussed in the paper are considered to be valid since the marginal effects of those variables are consistent with similar studies that have adopted the same approach in terms of magnitude (Renski et al., 1999; Khattak et al., 2002; Jiang et al., 2013; Garrido et al., 2014).

To summarize, ten of the studied factors are found to have a significant influence on the injury severity of both riders and drivers. In comparison, six have shown consistent impacts on the same levels (i.e. age, error types, vehicle maneuvers before accident, road surface condition, time of accident, license status and drink driving), two depicts opposite influence (i.e. vehicle registration type, license status) and two do not share mutually significant level to compare with (i.e. posted speed limit and lane position). Apart from that, there are five independent variables influential to the injury severity of riders only (race, at-fault status, road traffic type, lighting and colliding with stationary object) and three to drivers only (i.e. nationality, weather and presence of pedestrian).

Collectively, these findings indicate three situations that may aggregate the injury severity of riders and drivers involved in SV out-of-control crashes. It offers insight into the proneness of high injury severity related to this type of crashes, thus facilitating the design of potential countermeasures to prevent that for all vehicle operators in the future.

(1) Risky riding/driving behaviors: Risky behaviors (usually occurred when operating under the influence of alcohol, riding with expired licenses and riding on expressways, roads with high speed limit of 70 km/h) are closely related to the injury severity of riders and drivers in general. Once involved in out-of-control crashes, the adverse consequences of those behaviors such as high speed could result in increased braking time and skidding distance, thus leading to more severe injuries.
(2) Impaired judgment: Impaired judgment may be another cause for exacerbated injury severity of drivers and riders in SV out-of-control crashes (e.g. operators aged 65 and above, driving with inclement weather, making errors due to objective disruptions, riding with poor lighting condition). Under those circumstances, drivers and riders may be unable to take proper reactions in time, which may inevitably lead to behaviors with greater deceleration rates and consequently more severe injuries.
(3) Potential interaction with other vehicles: Potential interaction with other vehicles may also lead to severe injuries in SV out-of-control crashes (e.g. steering left or right before crashes, riding on two-way undivided roads). Passing vehicles on the left and right side may bring collateral damage to the falling rider and shifted vehicle.

Under the majority of those circumstances where the influence by the variables is both significant and consistent, the increased fatality rate for riders is approximately 1.65 times higher than that of drivers on average. The finding is consistent with the literature since motorized two-wheelers are generally more vulnerable due to their direct exposure to hazards and lack of passive safety devices. However, there are a few exceptions. When involving in out-of-control SV crashes on dry road surface or due to failure to have proper control, the increased fatality for drivers are found to be higher than riders. This indicates that the resilience of drivers relative to riders is conditional for this type of crashes. Further studies with investigation into more specific circumstances (e.g. involving interaction terms) are required to reveal the detailed conditions and the causation.

Furthermore, in light of different influences on the injury severity of riders and drivers, countermeasures may need to be designed targetedly to increase overall road safety. For example, given that drivers of foreign-registered vehicles tend to suffer more serious injuries than riders, it is necessary to conduct vehicle inspection especially on foreign-registered motorized four-wheelers to prevent the objective disruptions caused by vehicle defects. When admitting foreign vehicles at the customs checkpoint, random inspection may be introduced to ensure the proper maintenance. Moreover, different emphasis should also be placed regarding the education of riders and drivers. For instance, since older riders are prone to more severe injury than their counterparts among drivers, they should be inspected for health conditions and warned of the hazardous locations more frequently. Additionally, considering that riders with illegal licenses and influence of alcohol are particularly prone to more severe injuries, the awareness to strictly avoid against such behaviors should be raised during the training classes. Meanwhile, enforcement officers should also conduct more random checks with emphasis on motorized two-wheelers, especially during midnight to regulate the illegal riding behaviors.

The study also sheds light on some intriguing directions for future research. For instance, familiarity with road conditions and intensive experience seems to indicate different influences on the injury severity of drivers and riders involved in out-of-control SV crashes. Riders who are generally considered to be more experienced and familiar with road condition, such as Malay riders, are found to be less severely injured than others. On the other hand, such drivers, e.g. the local Singaporean drivers and drivers with formal driving licenses, are found to suffer from more serious injuries than foreign-nationality drivers and drivers under probation respectively. In order to validate this speculation, further studies designed delicately without other confounding effects may be required.

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