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Accident Severity Analysis Using Ordered Probit Model

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To reduce injuries in road crashes, better understanding is needed between the relationship of injury severity and risk factors. This study seeks to identify the contributing factors affecting crash severity with broad considerations of driver characteristics, roadway features, vehicle types, pedestrian characteristics and crash characteristics using an ordered probit model. It also explores how the interaction of these factors will affect accident severity risk. Three types of accidents were investigated: two-vehicle crashes, single vehicle crashes and pedestrian accidents. The reported crash data in Singapore from 1992 to 2001 were used to illustrate the process of parameter estimation. Several factors such as vehicle type, road type, collision type, location type, pedestrian age, time of day of accident occurrence were found to be significantly associated with injury severity. It was also found that injury severity decreases over time for the three types of accident investigated.

Keywords: Accident severity, Ordered probit model, Accident risk, Two-vehicle crashes, Single- vehicle crashes, Pedestrian accidents.

Introduction

Singapore, a heavily motorized country, has one of the best road and transportation systems in Asia. Although the level of road safety is in a satisfactory position by the Asian standards, the traffic accident rates are still high when compared with developed countries and the tendency is on the increase in recent years. For example, a comparison between the accident statistics of 1992 and 2001 shows that the number of casualties

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increased from 6144 in 1992 to 7091 in 2001. This figure shows that accident situation in Singapore requires attention. Clearly, for developing countermeasures in reducing the road crashes and the consequent injuries, there is a need for better understanding about the relationship between risk factors and the injury severity of crashes.

Extensive literature has been found that investigated the influence of risk factors related to the driver, the vehicle, the road environment and crash characteristics on severity in accidents. These studies mostly examined and emphasized on the different types of collision effect, larger mass effect, effect due to differing types of vehicle as well as the effect of age on severity. Amongst them, Evans and his associates (1985, 1987, 1992, 1993, and 1994) and Ducan, Khattak and Council (1998) investigated the relationship between vehicle masses and the degree of injuries. On the other hand, Haland, Lovsudn and Nygren (1993), Viner (1995a and 1995b), Farmer, Braver and Mitter (1997), Renski and his group (1999), Krull et al. (2000), Lee et al. (2002), Treachy et al. (2002), Yamamoto and Shankar (2002) have studied severity of injuries based on crash characteristics whereas Jones and Whitfield (1988), Sjogren et al. (1993), Abdel-Aty et al. (1998), Mercer (1987), Bedard et al. (2002), Lang et al. (1996), Dissanayake and Lu (2002a and 2002b) focused on the age of drivers affecting severity. Previous researches have also identified the relationship between type of vehicles and severity. Shankar and Mannering (1996), Kockelman and Kweon (2002), Blight and Mak (1999), Viner et al. (1994), Chang and Mannering (1999) did some of these studies. These studies helped the researchers to understand the factors affecting severity and provided an idea about the safety countermeasures to be adopted which would reduce the severity of accidents. Though the studies carried out in North America, Canada and Europe give some insight into the factors involving crashes and injury severity in Singapore, but their findings may not be applicable because the conditions and problems of these countries may not be the same as that of Singapore. Moreover, differences in road and driving conditions, as well as traffic and regulatory characteristics may prove difficult to apply, as their findings may not fully explain the issues encountered locally. Naturally it is necessary to examine the environmental aspects as well as involved vehicles, drivers and roadway characteristics to identify the factors and their interactions that may contribute to increase or decrease in the severity of crashes in Singapore. This would be needed for implementing road safety measures.

While there is a genuine awareness about safety studies made in different countries, very few works have been done in Singapore. So far the studies have been confined to general accident trends (Yuan, 2000) and specific evaluation of the effectiveness of safety measures (Jessie et al., 1998). On the other hand, if we examine the safety measures that have been taken by Singapore so far, it will be seen that most of them were targeted at general road users; such as the children and the elderly person's road crossing safety, necessity of children-restrained usage and proper bicycle riding. However, authorities in Singapore want to reduce the severity of accident in the country. But they are handicapped due to lack of knowledge about factors influencing severity. As very few studies were done in the past on such factors, they are hardly known or well understood. However, in recent years due to the rapid improvement of information and communication technology make it possible to handle easily a large data set of reported accidents over a period of years. These improvements help in using sophisticated and microscopic statistical models in the field of traffic safety.

This study was conducted to understand the contributing factors affecting severity of road crashes in Singapore with a broad consideration of driver characteristics, roadway features, vehicle types and environmental factors. For this purpose, three types of accident severity analyses have been incorporated, such as two-vehicle crash severity, single vehicle crash severity and pedestrian injury severity to get an overall picture of the factors affecting the severity throughout the country. The reason behind choosing these three types of accident in severity analysis is that they constitute about 93.58% accidents that occurred throughout the country from 1992 to 2001.

Methodology

Modeling methodology

In many studies on severity of accidents, discrete models have been used to identify factors affecting the severity. Since accident data are categorical in nature, some researchers have relied on logistic regression, (e.g., Jones and Whitfield 1988; Lui et al., 1988; Shibita and Fukuda, 1994), while others have used multinomial logit models (e.g., Shankar and mannering, 1996) or nested logit models (e.g., Chang and Mannering, 1998). Recognizing that the discrete nature of severity is ordinal in nature, some researchers (e.g., O'Donnell and Connor, 1996; Duncan et al., 1998; Long, 1997; Khattak, 2001; Kockelman and Kweon, 2002, Quddus et al., 2002) have considered the ordered probit or ordered logit models to be more suitable. The choice in the use of ordered probit or ordered logit lies in the assumption of distribution of errors. The ordered logit model is based on the assumption that the errors are independently and identically distributed with the logistic distribution whereas the ordered probit model is based on the assumption that the distribution of errors is multivariate normal. However, O'Donnell and Connor (1996) and Rensky et al. (1999) have indicated that the results from the ordered probit and ordered logit are fairly similar. Hence, any of these two models can be used in this study. Ordered probit model is employed in this regard. The theoretical framework of the ordered probit model including the model specification and method of evaluation was discussed thoroughly in several studies (i.e., O'Donnell and Connor, 1996; Long, 1997; Duncan et al., 1998; Rensky et al., 1999; Kockelman and Kweon, 2002; Khattak et al., 2002). Therefore, detail derivation of this model is not given in this paper. Only the general specification is given below,

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

where y_i^* is a latent variable measuring the injury severity of i^{th} accident or damage severity of i^{th} motorcycle; $\boldsymbol{X_i}$ is a (1×k) vector of observed non-random explanatory variables; $\boldsymbol{\beta}$ is a (k×1) vector of unknown parameters; ε_i is the random error term, which is assumed to be normally distributed with zero mean and unit variance.

Model Setup

To calibrate the accident severity model, data based on reported accidents in the period from 1992 to 2001 were used in the study. During this period, there were 52,524 accidents, of which 29,389 were two-vehicle crashes. From the 9 years of data, 2.6% of the nearly 30,000 cases were classified as fatal, 5.2% as serious injury and 92.2% as slight injury accident. Ten years of crash data in Singapore yielded a sample size of 13691 in case of single-vehicle crashes. Among these observations 4.42% of the cases are classified as fatal, 5.68% are classified as seriously injured and the rest are slightly Data related to pedestrian crashes have been sorted out to develop the model. The total number of pedestrian crashes during the period is 9327, of which 8.1% are classified as fatal, 7.8% are classified as seriously injured and the rest are classified as slightly injured.

In the proposed ordered probit model, the dependent variable used is accident severity which may take on one of three values based on the recorded degree of injury involved, viz, fatal, seriously injured and slightly injured. The accident is classified based on the worst condition sustained among the casualties. In the Singapore accident reporting system, a casualty is considered fatal if the person is killed within 30 days of the accident. A seriously-injured casualty is one who had suffered some kind of fracture, concussion, internal lesions, crushing, severe cuts and laceration or 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 the victim had suffered from other forms of injury requiring conveyance from the accident scene to hospital by an ambulance or otherwise, the medical treatment requires medical leave of at least 3 days.

To develop 3 models for three respective studies (i.e., two-vehicle crash severity, single-vehicle crash severity and pedestrian crash severity) it is necessary to pre-select various factors consisting of victim, vehicle, crash, road, pedestrian and environmental characteristics that could be reasonably expected to influence accident severity. One way of sorting out these factors is to deliberate upon similar research works where those factors have been used. Also some factors selected are thought to have influence on accident severity in Singapore condition. Following this, 22 factors forming 83 independent variables are defined for further investigation in case of two-vehicle crashes. Several factors were dropped after correlation test between variables. For example, type of road and speed limit were found strongly correlated. The type of road was a better indicator in predicting injury severity than speed limit; therefore type of road was kept in the model. Some other factors were also excluded because they are found to be statistically insignificant. These include the day of week, gender of driver, surveillance camera, race of driver, central business district area, electronic road pricing hours if in central business district area, area of occurrence and make of vehicle. At last 49 variables from 13 factors are retained in the final model and these are shown in Table 1. It is noted that a majority of these variables are categorical dummy in nature shows the existence of effect.

Following the similar procedure in case of variable selection of two-vehicle crashes, 53 variables from 15 factors are retained in the final model of the single vehicle crashes (Table3) and 46 variables from 8 factors (Table5) are retained in pedestrian crashes model.

The results of the calibrated models are shown in Table1 and Table3 for two-vehicle crashes and single-vehicle crashes respectively, in which the independent variables are organized into 5 groups (I to V) under (I) general characteristics, (II) vehicle characteristics, (III) road characteristics, (IV) driver characteristics and (V) crash characteristics. Based on the p-values of the t-tests, 29 variables from 13 factors are found to be significant, i.e. those with $p<0.1$ in case of two-vehicle crashes. On the other hand, in the pedestrian crashes study, the independent variables are organized into 3 groups (I to III) of 8 factors (1 to 8) under (I) general characteristics, (II) pedestrian characteristics and (III) road characteristics where 24 variables are found to be significant, i.e. those with $p<0.1$(Table5). As suggested by Kockelman and Kweon (2002), variables with low statistical significance may also be retained in the model if they belong to factors those have some significant effects on injury severity.

Model Evaluation

To confirm suitability of the fitted models, the log likelihood ratio index, ρ^2 and the adjusted log likelihood ratio index, $\overline{\rho}^2$ are used though O' Donnel and Connor (1996) suggested that usual practice is to ignore such goodness-of-fit measure in models of ordered multiple choice since sometimes the value of the log likelihood ratio index is substantially less than one. ρ^2 and $\overline{\rho}^2$ of the three studies are reported in Table1, Table3 and Table5 respectively. Although these values seem low in our study, they are comparable with those in other severity studies where ordered probit model was employed (Kockelman and Kweon, 2002; Khattak, 2001; Ducan, Khattak and Council, 1998; Renski, Khattak and Council, 1999; Khattak et al., 2002; Quddus et al., 2002). Hence, the model result is justified to explain variations in injury severity.

Table 1. Parameter estimates of the model for two-vehicle crashes

Variables	Estimated Coefficient (β)	t-statistic	p-value	Estimated probability (Ratio relative to reference case)		
				Slight Injury	Serious Injury	Fatal
Reference case				0.9760	0.0184	0.0056
I.GENERAL						
1.Time trend (Relative to 1992)	-0.0204	-6.80	0.000	0.9838 (1.01)	0.0127 (0.69)	0.0035 (0.63)
Year after 1992						
2.Time of the day (Relative to day off peak period)						
Night Time	0.2031	9.91	0.000	0.9620 (0.99)	0.0282 (1.53)	0.0098 (1.75)
Peak Period	0.0431	2.16	0.031	0.9735 (1.00)	0.0202 (1.10)	0.0063 (1.13)
3. Hit & Run accident (Relative to non-hit and run case)						
Hit & run	0.1727	2.51	0.012	0.9644 (0.99)	0.0266 (1.45)	0.0090 (1.61)
II. VEHICLE CHARACTERISTICS						
4.Type of vehicle (Relative to car)						
Bicycle	0.4549	12.06	0.000	0.9361 (0.96)	0.0453 (2.46)	0.0186 (3.32)
Truck	0.4310	16.15	0.000	0.9390 (0.96)	0.0434 (2.36)	0.0176 (3.14)
Bus	0.3769	9.60	0.000	0.9453 (0.97)	0.0394 (2.14)	0.0153 (2.73)
Motorcycle	0.2016	9.41	0.000	0.9621 (0.99)	0.0281 (1.53)	0.0097 (1.73)
Van & pickup	0.1425	4.21	0.000	0.9667 (0.99)	0.0250 (1.36)	0.0083 (1.48)
Others	0.5158	7.48	0.000	0.9281 (0.95)	0.0504 (2.74)	0.0216 (3.86)
5.Country of registration (Relative to Singapore)						
Neighboring countries	0.1320	4.58	0.000	0.9675 (0.99)	0.0244 (1.33)	0.0081 (1.45)
III. ROAD CHARACTERISTICS						
6.Type of road (Relative to one way)						
Undivided Road	0.1408	4.21	0.000	0.9669 (0.99)	0.0249 (1.35)	0.0083 (1.48)
Divided Road	0.2733	8.72	0.000	0.9558 (0.98)	0.0324 (1.76)	0.0118 (2.11)
Limited Access Road (Expressway)	0.3166	8.15	0.000	0.9516 (0.98)	0.0352 (1.91)	0.0132 (2.36)
7.Type of location (Relative to straight)						
Bend	0.2631	6.04	0.000	0.9568 (0.98)	0.0318 (1.73)	0.0115 (2.05)
Slip road	0.0845	1.73	0.084	0.9708 (0.99)	0.0221 (1.20)	0.0071 (1.27)
Intersection	0.0076	0.39	0.698	0.9756 (1.00)	0.0187 (1.02)	0.0057 (1.02)
Bridge and flyover	0.0244	0.32	0.748	0.9746 (1.00)	0.0194 (1.05)	0.0060 (1.07)
Others	-0.1962	-3.46	0.001	0.9851	0.0117	0.0031

				(1.01)	(0.64)	(0.55)
8. Road surface (Relative to dry)						
Wet	-0.1113	-4.29	0.000	0.9816 (1.01)	0.0143 (0.78)	0.0040 (0.71)
Oily	0.1625	0.48	0.633	0.9652 (0.99)	0.0260 (1.41)	0.0088 (1.57)
Sandy	0.0811	0.70	0.485	0.9710 (0.99)	0.0220 (1.20)	0.0070 (1.25)
9.Special Road feature (Relative to Normal Roadway)						
Merging	-0.1381	-1.44	0.151	0.9828 (1.01)	0.0135 (0.73)	0.0037 (0.66)
Narrow	-0.2366	-2.04	0.041	0.9866 (1.01)	0.0107 (0.58)	0.0028 (0.50)
Sharp turn	0.0562	0.52	0.605	0.9727 (1.00)	0.0208 (1.13)	0.0065 (1.16)
Blind corner	-0.1091	-0.85	0.395	0.9815 (1.01)	0.0144 (0.78)	0.0041 (0.73)
IV.DRIVER CHARACTERISTICS						
10.Age of driver (Relative to Age between 25-44)						
< 25	0.0021	0.10	0.922	0.9759 (1.00)	0.0185 (1.01)	0.0056 (1.00)
45- 69	0.0496	2.58	0.010	0.9731 (1.00)	0.0205 (1.11)	0.0064 (1.14)
70 and above	0.3846	5.25	0.000	0.9444 (0.97)	0.0400 (2.17)	0.0156 (2.79)
11. Offending Party (Relative to non-offending)						
Offending driver	0.0777	4.34	0.000	0.9713 (1.00)	0.0218 (1.18)	0.0069 (1.23)
V. CRASH CHARACTERISTICS						
12. Type of collision (Relative to Head to Rear)						
Head On	0.5135	14.58	0.000	0.9284 (0.95)	0.0502 (2.73)	0.0214 (3.82)
Head to Side	0.1239	5.34	0.000	0.9681 (0.99)	0.0240 (1.30)	0.0079 (1.41)
Side Swipe	-0.0673	-2.34	0.019	0.9796 (1.00)	0.0159 (0.86)	0.0046 (0.82)
Others	0.1920	3.31	0.001	0.9629 (0.99)	0.0276 (1.50)	0.0095 (1.70)
13. Maneuver of vehicle before accident (Relative to Driving Ahead)						
Turning right	-0.0029	-0.12	0.903	0.9762 (1.00)	0.0183 (0.99)	0.0055 (0.98)
Stopping/Slowing	-0.0843	-2.25	0.025	0.9804 (1.00)	0.0153 (0.83)	0.0043 (0.77)
Turning left	-0.1629	-3.22	0.001	0.9838 (1.01)	0.0127 (0.69)	0.0035 (0.63)
Changing lane	- 0.0816	-1.74	0.082	0.9803 (1.00)	0.0153 (0.83)	0.0044 (0.79)
U-turn	-0.0687	-1.28	0.202	0.9796 (1.00)	0.0158 (0.86)	0.0046 (0.82)
Others	0.0177	0.43	0.668	0.9750 (1.00)	0.0192 (1.04)	0.0059 (1.05)
Number of observations	57428	ρ^2	0. 0322	Log likelihood	-17570.94	

τ_1	1. 957	$\overline{\rho}^2$	0. 0300	Restricted log likelihood	-18156.20	
τ_2	2. 517					

Table 2. Estimated probability of injury severity for combined factors for two-vehicle crashes model

Combined factors	**Estimated Probability (ratio= 1st row / 2nd row)**		
	Slight Injury	**Serious Injury**	**Fatal**
Motorcycle + Year 2000 Motorcycle + Year 1992	0.9737 0.9621 (1.01)	0.0200 0.0281 (0.71)	0.0062 0.0097 (0.64)
Truck + Year 2000 Truck + Year 1992	0.9563 0.9390 (1.02)	0.0321 0.0434 (0.74)	0.0116 0.0176 (0.66)
Bus+ Year2000 Bus+ Year1992	0.9611 0.9453 (1.02)	0.0288 0.0394 (0.73)	0.0101 0.0153 (0.66)
Night + Hit & Run Night + Not hit & run case	0.9454 0.9620 (0.98)	0.0393 0.0282 (1.39)	0.0153 0.0098 (1.56)
Motorcycle + Expressway Motorcycle + One-way	0.9278 0.9621 (0.96)	0.0506 0.0281 (1.80)	0.0217 0.0097 (2.24)
Motorcycle + Curve Motorcycle + Straight	0.9348 0.9621 (0.97)	0.0461 0.0281 (1.64)	0.0191 0.0097 (1.97)
Truck + Expressway Truck + One-way road	0.8906 0.9390 (0.95)	0.0727 0.0434 (1.68)	0.0367 0.0176 (2.09)
(Motorcycle+ Country of registration + Offending) (Motorcycle + Registered vehicle in Singapore + Offending)	0.9413 0.9553 (0.99)	0.0419 0.0328 (1.28)	0.0167 0.0119 (1.40)
Expressway + Curve Expressway + Straight	0.9189 0.9516 (0.97)	0.0560 0.0352 (1.59)	0.0251 0.0132 (1.90)
Expressway + Wet + Curved Expressway + Dry + Straight	0.9344 0.9516 (0.98)	0.0464 0.0352 (1.32)	0.0192 0.0132 (1.45)
Expressway + Narrow	0.9711	0.0219	0.0070

Expressway + Straight	0.9516 (1.02)	0.0352 (0.62)	0.0132 (0.53)
Lane changing + Expressway Lane changing +One-way road	0.9593 0.9803 (0.98)	0.0301 0.0153 (1.97)	0.0106 0.0044 (2.41)

Table 3. Parameter estimates of the model for single-vehicle crashes

Variables	Estimated Coefficient (β)	t-statistic	p-value	Estimated probability (Ratio relative to reference case)		
				Slight Injury	Serious Injury	Fatal
Reference case				0.9968	0.0025	0.0007
I.GENERAL						
1.Time trend (Relative to 1992)						
Year after 1992	-0.0296	-5.67	0.000	0.9985 (1.00)	0.0012 (0.48)	0.0003 (0.43)
2.Time of the day (Relative to day off peak period)						
Night Time	0.3351	8.39	0.000	0.9916 (0.99)	0.0064 (2.56)	0.0020 (2.86)
Peak Period	-0.0173	-0.38	0.701	0.9970 (1.00)	0.0024 (0.96)	0.0006 (0.86)
3. Central business district area (Relative to non-central business district area)						
Central business district area	0.1668	2.03	0.042	0.9948 (1.00)	0.0041 (1.64)	0.0012 (1.71)
4. **Day of week (Relative to weekdays)**						
Weekend	0.1377	4.32	0.000	0.9952 (1.00)	0.0037 (1.48)	0.0011 (1.57)
II. VEHICLE CHARACTERISTICS						
5.Type of vehicle (Relative to car)						
Truck	0.1859	2.55	0.011	0.9945 (1.00)	0.0043 (1.72)	0.0012 (1.71)
Bus	-0.0129	-0.12	0.902	0.9969 (1.00)	0.0024 (0.96)	0.0006 (0.86)
Motorcycle	0.3132	6.33	0.000	0.9921 (1.00)	0.0060 (2.40)	0.0019 (2.71)
Van & pickup	-0.0743	-0.89	0.373	0.9975 (1.00)	0.0020 (0.80)	0.0005 (0.71)
Others	0.1007	0.67	0.502	0.9957 (1.00)	0.0034 (1.36)	0.0009 (1.29)
6.Country of registration (Relative to Singapore)						
Neighboring countries	0.1665	3.46	0.001	0.9948 (1.00)	0.0041 (1.64)	0.0012 (1.71)
III. ROAD CHARACTERISTICS						
7.Type of road (Relative to one way)						
Undivided Road	0.0784	1.33	0.184	0.9960 (1.00)	0.0032 (1.28)	0.0009 (1.29)
Divided Road	0.1899	3.61	0.000	0.9944 (1.00)	0.0043 (1.72)	0.0013 (1.86)
Limited Access Road	0.2704	4.84	0.000	0.9930 (1.00)	0.0054 (2.16)	0.0016 (2.29)

(Expressway)						
8.Type of location (Relative to straight)						
Curve/Bend	0.2301	5.60	0.000	0.9937 (1.00)	0.0048 (1.92)	0.0014 (2.00)
Slip road	0.1319	2.13	0.033	0.9953 (1.00)	0.0037 (1.48)	0.0010 (1.43)
Intersection	-0.1089	-1.74	0.082	0.9977 (1.00)	0.0018 (0.72)	0.0004 (0.57)
Bridge and flyover	0.0950	1.05	0.292	0.9958 (1.00)	0.0033 (1.32)	0.0009 (1.29)
Others	0.0164	0.20	0.843	0.9966 (1.00)	0.0027 (1.08)	0.0007 (1.00)
9. Road surface (Relative to dry)						
Wet	-0.2829	-6.05	0.000	0.9987 (1.00)	0.0011 (0.44)	0.0002 (0.29)
Oily	-0.2889	-1.55	0.120	0.9987 (1.00)	0.0010 (0.40)	0.0002 (0.29)
Sandy	-0.1449	-1.10	0.273	0.9980 (1.00)	0.0016 (0.64)	0.0004 (0.57)
10.Special Road feature (Relative to Normal Roadway)						
Merging	-0.0953	-0.46	0.645	0.9976 (1.00)	0.0019 (0.76)	0.0005 (0.71)
Narrow	-0.4445	-2.14	0.032	0 0.9992 (1.00)	0.0006 (0.24)	0.0001 (0.14)
Sharp turn	-0.0849	-1.00	0.319	0.9975(1.00)	0.0020 (0.80)	0.0005 (0.71)
Blind corner	0.2462	1.79	0.073	0.9935 (1.00)	0.0050 (2.00)	0.0015 (2.14)
IV.DRIVER CHARACTERISTICS						
11.Age of driver (Relative to Age between 25-44)						
< 25	0.0645	1.85	0.065	0.9961 (1.00)	0.0030 (1.20)	0.0008 (1.14)
45- 69	0.1236	2.81	0.005	0.9954 (1.00)	0.0036 (1.44)	0.0010 (1.43)
70 and above	0.0236	0.10	0.921	0.9966 (1.00)	0.0027 (1.08)	0.0007 (1.00)
12. Gender (Relative to female)						
Male	0.3923	3.93	0.000	0.9902 (1.00)	0.0074 (2.96)	0.0024 (3.43)
13. Offending Party (Relative to non-offending)						
Offending driver	0.3101	4.94	0.000	0.9922 (1.00)	0.0060 (2.40)	0.0019 (2.71)
V. CRASH CHARACTERISTICS						
14. Crash type (Relative to collision with road objects after skidding)						
Parked vehicle	0.7515	7.58	0.000	0.9759 (0.98)	0.0171 (6.84)	0.0069 (9.86)
Lamppost	0.7084	9.44	0.000	0.9783 (0.98)	0.0156 (6.24)	0.0062 (8.86)
Guardrail	0.8031	13.51	0.000	0.9728 (0.98)	0.0191 (7.64)	0.0080 (11.43)
Traffic sign	0.4859	4.00	0.000	0.9875 (0.99)	0.0093 (3.72)	0.0032 (4.57)
Road divider/curb	0.3928	7.87	0.000	0.9902	0.0074	0.0024

				(0.99)	(2.96)	(3.43)
Trees	1.034	15.85	0.000	0.9548 (0.96)	0.0304 (12.16)	0.0147 (21.00)
Others	0.4888	7.16	0.000	0.9874 (0.99)	0.0094 (3.76)	0.0032 (4.57)
15. Maneuver of vehicle before accident (Relative to Driving Ahead)						
Turning right	-0.0556	-0.53	0.594	0.9973 (1.00)	0.0021 (0.84)	0.0005 (0.71)
Stopping/Slowing	0.1408	1.09	0.278	0.9952 (1.00)	0.0038 (1.52)	0.0011 (1.57)
Turning left	-0.3304	-3.21	0.001	0.9989 (1.00)	0.0009 (0.36)	0.0002 (0.29)
Changing lane	-0.3164	-1.23	0.217	0.9988 (1.00)	0.0010 (0.40)	0.0002 (0.29)
U-turn	-0.0288	-0.10	0.917	0.9971 (1.00)	0.0023 (0.92)	0.0006 (0.86)
Others	0.0747	0.92	0.360	0.9960 (1.00)	0.0031 (1.24)	0.0009 (1.29)
Number of observations	13691	ρ^2	0.095	Log likelihood	-4910.823	
τ_1	2.698	$\bar{\rho}^2$	0.087	Restricted log likelihood	-5428.948	
τ_2	3.182					

Table 4. Estimated probability of injury severity for combined factors for single-vehicle crashes model

Combined factors	Estimated Probability (Ratio = 1st row/ 2nd row)		
	Slight Injury	**Serious Injury**	**Fatal**
Night Truck Night+Car	0.9863 0.9916 (0.99)	0.0101 0.0064 (1.58)	0.0036 0.0020 (1.80)
Weekend+ Expressway Weekend+ One way street	0.9898 0.9952 (0.99)	0.0077 0.0037 (2.08)	0.0025 0.0011 (2.27)
Motorcycle+ Lamppost Motorcycle+ Traffic sign	0.9560 0.9731 (0.98)	0.0297 0.0190 (1.56)	0.0143 0.0079 (1.81)
Motorcycle +Expressway+ Curve Motorcycle+ Expressway+ Straight	0.9722 0.9840 (0.99)	0.0196 0.0117 (1.68)	0.0082 0.0043 (1.91)
Truck + Expressway Truck + One way Street	0.9884 0.9945	0.0086 0.0043	0.0029 0.0012

	(0.99)	(2.00)	(2.42)
Registered in Neighboring Countries+ Motorcycle Registered in Neighboring Countries +Car	0.9877 0.9948 (0.99)	0.0091 0.0041 (2.22)	0.0031 0.0012 (2.58)
Expressway + Curve Expressway + Straight	0.9870 0.9930 (0.99)	0.0096 0.0054 (1.78)	0.0034 0.0016 (2.13)
Expressway + Narrow Expressway + Normal Roadway	0.9981 0.9930 (1.01)	0.0015 0.0054 (0.28)	0.0004 0.0016 (0.25)
<25 age +Offending+ Motorcycle <25age +Offending+ Car	0.9793 0.9907 (0.99)	0.0149 0.0070 (2.13)	0.0058 0.0023 (2.52)
Traffic sign + Expressway Traffic sign+ One way street	0.9756 0.9875 (0.99)	0.0173 0.0093 (1.86)	0.0070 0.0032 (2.19)
Lamppost + Curve Lamppost+ Straight	0.9632 0.9783 (0.98)	0.0253 0.0156 (1.62)	0.0115 0.0062 (1.85)
Turning left+ Expressway Turning left+ One way street	0.9973 0.9989 (1.00)	0.0021 0.0009 (2.33)	0.0005 0.0002 (2.50)

Table 5. Parameter estimates of the model for pedestrian crashes

Variables	**Estimated Coefficient** (β)	**t-statistic**	**p-value**	**Estimated probability (Ratio relative to reference case)**		
				Slight Injury	**Serious Injury**	**Fatal**
Reference case				0.8882	0.0684	0.0435
I.GENERAL						
1.Time trend (Relative to 1992)						
Year after 1992	-0.0215	-3.61	0.000	0.9207 (1.04)	0.0509 (0.74)	0.0284 (0.65)
2.Time of the day (Relative to day time)						
Night Time	0.2298	6.69	0.000	0.8382 (0.94)	0.0926 (1.35)	0.0692 (1.59)
3. Area of occurrence (Relative to public housing estate)						
Nearby school	0.2127	2.28	0.023	0.8423 (0.95)	0.0907 (1.33)	0.0669 (1.54)
Private Residential Area	0.1270	2.02	0.044	0.8621 (0.97)	0.0814 (1.19)	0.0565 (1.30)
Factory	0.1634	1.73	0.083	0.8539 (0.96)	0.0853 (1.25)	0.0608 (1.40)

Shopping Complex	-0.1101	-1.53	0.127	0.9077 (1.02)	0.0580 (0.85)	0.0342 (0.79)
Shop House	-0.0475	-0.71	0.479	0.8969 (1.01)	0.0638 (0.93)	0.0393 (0.90)
Near MRT Station	-0.0816	-0.60	0.551	0.9029 (1.02)	0.0606 (0.89)	0.0365 (0.84)
Others	0.1206	2.94	0.003	0.8635 (0.97)	0.0807 (1.18)	0.0558 (1.28)
II. PEDESTRIAN CHARACTERISTICS						
4. **Gender (Relative to female)**						
Male	0.0675	2.00	0.045	0.8748 (0.98)	0.0752 (1.10)	0.0501 (1.15)
5. Age of pedestrian (Relative to age between 25-44)						
< 5	-0.0601	-0.42	0.675	0.8973(1 .01)	0.0636 (0.93)	0.0391 (0.90)
5-9	-0.3196	-4.05	0.000	0.9378 (1.06)	0.0411 (0.60)	0.0211 (0.49)
10- 14	-0.2117	-3.50	0.000	0.9234 (1.04)	0.0494 (0.72)	0.0272 (0.63)
15-24	-0.1941	-3.68	0.000	0.9209 (1.04)	0.0508 (0.74)	0.0283 (0.65)
45-64	0.1702	3.54	0.000	0.8524 (0.96)	0.0860 (1.26)	0.0616 (1.42)
65-74	0.4728	7.91	0.000	0.7716 (0.87)	0.1207 (1.76)	0.1077 (2.48)
>74	0.7675	12.58	0.000	0.6734 (0.76)	0.1541 (2.25)	0.1725 (3.97)
6. Pedestrian activities (Relative to crossing the road under signalized crossing with traffic light in his favor)						
Walking on the footpath	0.0244	0.25	0.799	0.8834 (0.99)	0.0708 (1.04)	0.0458 (1.05)
Walking along the road (with traffic)	0.0084	0.08	0.937	0.8866 (1.00)	0.0692 (1.01)	0.0443 (1.02)
Walking along the road (against traffic)	0.0072	0.07	0.948	0.8868 (1.00)	0.0691 (1.01)	0.0442 (1.02)
Standing on the road	-0.1602	-1.26	0.206	0.9157 (1.03)	0.0536 (0.78)	0.0306 (0.70)
Crossing the road (Non-signalized crossing)	0.0282	0.30	0.766	0.8827 (0.99)	0.0712 (1.04)	0.0461 (1.06)
Crossing the road (Signalized crossing with traffic light not in his favor)	0.0119	0.16	0.877	0.8859 (1.00)	0.0695 (1.02)	0.0446 (1.03)
Crossing the road (unlawfully)	0.1807	2.49	0.013	0.8499 (0.96)	0.0872 (1.27)	0.0629 (1.45)
Crossing the road (without pedestrian crossing)	0.1516	2.31	0.021	0.8566 (0.96)	0.0840 (1.23)	0.0594 (1.37)
Crossing the road (wait on the central road divider)	0.0204	0.09	0.925	0.8842 (1.00)	0.0704 (1.03)	0.0454 (1.04)
Crossing the road	-0.0775	-0.74	0.458	0.9022	0.0610	0.0368

(In front/behind stationary vehicle)				(1.02)	(0.89)	(0.85)
Working on the road	-0.0139	-0.09	0.931	0.8908 (1.00)	0.0670 (0.98)	0.0422 (0.97)
Others	0.2466	2.67	0.008	0.8340 (0.94)	0.0945 (1.38)	0.0715 (1.64)
III. ROAD CHARACTERISTICS						
7.Type of road (Relative to divided road)						
One way Street	-0.2053	-4.15	0.000	0.9225 (1.04)	0.049 9(0.73)	0.0276 (0.63)
Undivided Road	-0.1915	-4.91	0.000	0.9205 (1.04)	0.0510 (0.75)	0.0285 (0.66)
Limited Access Road (Expressway)	0.7431	7.87	0.000	0.6821 (0.77)	0.1515 (2.21)	0.1664 (3.83)
8.Type of location (Relative to straight)						
Curve	0.1894	2.46	0.014	0.8479 (0.95)	0.0881 (1.29)	0.0640 (1.47)
Slip road	-0.3175	-2.14	0.032	0.9375 (1.06)	0.0413 (0.60)	0.0212 (0.49)
Intersection	0.0897	1.91	0.056	0.8702 (0.98)	0.0774 (1.13)	0.0524 (1.20)
Road shoulder	0.5015	2.05	0.040	0.7628 (0.86)	0.1241 (1.81)	0.1131 (2.60)
Car Park	-0.3421	-3.34	0.001	0.9405 (1.06)	0.0395 (0.58)	0.0200 (0.46)
Others	0.0911	0.77	0.440	0.8699 (0.98)	0.0776 (1.13)	0.0526 (1.21)
Number of observations	9327	ρ^2	0. 072	Log likelihood	-4543.57	
τ_1	1. 195	$\overline{\rho}^2$	0.064	Restricted log likelihood	-4895.25	
τ_2	1.690					

Table 6. Estimated probability of injury severity for combined factors for pedestrian crashes model

Combined factors	**Estimated Probability (Ratio = 1st row/ 2nd row)**		
	Slight Injury	**Serious Injury**	**Fatal**
Night time + Curve Night time + Straight	0.7874 0.8382 (0.94)	0.1145 0.0926 (1.24)	0.0981 0.0692 (1.42)
Night time+ Divided road Night time+ One way street	0.8382 0.8834 (0.95)	0.0926 0.0708 (1.31)	0.0692 0.0458 (1.51)
(Near school + Crossing the road	0.7948	0.1114	0.0937

unlawfully) (Near school + Crossing the road at signalized crossing with traffic light in favor)	0.8423 (0.94)	0.0907 (1.23)	0.0669 (1.40)
(Private Residential Area+ Crossing the road unlawfully) (Private Residential Area+ Crossing the road at signalized crossing with traffic light in favor)	0.8183 0.8621 (0.95)	0.1015 0.0814 (1.25)	0.0802 0.0565 (1.42)
Male + Night time Male + Day time	0.8211 0.8748 (0.94)	0.1003 0.0752 (1.33)	0.0786 0.0501 (1.57)
(Male+ Crossing the road unlawfully) (Male+ Crossing the road at signalized crossing with traffic light in his favor)	0.8336 0.8748 (0.95)	0.0947 0.0752 (1.26)	0.0717 0.0501 (1.43)
Age group 65-74 + Night time Age group65-74 + Day time	0.6964 0.7716 (0.90)	0.1471 0.1207 (1.22)	0.1565 0.1077 (1.45)
Age group 15-24 + Expressway Age group15-24 + One way street	0.7479 0.9470 (0.79)	0.1297 0.0356 (3.64)	0.1225 0.0174 (7.04)
(Age group 10-14 + Unlawfully) (Age group 10-14 + Crossing the road at signalized crossing with traffic light in favor)	0.8939 0.9234 (0.97)	0.0654 0.0494 (1.32)	0.0407 0.0272 (1.50)
Crossing the road unlawfully + Curve Crossing the road unlawfully+ Straight	0.8014 0.8499 (0.94)	0.1087 0.0872 (1.25)	0.0899 0.0629 (1.43)
Curve + Expressway Curve + One way	0.6119 0.8479 (0.72)	0.1702 0.0881 (1.93)	0.2179 0.0640 (3.40)
Road shoulder + Night time Road shoulder + Day time	0.6863 0.7628 (0.90)	0.1502 0.1241 (1.21)	0.1635 0.1131 (1.45)

Interpretation of Significant Variables in the Model

To better show how the variations in the independent variables would change the different injury probabilities, three reference cases have been defined to form three benchmarks for comparison which describe typical accident victim or pedestrian victim. These can be done by setting the variables in their most common default value for example, all dummy variables are set to 0 and time trend set to any year (in our study it is 1992). Hence, for example, the reference case in two-vehicle crashes describe an accident victim involved in a head to rear car-car not hit and run collision on normal one way dry straight road while was in a Singapore registered vehicle which was moving ahead at day off peak period in 1992 and the non-offending driver of the vehicle had the age in between 25-44. The positive value of the estimated coefficient (β) means to increase the severity whereas the negative value indicates vise versa. The main focus of this discussion is on the t statistics, which reflects the statistical significance of the independent variables. From the calibrated model, the effect of the identified factors on accident severity is studied by examining the injury odd ratios against the reference case. Similarly, the combined effect of several factors on injury severity is also investigated by comparing the relative risk probabilities (Table 2, Table 4 and Table 6). A detailed discussion on the effects of the significant factors on accident severity is given in the following. These significant factors are mainly identified based on the p-value of t statistics, which reflect the statistical significance of the independent variables. This is followed by suggestions for precautionary measures to be taken to enhance safety as well as suggestions for future research.

Time trend factor (see Table1, Table3, Table 5) in all three case studies shows that beneficial effects from some unmeasured factors lead to a downward trend of crash severity (β= -0.0204, -0.0296 and -0.0215 respectively). Among the considered time related factors time of day has the greatest impact on the severity of all three types of crashes, particularly the nighttime crashes are the severest (see Table1, Table3, Table 5). At night, possibly because of lower density of vehicles the driver has a tendency to speed. Low visibility and late night drowsiness may delay driver's reaction at the impending collision with another vehicle or with roadside objects or with pedestrians. Therefore the collision impact is high due to high vehicle speed, which subsequently causes severe injury to a victim. In case of two-vehicle night time crashes the severity of the crash even more deteriorates because of delayed crash notification and medical support if the offending driver runs away without attending the victim (see Table 2). In order to reduce night time crash severity, drivers should be alert and not be tempted to increase speed to such an extent that makes it difficult to control the vehicle.

Vehicle type and the country of registration have been found to affect accident severity both in two-vehicle and single-vehicle crashes (see Table1 and Table3). The severity of crashes increases significantly when the two-wheelers especially the motorcycle and the heavy vehicle, specially the truck are involved. In case of two-vehicle crashes, the motorcycle is vulnerable by itself while in case of the truck it is associated with making more severe injury to its collision partner. The vulnerability of the motorcycle increases on the expressway where the fast moving traffic exists or along curve where the manipulation of the vehicle is difficult. The higher fatality risk related to heavy vehicle is due to its greater vehicle mass which translates into longer braking distance during collision instances with another vehicle or any roadside object. This results in larger impact force. This impact force is also higher on high-speed road, i.e., expressways. Interestingly both in two-vehicle and single-vehicle crashes it has been found that vehicles from the neighboring countries are involved in severer crashes than the Singaporean counterpart particularly when motorcycle is involved (Table 2 and Table 4). Thus to reduce the severity of motorcycle and truck involved crashes, if possible, one way is to provide separate lanes for motorcycles and heavy vehicles specially on expressways to avoid intermingling with different types of vehicles. Perhaps separate lanes for motorcycles and heavy vehicles on expressways not only reduce the crash severity but also reduce the occurrence of crashes.

There is also evidence that road type and location type have strong influence on severity of all three types of crashes (Table 1, Table3 and Table5). Particularly crashes on expressways and crashes along curve make the severity condition worse. This study results support the fact that though the expressways are better-designed road, this advantage is compensated by the presence of high speed during collision. The resultant collision force is even higher along curve when the restricted sight distance limits the ability of the driver to react promptly at the collision instances. Thus it is expected that the road designers will try to reduce the presence of curves as much as possible to enhance sight distance while designing roads.

On the other hand, only the wet road surface condition and the narrow road way from the special road features have been found to reduce significantly the severity of both two-vehicle and single-vehicle crashes (Table 1 and Table3). However, the reduction of severity risk on wet road surface is not always true in all situations, certain situations particularly during turning at the curve increase the risk of injury (Table 2).

Among the factors associated with driver's characteristics, the age of the driver has strong influence on accident severity both in two and single vehicle crashes (seeTable 1and Table3). Older drivers involved in both type of crashes significantly increase the severity while in case of younger drivers they only increase the severity of single-vehicle crashes particularly the motorcycle involved crashes (Table4). These age related findings provide an insight that with increase in age the visual and physical ability of drivers deteriorate which often involved older drivers in severe injury crashes; on the other hand, risk taking behavior as well as inexperience, immaturity and lack of proper judgment may be the reason in case of younger drivers. The risk taking behavior of males also promotes aggressive driving; often resulting in severe injury to victim in single-vehicle crashes. Hence, public information programs should be developed to encourage all drivers to follow traffic legislation properly, to avoid traveling at high speed and to drive soberly.

Among the factors considered in crash characteristics, the type of collisions is found to have severe impact on both two-vehicle and single-vehicle crashes (see Table1 and Table3). Table 1 shows that head-on collisions ($p<0.001$) inflict greater injury to victim in two-vehicle crashes while in case of single vehicle crashes Table3 shows that direct collisions with road side objects such as trees ($p<0.001$), guard rail ($p<0.001$), lamppost ($p<0.001$), traffic sign ($p<0.001$), parked vehicle ($p<0.001$) result in severer injury. However, injury risks for collisions with these fixed objects also vary because of their different rigidity and the collision with trees shows the greatest fatality risk. Moreover, the same roadside object placed on different roads as well as different locations affect the severity of crashes (see Table 4).

Hence to minimize the crash related damages innovative design and proper placement of those roadside objects are necessary. The first priority is trying to provide a crash recovery area and if not possible then to relocate those roadside objects on a relative safer place, for example, specially the utility poles or the traffic signs can be eliminated from outer side of the curve and placed inside. In addition, the design should be such that utility poles or the traffic sign should be flexible enough to be broken down during the collision. In situations where trees cannot be cut down due to environmental and aesthetic reason, guardrails can be installed to protect the errant vehicle. While placing the guardrail it should be borne in mind that this safety appurtenance is a hazard in itself and its use should be limited to situations in which the severity of impacting the guardrail are less than the consequences of striking the guarded object.

From the pedestrian characteristics it is found that pedestrian age significantly affects the injury severity by showing higher injury risk for older pedestrians and lower injury risk for younger pedestrians (see table 5). This result supports the fact that older pedestrian are more susceptible to injury than younger ones. In addition older pedestrian are more vulnerable at nighttime crashes (Table 6). Though the younger pedestrians are less affected in crashes; their risk taking behavior such as unlawful road crossing often cause severe injury crashes (see Table 6). Hence it is needed to provide better pedestrian walking and crossing facilities that will discourage unlawful crossing or walking along the road.

Conclusion

In summary, the present research work has identified the factors affecting the severity of road crashes in Singapore using ordered probit model. This work suggests that several factors such as vehicle type, road type, collision type, location type, pedestrian age, time of day of accident occurrence play major roles in affecting the severity of crashes. The identification of these factors has been only possible due to the improvement of application of information and communication technology. This improvement makes it easier to utilize a large number of reported accident data to achieve the objective of this study. Finally the findings of this study give a basis for developing effective countermeasures to improve road safety. This study has focused on a broader overview by considering all types of vehicles involved in two-vehicle and single-vehicle crashes. Only the motorcycle or truck or car involved crashes in case of single-vehicle collisions and truck-car, car-motorcycle crashes in case of two-vehicle collisions can be considered in different studies in future for developing crash-specific countermeasures. In case of pedestrian crashes, age wise analysis can be done in future studies, for example, study on crash severity of older pedestrians or younger pedestrians.

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