Severity of Two-Vehicle Crashes in Singapore

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Introduction

Two-vehicle crashes form about 55% of the reported collisions in Singapore and account for about 44% of traffic-related serious injuries and fatalities. The number of two vehicle collisions has also increased in the last decade, rising from 3149 in 1992 to 3978 in 2000. Over the last decade, a variety of countermeasures to reduce traffic collisions have been introduced in Singapore. However, there has been little work done to understand the causes of collisions or the effects of many of the countermeasures, especially the issues related to two-vehicle collisions.

In contrast, there have been many studies in North America and Europe dealing with two-vehicle collisions. In a series of studies, Evans and his associates (1985, 1987, 1992, 1993, and 1994) have investigated the relationship between vehicle masses and the degree of injuries sustained by vehicle occupants in two-vehicle collisions. Evans reported that in a two-vehicle crash, passengers in the heavier vehicle are safer than those in the lighter vehicle. Farmer et al (1997) and Haland et al (1993) extended these works by considering side-impact crashes between two vehicles, Ducan et al (1998) included truck-car collisions, and Khattak (2001) and Ouyang et al (2002) explored multi-vehicle collisions. Also, other researchers like Jones and Whitfield (1988) and Khattak et al. (2002) have examined the effect of driver age on collision severity in two-vehicle collisions.

While these previous studies provided some insights into the problems associated with two-vehicle crashes in the western countries, they might not fully explain the issues encountered locally in Singapore. Singapore has a very different social and political environment, completely urbanized with no rural or suburban areas, and draconian travel demand management and vehicle control policies. Therefore, this study aims to understand the factors contributing to the severity of two-vehicle crashes in Singapore using a broad range of road user characteristics, roadway features, vehicle types and environmental factors and compare them with those obtained in previous studies.

Methodology

Since many of the variables in collision data are categorical in nature, a number of road safety researchers have relied on logistic regression to model collision occurrence, (Jones & Whitfield, 1988; Lui et al., 1988; Shibita & Fukuda, 1994) while others have made used of multinomial logit models (Shankar & Mannering, 1996) or nested logit models (Chang & Mannering, 1998). Recognizing that crash severity is usually recorded in an ordinal nature, some researchers have instead used the ordered probit or ordered logit models (O'Donnell & Connor, 1996; Duncan et al., 1998; Long, 1997; Khattack, 2001; Kockelman & Kweon, 2002; Quddus et al., 2002; Tay & Rifaat, 2007). O'Donnell & Connor (1996) and Renski et al. (1999) have indicated in their studies that the results from the ordered probit and logit models are similar and that either model can be used.

In this study, the widely used ordered probit model is chosen for simplicity. To calibrate the collision severity model, data based on reported collisions from 1992 to 2000 were used in this study. During this period, there were 52,524 collisions, of which 29,389 were two-vehicle crashes. From the 9 years of data, 2.6% of the cases were classified as fatal, 5.2% were serious injury and 92.2% as minor crashes.

Therefore, the dependent variable used in the model may take on one of three values based on the recorded degree of injury involved: fatal, seriously or minor crash. The collision 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.

In each collision report, there are 65 entries of information on general characteristics and crash-specific characteristics as well as roadway conditions, vehicle and driver characteristics. From these, 22 entries are relevant for the analysis and a total of 74 variables were defined. After some preliminary analyses of the data, 49 independent variables were considered for the model. For all categorical variables, a reference case has to be chosen and the effect of the identified factors on collision severity is studied by examining the injury odds ratios against the reference case.

Discussion of Results

The results of the model calibration are shown in Table 1, in which the independent variables are organized into 5 groups (I to V) of 13 attributes (1 to 13). Based on the p-values of the t-tests, 29 variables were found to be significant. As suggested by Kockelman and Kweon (2002), variables with low statistical significance may also be retained in the model if they belong to attributes that have some significant effects on injury severity. This approach is chosen to facilitate interpretation even though it may reduce the efficiency of the estimates. A more liberal p-value (0.10) may be then used when interpreting the results instead of the traditional value of 0.05.

Table 1: Estimation Results

Variables	**Estimated Coefficient**	**p-value**	**Odds Ratio**		
			Minor	**Serious**	**Fatal**
I. GENERAL					
1. Time trend (Relative to 1992)					
Year after 1992	-0.0204	0.000	1.01	0.69	0.63
2. Time of the day (Relative to daytime off peak period)					
Night Time	0.2031	0.000	0.99	1.53	1.75
Peak Period	0.0431	0.031	1.00	1.10	1.13
3. Hit & Run collision (Relative to non-hit-and-run case)					

Hit & run	0.1727	0.012	0.99	1.45	1.61
II. VEHICLE CHARACTERISTICS					
4. Type of vehicle (Relative to car)					
Bicycle	0.4549	0.000	0.96	2.46	3.32
Truck	0.4310	0.000	0.96	2.36	3.14
Bus	0.3769	0.000	0.97	2.14	2.73
Motorcycle	0.2016	0.000	0.99	1.53	1.73
Van & pickup	0.1425	0.000	0.99	1.36	1.48
Others	0.5158	0.000	0.95	2.74	3.86
5. Country of registration (Relative to Singapore)					
Neighboring countries	0.1320	0.000	0.99	1.33	1.45
III. ROAD CHARACTERISTICS					
6. Type of road (Relative to one way)					
Undivided Road	0.1408	0.000	0.99	1.35	1.48
Divided Road	0.2733	0.000	0.98	1.76	2.11
Expressway	0.3166	0.000	0.98	1.91	2.36
7. Type of location (Relative to straight road)					
Bend	0.2631	0.000	0.98	1.73	2.05
Slip road	0.0845	0.084	0.99	1.20	1.27
Intersection	0.0076	0.698	1.00	1.02	1.02
Bridge and flyover	0.0244	0.748	1.00	1.05	1.07
Others	-0.1962	0.001	1.01	0.64	0.55
8. Road surface (Relative to dry)					
Wet	-0.1113	0.000	1.01	0.78	0.71
Oily	0.1625	0.633	0.99	1.41	1.57
Sandy	0.0811	0.485	0.99	1.20	1.25
9. Special Road feature (Relative to Normal Roadway)					
Merging	-0.1381	0.151	1.01	0.73	0.66
Narrow	-0.2366	0.041	1.01	0.58	0.50
Sharp turn	0.0562	0.605	1.00	1.13	1.16
Blind corner	-0.1091	0.395	1.01	0.78	0.73
IV. ROAD USER CHARACTERISTICS					
10. Age of driver (Relative to Age between 25-44)					
< 25	0.0021	0.922	1.00	1.01	1.00
45- 69	0.0496	0.010	1.00	1.11	1.14
70 and above	0.3846	0.000	0.97	2.17	2.79
11. Offending Party (Relative to non-offending)					
Offending driver	0.0777	0.000	1.00	1.18	1.23
V. CRASH CHARACTERISTICS					
12. Type of collision (Relative to Head to Rear)					
Head On	0.5135	0.000	0.95	2.73	3.82
Head to Side	0.1239	0.000	0.99	1.30	1.41
Side Swipe	-0.0673	0.019	1.00	0.86	0.82
Other	0.1920	0.001	0.99	1.50	1.70
13. Maneuver of vehicle before accident(Relative to Driving Ahead)					

Turning right	-0.0029	0.903	1.00	0.99	0.98
Stopping/Slowing	-0.0843	0.025	1.00	0.83	0.77
Turning left	-0.1629	0.001	1.01	0.69	0.63
Changing lane	- 0.0816	0.082	1.00	0.83	0.79
U-turn	-0.0687	0.202	1.00	0.86	0.82
Others	0.0177	0.668	1.00	1.04	1.05
Number of observations	57428				
log likelihood	-17570.94				
restricted log likelihood	-18156.20				
τ_2	2. 517				
τ_1	1. 957				

General Characteristics

The time trend of injury severity can be examined using the year of collision occurrence. The negative coefficient (-0.0204, p<0.001) indicated that collision severity was declining with time. As shown in Table 1, the relative fatality risk (ratio of fatality risk in the control situation to fatality risk in the reference case) was 0.63, indicating that the chances of a fatal collision was reduced by 37% over the 9 year period. This reduction had been similarly observed in a number of countries and is usually attributed to improved safety in vehicles as well as better designs in road engineering (Tay, 2005a,b,c,d, 2006; Evans, 1999; Tay & Rifaat, 2007, Rifaat & Tay 2007; Rifaat & Chin, 2007).

The time of collision was analyzed in 3 periods: peak (7:00 to 10:00 am and 4:30 to 8:00 pm), off-peak (10:00 am to 4:30 pm) and night-time (8:00 pm to 7:00 am). Compared with the off-peak period, the risk of severe injury and fatality was higher during the peak (p=0.031) and at night (p<0.001). The relative fatality risk was 1.125 during the peak and 1.75 at night. These results are expected because severity is highly correlated with speed. Due to the road pricing scheme in Singapore, the traffic speed during peak period is higher than during off-peak periods (McCarthy & Tay, 1993). At night, possibly because of a lower traffic density, motorists tend to travel at higher speeds. Consequently, the risk of injury is higher, especially in areas with inadequate lighting conditions resulting in poorer visibility and possibly delayed driver reaction. In some instances, driver drowsiness and drink driving may also severely impair the ability of drivers to respond quickly and effectively in a critical situation.

A higher severity risk was also associated with hit-and-run collisions (p=0.01) and the fatality risk was 61% higher in hit-and-run collisions. It is possible that when help is not rendered by the offending driver, the collision victim may suffer a higher injury due to delayed notification and treatment. On the other hand, it is also possible that, offending drivers may ignore the collision victim out of panic and fear, especially if they judge that a rather serious injury has been sustained.

Vehicle Characteristics

The results from Table 1 showed that the fatality risk of motorcycle-related collisions was 1.73 times that of a two-car collision (p<0.001). On the other hand, the relative fatality risk of a bicycle-related collision with respect to a two-car collision was 3.32 (p<0.001). Clearly users of two-wheelers are more vulnerable compared to occupants of cars for many reasons. Unlike cars, motorcycles and bicycles are not equipped with any protective features. The difference in body sizes and masses also make the two-wheelers subject to greater impact forces in any collision. Even in minor collisions, riders on two-wheelers may easily lose their balance causing further injuries from the fall. Furthermore, motorcycles and bicycles are less conspicuous in the traffic stream and drivers may not see them as early as vehicles, which may reduce the deceleration time in any impending collision.

Compared to a collision involving only cars, the relative fatality risk of a truck-related collision was 3.14 (p<0.001) and that of a bus-related collision was 2.73 (p<0.001). These results are consistent with similar studies which showed that heavy vehicles involved a collision increase the likelihood of severe injury for the collision partner (Valent et al, 2002; Chang & Mannering, 1998; Kockelman & Kweon, 2002 and Ouyang et al, 2002). The higher fatality risk is due to greater vehicle masses that translate to longer braking distances in an emergency and larger impact forces in a collision. This inference is further supported by the finding that the relative fatality risk of medium size vehicles (such as vans and light goods vehicles) was only 1.48 times (p<0.001) that of cars.

Our study also found that the severity of collisions was significantly related to country of registration of the vehicles. The fatality risk of vehicles from the neighboring countries was 1.45 times that of local vehicles ($p<0.001$). The difference in risk may be due to the different national standards of maintenance and inspection imposed on vehicles. As drivers of foreign vehicles also hold foreign licenses, the severity risk may also be affected by the different driver training and licensing standards as well as other cultural factors influencing risk taking and driver behavior.

Road Characteristics

Four road types are considered: one-way streets, undivided roads, divided roads and limited-access roads (i.e., expressways); with the one-way streets chosen as the reference case. The severity of collisions was found to be significantly higher on all other road types in relation to one-way roads. For example, serious injury and fatality risks on undivided roads were respectively 35% and 48% higher than on one-way streets ($p<0.001$). One possible reason for this finding is the higher potential of head-on collisions on undivided roads. On the other hand, the relative fatality risk is 2.11 for divided roads ($p<0.001$) and 2.36 for expressways ($p<0.001$). These road categories are usually designed for higher speed movements, suggesting that the increased injury severity may be due the higher speeds allowed.

Several location types were investigated: straight roadway, bend, slip road and intersection. Using straight roadway as the reference, the relative fatality risk on bends was 2.05 ($p<0.001$). There are several possible reasons including a higher driver workload, greater demand on vehicle control, and possible sight-distance restrictions limiting the ability of drivers to react promptly in an impending collision. Moreover, vehicles losing control on curved sections may also be involved in secondary collisions with roadside objects.

It is interesting to note that the severity of collisions on slip roads is significantly higher than that on straight roads ($p=0.084$). If a crash occurs on slip roads instead of straight roads, the fatality risk increased by about 27%. Collisions on slip roads tend to be more serious because there is usually a speed differential between merging or diverging vehicles and the straight-moving vehicles. Collisions may also be more serious because of reduced sight distances, physical restrictions on vehicle movements.

For the purpose of examining the effect of road surface on severity of accidents, four surface conditions are considered: dry, wet, sandy and oily. The results show that severity was significantly lower on wet surfaces with the relative fatality risk of 0.71 compared to the dry surface ($p<0.001$). This finding is consistent with those of Duncan et al. (1998) who suggested drivers are more cautious on wet days, consciously reducing their speed and maintaining a longer headway to compensate for the increased risk of skidding and losing control of their vehicles on wet surfaces. Since Singapore is a tropical island, the downpour is often very heavy and it is natural for drivers to reduce their speed due to reduced visibility.

Among the road features examined, narrow roadway was found to significantly affect severity ($p=0.041$). Compared to the normal roadway, a narrow roadway has a lower relative fatality risk of 0.50. Provided that there is good visibility, roadway constriction often causes vehicles to slow down thereby lowering the risk of serious injury as well as fatality. Such a condition is also observed on expressways where the narrowing of roadway is likely to be well signed and anticipated by drivers.

Road User characteristics

In the collision data, road users involved in collisions were divided into four age groups: <25, 25 to 44, 45 to 69, and over 69 years old. Taking the economically active group (i.e., 25 to 44 years old) as the reference case, severity was found to be higher for the two older age groups (45 to 69 and > 69). The higher severity risk is particularly significant among those aged 70 and above with a relative fatality risk of 2.79 ($p<0.001$). This is not surprising since the mental, visual and physical ability of a person will deteriorate with age and especially in the later years as indicated by Zhang et al. (2000). More importantly, the increased fragility implies that they are more likely to sustain serious or fatal injuries in a crash (Li et al, 2003; Tay, 2006)

Crash Characteristics

Among the collision types, the most common one is the rear end collision and this is taken as the reference case. Our analysis found that at a relative fatality risk of 3.82 ($p<0.001$), head-on collisions were more likely to result in severe injuries than rear end collisions. This finding is consistent with those of O'Donnel & Connor (1996) and Zhang et al. (2000). Head-on collisions will result in more severe injuries because of the greater dissipation of kinetic energy compared to rear end collisions due to the greater differential in speed.

Furthermore, side-impact collisions also produced more serious injuries than rear end collisions ($p<0.001$). For example, the fatality risk for side-impact collisions was 1.41. The impact force of a side-impact collision is generally greater than in a rear end collision. In addition, vehicles have less collapsible space on the side. Moreover, vehicle occupants in a lateral crash are less protected compared those in a longitudinal crash, who may be cushioned by seat belts and air bags. Sideswipe collisions, however, had a significantly lower fatality risk (0.82, $p=0.019$) compared with rear end collision. This may be because lower impact forces are involved in sideswipe collisions.

The influence of maneuver type before collision on crash severity was examined under several categories: straight-ahead, right-turn, left-turn, stopping/slowing, lane-changing, U-turn and other maneuvers. Using the straight-ahead maneuver as the reference case, the results indicated that three other maneuvers were significant in influencing severity: left-turn maneuver ($p=0.001$), lane-changing maneuver ($p=0.082$) and stopping/slowing maneuver ($p=0.025$). All these cases experienced lower fatality risks of 0.63, 0.79 and 0.77 respectively. Generally, these maneuvers are undertaken at lower speeds, which may account for the less severe injuries sustained.

Concluding Remarks

In this study, the ordered-probit model is applied to a large and highly disaggregated set of traffic collision data to identify the risk factors that may affect the injury severity levels of two-vehicle crashes. An important finding is that there is a general reduction in the severity of two-vehicle crashes from 1992 to 2001. This reduction gives assurance that various measures such as improvements in vehicle safety, better road designs, developments of telecommunication systems and increasing application of information technology in transportation systems have brought about better traffic safety standards.

The study recognizes that there is a multiplicity of factors that affect crash severity. However, examining these factors together, it is clear that there are some common features that are worth noting. The severity of crashes is determined mainly by the speed and masses of the units involved, the protection of the users, and the characteristics of the users involved. As expected, according to simple physics, collisions involving larger units (e.g., trucks and buses) and units with large mass differentials (e.g, vehicles versus motorcycles, bicycles and pedestrians) are associated with higher severity.

More importantly, the higher the speed involved in the crash and the larger speed differential, the higher the severity level tends to be. For example, the speed differentials between colliding vehicles in head-on and side-impact collisions are usually higher, thereby inflicting more severe injuries to the occupants. Naturally to reduce injury severity, measures which promote reduction and harmonization of speeds can be effective. These may include the provision of separate lanes for slower vehicles or the imposition of speed control, for example with minimum and maximum speed limits. These measures have to be considered in greater extend in Singapore.

Another common feature that is associated with high severity is conditions that may result in delayed driver or rider reaction, which will result in higher impact speed. For example, more severe injuries are sustained during night crashes and along curves. Drivers or riders in these conditions may have responded too late due to reduced visibility. This problem is also seen among the elderly drivers who are physically less able to perceive well and react swiftly to any critical situation, compared to the younger drivers. It would then be prudent to examine countermeasures that will enhance road visibility and readability, such as the use of more conspicuous and reflective signs, as well as provision for more forgiving roadways for errant drivers and riders.

The protection of road users is another important factor. Compared to motor vehicle drivers, motor riders, cyclists and pedestrians are less protected and thus are likely to sustain severe injuries in a crash. It is therefore important to separate them from the main traffic stream, reduce the speed in environments where there are more of these vulnerable road users, and to increase their conspicuity.

The study also shows that human factors play an important role in influencing crash severity. More serious injuries are sustained in crashes involving young drivers and riders as well as elderly drivers and riders. The former group is likely to have risk-taking tendencies while the latter are less able to judge and react well in critical situations. Crashes are also more severe when they involve foreign drivers and riders who have different road-user behavior and may not appreciate the local road and traffic environments. In dealing with these problems, targeted campaigns to educate specific road user types may be more effective.

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