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Modeling fault among motorcyclists involved in crashes

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ABSTRACT

Singapore crash statistics from 2001 to 2006 show that the motorcyclist fatality and injury rates per registered vehicle are higher than those of other motor vehicles by 13 and 7 times, respectively. The crash involvement rate of motorcyclists as victims of other road users is also about 43%. The objective of this study is to identify the factors that contribute to the fault of motorcyclists involved in crashes. This is done by using the binary logit model to differentiate between at-fault and not-at-fault cases and the analysis is further categorized by the location of the crashes, i.e., at intersections, on expressways and at non-intersections. A number of explanatory variables representing roadway characteristics, environmental factors, motorcycle descriptions, and rider demographics have been evaluated. Time trend effect shows that not-at-fault crash involvement of motorcyclists has increased with time. The likelihood of night time crashes has also increased for not-at-fault crashes at intersections and expressways. The presence of surveillance cameras is effective in reducing not-at-fault crashes at intersections. Wet-road surfaces increase at-fault crash involvement at non-intersections. At intersections, not-at-fault crash involvement is more likely on single-lane roads or on median lane of multi-lane roads, while on expressways at-fault crash involvement is more likely on the median lane. Roads with higher speed limit have higher at-fault crash involvement and this is also true on expressways. Motorcycles with pillion passengers or with higher engine capacity have higher likelihood of being at-fault in crashes on expressways. Motorcyclists are more likely to be at-fault in collisions involving pedestrians and this effect is higher at night. In multi-vehicle crashes, motorcyclists are more likely to be victims than at-fault. Young and older riders are more likely to be at-fault in crashes than middle-aged group of riders. The findings of this study will help to develop more targeted countermeasures to improve motorcycle safety and more cost-effective safety awareness program in motorcyclist training.

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1. Introduction

In Singapore, motorcycles constitute about 19% of the vehicle population but account for 36% of the total crashes. Furthermore, motorcyclists account for 50.2% of all road fatalities and 53.1% of injured victims. As shown in Fig. 1, motorcycles are overrepresented consistently in the road traffic crashes. While the crash rate of cars and heavy vehicles has declined in recent two years, the rate for motorcycles has remained almost the same. Over this time period, the fatality and injury rates of motorcyclists per registered vehicle are respectively 13 and 7 times higher than those of other motor vehicles. Huang et al. (2007) have also reported that the odds of being injured are 2.63 times higher among motorcyclists than for drivers of light vehicles. Moreover the crash involvement rate of motorcyclists as victims is also about 43%. However, despite this safety concern, there are very few studies in Singapore that address the specific safety problems of motorcyclists.

Recent research on motorcycle safety tends to develop mainly in two different directions, first on crash severity and next on crash risk. For example, Branas and Knudson (2001), Evans and Frick (1988), Gabella et al. (1995) and Ouellet and Kasantikul (2006) have examined severity based on helmet usage while Quddus et al. (2002), Shankar and Mannering (1996), Pai and Saleh (2007), Savolainen and Mannering (2007a) have examined specific roadway, environmental and human-vehicle factors which influence the crash severity. On crash risk, Yuan (2000), Zador (1985), Williams and Hoffmann (1979) have considered the problem of conspicuity, Kim et al. (2000) and Turner and Georggi (2001) have examined the alcohol impairment, Haque et al. (in press) have investigated the problem of over-exposure at signalized intersections. Crash risk has also been found to have significant association with the rider-motorcycle characteristics such as rider age (Harrison and Christie, 2005; Rutter and Quine, 1996), rider sex (Lin et al.,

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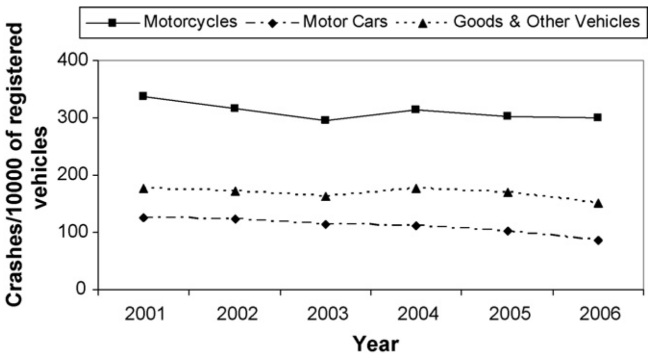

Fig. 1. Year trend of Crashes per 10,000 registered vehicles.

2003; Mannering and Grodsky, 1995), riding experience (Sexton et al., 2004; Savolainen and Mannering, 2007a), riding exposure (Mannering and Grodsky, 1995; Lin et al., 2003), and engine capacity (Harrison and Christie, 2005).

These studies provide useful information on the contributing factors based on the perspective of risk and injury severity. However, they do not consider whether the motorcyclist involvement is due to their fault or not.

In other traffic safety studies, researchers have found it necessary to distinguish at-fault and not-at-fault crashes in their analyses. For example, Stamatiadis and Deacon (1995) have examined the effect of age on the crash propensity by considering at-fault and not-at-fault cases. Yan et al. (2005) have explored the characteristics of rear-end crashes at signalized intersections and found different factors to influence at-fault and not-at-fault crashes. Kim and Li (1996) have examined the factors affecting the fault of drivers in motor-vehicle and bicycle collisions.

In fact, the case of who is at-fault is even more important in motorcycle crashes. Waller et al. (1968), Foldvary (1967) and Lehmann (1962) have pointed out that motorcyclists are more likely to be the victims in a crash rather than the guilty party. Savolainen and Mannering (2007a) have reported that the likelihood of fatality is 126% higher when the motorcyclist is at-fault. Kim and Boski (2001) have identified specific contributing factors in two-vehicle crashes where the motorcyclists are at-fault.

It appears that without addressing the issue of whether the motorcyclists are at-fault or not, the true interpretation on the causes of motorcycle crashes may not be properly investigated. Hence it may be difficult to recommend effective corrective measures to improve the motorcycle safety and any program to bring about behavior modification among motorcyclists may not be fruitful.

This may explain why many rider training programs are found to be ineffective (Mortimer, 1988; Jonah et al., 1982; Staten, 1980). Indeed, Savolainen and Mannering (2007b) have reported that the riders in Indiana who took the rider training courses are more likely to involve in crashes than those who had not taken the courses. The likelihood of crashes was found to be even higher among those who have taken the courses more than once. Therefore, there may be still lack of understanding of the causal factors that contribute to crashes due to motorcyclist negligence. Hence a comprehensive understanding on the fault of motorcyclists during the crash involvement may be helpful in this regard.

Moreover, whether the motorcyclists are at-fault or not and indeed which factors affect motorcycle crashes, may also differ according to where the crashes occur. Crash statistics in Singapore show that about 28% and 25% of motorcyclists are involved in crashes at intersections and expressways, respectively. Crash involvement characteristics may be different at different location types. For example, the higher power-to-weight ratio of motorcycles (Elliot et al., 2003) coupled with violations of motor vehicles can increase the exposure of motorcyclist hazards at intersections (Haque et al., in press; Preusser et al., 1995; Hurt et al., 1981). This may explain why at intersections, 58% of the motorcyclists are victims but on expressways, only 33% are victims.

The objective of this paper is to identify the key factors that contribute to motorcycle crashes by explicitly considering whether the motorcyclists are at-fault or not in the crash. This is carried out by formulating a logit model, based on the binary response of whether the motorcyclist is at-fault or not, to explain how variations in roadway characteristics, environmental factors, as well as rider and motorcycle characteristics will influence the crash involvement. To examine these factors more specifically, the analysis is undertaken by categorizing the crashes into location types, i.e., at intersections, on expressways and elsewhere (denoted as non-intersections).

2. Methodology

Using the outcomes: at-fault or not-at-fault as the response variable, the problem can be well formulated using the binary logit model. In any given motorcycle crash, it is reasonable to expect that rider can be identified either as the at-fault party or not-at-fault party. Let, T_{in} be a linear function of covariates that determine the likelihood of crash-involved motorcyclist n's having discrete outcome i as,

$$T_{in} = \boldsymbol{\beta}_i \mathbf{X}_{in} + \varepsilon_{in} \tag{1}$$

where T_{in} is a fault function determining the fault category (e.g., crash-involved motorcycle is at-fault party or not-at-fault party); $\mathbf{X}_{in}$ is a vector of measurable characteristics that determine outcome i (e.g., roadway characteristics, environmental factors, motorcyclist's attributes, and so on); $\boldsymbol{\beta}_i$ is a vector of estimable parameters; ε_{in} is an error term. McFadden (1981) has shown if ε_{in} follow generalized extreme value distribution, the logit formulation results will be,

$$P_n(i) = \frac{\exp[\boldsymbol{\beta}_i \mathbf{X}_{in}]}{\sum_I \exp[\boldsymbol{\beta}_i \mathbf{X}_{in}]} \tag{2}$$

where $P_n(i)$ is the probability that the crash-involved motorcyclist n has a particular discrete outcome category i from the set of all outcome categories I. It should be noted that if the error term, ε_{in} follow normal distribution, the Probit formulation will result. However, both formulations are suitable but the logit formulation is selected as both formulations give very similar results. The model in the Eq. (2) can be estimated by the Standard Maximum Likelihood methods (See Washington et al., 2003, for details on the model estimation).

To evaluate the statistical significance of separating motorcycle crashes in three location types, namely: intersection, expressway, and non-intersection, the likelihood ratio test can be conducted. The likelihood ratio statistic, X^2 (see Washington et al., 2003) is defined as,

$$X^2 = -2[LL(\beta_{\mathrm{F}}) - LL(\beta_{\mathrm{I}}) - LL(\beta_{\mathrm{E}}) - LL(\beta_{\mathrm{N}})] \tag{3}$$

where $LL(\beta_{\mathrm{F}})$ is the log-likelihood at convergence of the aggregate model estimated with data from all locations, $LL(\beta_{\mathrm{I}})$ is the log-likelihood at convergence of the model using the intersection data, $LL(\beta_{\mathrm{E}})$ is the log-likelihood at convergence of the model using the expressway data, and $LL(\beta_{\mathrm{N}})$ is the log-likelihood at convergence of the model using the non-intersection data. The likelihood ratio statistic is assumed to be χ^2 distributed with degrees of freedom equal to the sum of the number of the estimated parameters in all the disaggregate models (i.e., intersection, expressway, non-intersection) minus the number of the estimated parameters in the aggregate model.

The next step is to identify the subset of independent variables which yield the most parsimonious model. In order to select the

Table 1
Explanatory variables included in the models.

Explanatory variables	Description of the variables	Intersection		Expressway		Non-intersection	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Time trend	Month of crash (assuming that January 2001 = 1 to December 2006 = 72)	31.718	21.118	37.634	21.039	36.361	21.669
Night time indicator	If crash between 1900 and 0700 = 1, otherwise = 0	0.434	0.496	0.356	0.479	0.388	0.487
Presence of surveillance camera[a]	If camera exists at crash location = 1, otherwise = 0	0.061	0.240	0.018	0.132	0.008	0.091
Wet surface	If crash on wet-road surface = 1, otherwise = 0	0.095	0.293	0.241	0.428	0.112	0.315
Lane position							
Single lane	If crash is on single lane = 1, otherwise = 0	0.114	0.317	0.044	0.204	0.195	0.396
Curb lane*	If crash is on curb lane = 1, otherwise = 0	0.271	0.444	0.380	0.485	0.327	0.469
Median lane	If crash is on right lane = 1, otherwise = 0	0.292	0.455	0.291	0.454	0.295	0.456
Others lane	If crash is on center lane = 1, otherwise = 0	0.323	0.468	0.285	0.452	0.182	0.386
Speed limit							
≤40 km/h	If speed limit ≤40 km/h = 1, otherwise = 0	0.019	0.136	0.003	0.054	0.036	0.187
50 km/h	If speed limit 50 km/h = 1, otherwise = 0	0.902	0.298	0.104	0.306	0.832	0.373
70 km/h*	If speed limit 70 km/h = 1, otherwise = 0	0.077	0.267	0.014	0.117	0.108	0.311
>70 km/h	If speed limit >70 km/h = 1, otherwise = 0	0.002	0.048	0.879	0.326	0.023	0.150
Rider age	Continuous	32.764	13.101	32.940	11.936	32.571	13.200
Rider sex	If rider is male = 1, otherwise = 0	0.972	0.166	0.972	0.164	0.973	0.161
Pillion passenger	If a pillion passenger involved = 1, otherwise = 0	0.184	0.388	0.187	0.390	0.165	0.371
Rider race							
Chinese	If rider is Chinese = 1, otherwise = 0	0.559	0.496	0.543	0.498	0.534	0.499
Malay	If rider is Malay = 1, otherwise = 0	0.330	0.470	0.306	0.461	0.330	0.470
Others*	If rider is other race = 1, otherwise = 0	0.110	0.313	0.151	0.358	0.136	0.343
Licence class							
Class 2B	If rider at beginner licence = 1, otherwise = 0	0.791	0.406	0.824	0.381	0.796	0.403
Class 2A	If rider at intermediate licence = 1, otherwise = 0	0.105	0.307	0.090	0.287	0.102	0.303
Class 2*	If rider at advanced licence = 1, otherwise = 0	0.104	0.305	0.085	0.280	0.101	0.302
Engine capacity	Continuous	185.255	145.781	178.514	137.851	188.311	152.248
Registration[b]	If motorcycle registered other than Singapore = 1, otherwise = 0	0.128	0.334	0.209	0.407	0.061	0.239
Headlight	If headlight is on during crash = 1, otherwise = 0	0.937	0.244	0.929	0.258	0.930	0.255
Pedestrian	If pedestrian involved in crash = 1, otherwise = 0	0.019	0.137	0.003	0.056	0.061	0.239
Multi-vehicle	If multi-vehicle collision = 1, otherwise = 0	0.896	0.306	0.573	0.495	0.612	0.487

* Reference category for categorical independent variables.
[a] Represents red-light camera at intersection but speed camera at expressway and non-intersection.
[b] A large number of motorcyclists from Malaysia enter into Singapore for work everyday because of geographical proximity.

appropriate explanatory variables, the Akaike's Information Criteria (AIC) developed by Akaike (1973), is used. The AIC is defined as

$$AIC = -2LL(\beta) + 2k \quad (4)$$

where $LL(\beta)$ is the log-likelihood value of the model at convergence, and k is the number of variables included in the model. The better model will result a smaller AIC value. Starting with the full set of independent variables, a systematic procedure has been followed to eliminate insignificant variables one at a time by comparing the corresponding AIC values until the model with minimum AIC value is found. Moreover, to measure the overall goodness-of-fit, the deviance value, i.e., $2(LL(\beta)–LL(C))$ where $LL(C)$ is the log-likelihood of the model with the constant term only, which follows a χ^2 distribution has been used for testing overall goodness-of-fit (Agresti, 1990). The log-likelihood ratio ρ^2, i.e., $1 - LL(\beta)/LL(C)$ is also used to justify the additional variation of the obtained model to the constant term model.

In order to interpret the effect of coefficient estimation, the exponential of the parameter estimates, i.e. $\exp(\beta)$ is calculated to obtain the odds ratio which indicates the effect of factor change in the odds of an event occurring. For the categorical variables, $\exp(\beta_a - \beta_b)$ is used to represent the odds ratios between two categories, a and b for comparison purposes.

The percentage change in the predicted probabilities for each category is obtained by computing the effect of a unit change in a continuous explanatory variable from its mean or value change from 0 to 1 for a categorical variable while holding all other variables at their mean. For variables with more than two categories, the percentage change is computed based on a category change from 0 to 1 while holding other categories at 0 and all other variables at the mean (Long and Freese, 2006).

Table 2
Logit model estimates of significant variables for the not-at-fault crash involvement of motorcyclists.

Explanatory variables	Intersection model		Expressway model		Non-intersection model	
	Beta	*Z* statistics	Beta	*Z* statistics	Beta	*Z* statistics
Time trend	0.002	1.92	0.007	4.78	0.006	6.10
Night time indicator	0.131	2.44	0.248	3.97	–	–
Surveillance camera	−0.298	−2.75	–	–	–	–
Wet surface	–	–	–	–	−0.142	−2.02
Lane position						
Single lane	0.228	2.41	−0.333	−1.74	0.012	0.19
Median lane	0.112	1.59	−0.211	−2.82	0.256	4.69
Other lane	−0.060	−0.88	−0.063	−0.85	0.048	0.76
Speed limit						
≤40 km/h	–	–	−0.274	−0.33	0.479	3.59
50 km/h	–	–	0.365	1.19	0.042	0.60
>70 km/h	–	–	−0.509	−1.77	−0.121	−0.75
Rider age	0.071	6.08	0.057	3.82	0.060	6.41
Square of rider age	−0.001	−5.91	−0.001	−2.73	−0.001	−5.76
Pillion passenger	–	–	−0.988	−1.96	–	–
Licence class						
Class 2B	−0.178	−1.98	−0.454	−3.60	−0.209	−2.87
Class 2A	−0.029	−0.25	−0.165	−1.16	−0.147	−1.53
Engine capacity	–	–	−0.001	−3.21	–	–
Registration	–	–	−0.110	−1.45	–	–
Pedestrian	–	–	–	–	−0.357	−3.03
Multi-vehicle	1.810	18.40	1.365	20.50	1.709	33.82
Constant	−2.593	−10.11	−3.073	−7.21	−2.817	−13.83
Number of observation	6408	5710	10662			
Log-likelihood at zero	−4359.20	−3599.34	−7193.97			
Log-likelihood at convergence	−4116.36	−3296.42	−6324.99			
AIC	8256.72	6626.84	12679.98			
Deviance value	485.67 (11 df)	605.84 (16 df)	1737.96 (14 df)			
P-value for deviance	<0.001	<0.001	<0.001			
Log-likelihood ratio	0.056	0.084	0.121			

'–' not found significant.

3. Dataset for analysis

For this study, Singapore crash data maintained by the Singapore Traffic Police from 2001 to 2006 have been used. Singapore is a heavily urbanized island country with an area of about 700 km^2, about 3260 km of road and 150 km of expressways (in 2006). During the 6-year period, there were 22,780 motorcycle crashes of which 6408 occurred at intersections, 5710 crashes on expressways, and the rest at non-intersections.

In this study the definition of at-fault or not-at-fault follows that incorporated in the traffic police crash report. The crash report is prepared by the crash investigation team of the traffic police department after crash reconstruction and forensic investigation. The quality of traffic police crash report in Singapore is expected to be better as the crash investigation team is a small group of people who are well trained for crash investigation. And that group of people investigates all of the crashes in Singapore. Given the rigorous crash investigation process with the well trained crash investigation team, the possibility of reporting biasness is likely to be small. Kim and Li (1996) have argued that the purpose of crash reporting is to ascertain fault and the determination of fault is duty bound to be accurate. It is worth mentioning that fault, in some instances, may be a combination of all the people involved in crashes. However, assigning fault to the riders, drivers, or others (e.g., pedestrians) involved in crashes may be an effective way to examine and explore crashes. A similar approach of analyzing fault using the traffic police crash report has also been found elsewhere (Kim and Boski, 2001; Kim and Li, 1996).

A total of 16 explanatory variables assumed to influence motorcyclist fault are included in the model. As shown in Table 1, they include roadway characteristics, environmental factors, motorcycle and rider characteristics as well as time effects. To capture the non-linear relationship between the crash involvement and age, the square of rider age has been input to the model. The majority of the variables included are categorical dummy variables that simply indicate the existence of a certain condition. The variable indicates the presence of surveillance camera variable shown in the Table 1 refers to the red-light camera at intersections but the speed camera at expressways and at non-intersections. Beginner motorcycle rider must be at least 18 years old. And the riders receive the beginner licence (i.e., Class 2B) can ride motorcycle up to 200 cc. With 1 year experience of riding with Class 2B they may try to get intermediate licence (i.e., Class 2A) and can ride motorcycles up to 400 cc. With further 1 year experience of riding with Class 2A they may try to get advance licence (i.e., Class 2) and can ride motorcycles of any engine capacity.

4. Results and discussions

Before estimating the model parameters for each location, it is worthy to evaluate the statistical significance of separating motorcycle crashes in three location types, namely: intersection, expressway, non-intersection. The likelihood ratio statistic as shown in the Eq. (3) has been computed for this purpose. The log-likelihood values at convergence for the location-specific models, i.e., intersection, expressway, non-intersection are −4110.56 (24 df), −3293.03 (24 df) and −6321.14 (24 df), respectively, while the corresponding value for the aggregate model is −13795.90 (26 df). Note that the aggregate model is estimated with 22,780 observations with the location type (i.e., intersection, expressway, non-intersection) as a categorical variable. The resulting X^2 statistic of 142.34 (P-value < 0.001) indicates that the location-specific models are statistically better.

Table 3
Odds ratio and marginal effects of significant variables.

Explanatory variables	Intersection model			Expressway model			Non-intersection model		
	Odds ratio	%Probability change		Odds ratio	%Probability change		Odds ratio	%Probability change	
		NF[a]	AF[a]		NF	AF		NF	AF
Time trend	1.003	0.10	−0.14	1.007	0.50	−0.22	1.006	0.39	−0.24
Night time indicator	1.140	5.67	−7.35	1.281	18.64	−7.41	–	–	–
Surveillance camera	0.743	−12.62	17.66	–	–	–	–	–	–
Wet surface	–	–	–	–	–	–	0.868	−8.60	5.36
Lane position									
Single lane	1.256	9.61	−12.70	0.717	−21.10	10.05	1.012	0.78	−0.44
Median lane	1.119	4.78	−6.31	0.810	−13.70	6.53	1.292	16.92	−9.51
Other lane	0.942	−2.60	3.44	0.939	−4.21	2.01	1.049	3.08	−1.73
Speed limit									
≤40 km/h	–	–	–	0.760	−19.91	5.32	1.615	31.67	−18.48
50 km/h	–	–	–	1.441	31.86	−8.52	1.043	2.69	−1.57
>70 km/h	–	–	–	0.601	−45.90	12.27	0.886	−7.52	4.39
Rider age	1.074	2.99	−4.11	1.059	4.00	−1.74	1.062	3.76	−2.31
Square of rider age	0.999	−0.03	0.05	1.000	−0.03	0.01	0.999	−0.03	0.02
Pillion passenger	–	–	–	0.372	−43.81	50.88	–	–	–
Licence class									
Class 2B	0.837	−6.99	11.10	0.635	−25.95	16.61	0.811	−11.85	8.71
Class 2A	0.971	−1.14	1.81	0.848	−9.84	6.30	0.864	−8.35	6.14
Engine capacity	–	–	–	0.999	−0.07	0.03	–	–	–
Registration	–	–	–	0.896	−7.29	3.45	–	–	–
Pedestrian	–	–	–	–	–	–	0.700	−20.87	13.08
Multi-vehicle	6.110	192.13	−52.19	3.915	164.01	−32.55	5.525	206.60	−44.52

'–' not found significant.
[a] (NF) not-at-fault and (AF) At-fault.

Based on the formulated logit model, the model parameters were derived using the maximum likelihood estimation. Table 2 shows the estimates of the logit models along with the crash probabilities for the not-at-fault party at each of the locations. The deviance value associated with crashes at intersections, expressways, and non-intersections is 485.7, 605.8, and 1737.9, respectively, which are well above the critical value for significance at the 5% level of significance. It means that all the models have sufficient explanatory power. The log-likelihood ratios presented in Table 2 for the models also indicate a reasonable level of fit.

Table 2 also shows the significant factors that are strongly associated with the fault of motorcyclists at the different location types which have been found by minimizing the AIC. The AIC value for intersection, expressway, and non-intersection model is 8256.72, 6626.84, and 12679.98, respectively. At intersections, the time trend, night time occurrence, presence of surveillance cameras, the lane position, multi-vehicle crash occurrence, rider age, and licence class are all found to be significant. On the other hand, on expressways, the time trend, night time occurrence, lane position, speed limit, multi-vehicle crash occurrence, the country of vehicle registration, rider age, engine capacity, riding with pillion passenger, and licence class are found to be significantly associated with fault of motorcyclists. For non-intersections, the time trend, wet-road surface, lane position, speed limit, multi-vehicle crash occurrence, pedestrian involvement, rider age, and licence class are significantly associated with fault of motorcyclists.

The odds ratio and the percentage probability change from its reference category are computed and presented in the Table 3 and the results are discussed in the following sections.

4.1. *Time effect*

The time trend is found to be positive and significant in all location types, indicating that there is an upward trend for motorcycle involvement in crashes as the not-at-fault party. Although the crash involvement of motorcyclists shows a downward trend (Fig. 1), the not-at-fault crash involvements are in the upward trend. The probability of motorcycles being victims of crashes is increasing at a rate of 0.10%, 0.50%, and 0.39% per month, respectively, at intersections, on expressways, and at non-intersections. These results suggest that some unmeasured factors are contributing to increasing vulnerability of motorcyclists on the road. Further research is needed to investigate this effect.

4.2. *Night time crash occurrence*

Night time crashes are found to significantly affect the fault of motorcyclists both at intersections and on expressways. The results show that night time influence increases the odds of motorcyclists being involved in crashes as the not-at-fault party by 14% at intersections and 28.1% on expressways. This may be due to reduced conspicuity (e.g., Williams and Hoffmann, 1979) of motorcycles at

Table 4
Motorcyclists' fault in multi-vehicle crashes by time of the crash.

Location	Crash time	Crash fault		Odds ratio	Chi-square	*P*-value
		Not-at-fault	At-fault			
Intersection	Night	1,667	887	1.264	18.17	<0.001
	Day	1,904	1,281	Reference		
Expressway	Night	540	547	1.423	22.40	<0.001
	Day	895	1,290	Reference		

Table 5
Motorcyclists' fault in multi-vehicle crashes by lane position.

Location	Lane position	Crash fault		Odds ratio	Chi-square	P-value
		Not-at-fault	At-fault			
Intersection	Single	435	218	1.245	4.98	0.026
	Curb	936	584	Reference		
	Median	1,079	603	1.116	2.26	0.133
	Others	1,121	763	0.917	1.52	0.218
Expressway	Single	27	55	0.590	4.83	0.028
	Curb	516	620	Reference		
	Median	428	581	0.885	1.96	0.162
	Others	464	581	0.960	0.23	0.632
Non-intersection	Single	642	528	1.076	1.00	0.317
	Curb	1,089	964	Reference		
	Median	1,149	810	1.256	12.78	<0.001
	Others	712	627	1.005	0.01	0.941

night. As seen in Table 4, for multi-vehicle collisions, the odds of motorcycles being involved in crashes as a victim due to faults of other road users increase by 26.4% and 42.3% in the night time for intersections and expressways, respectively. Motorists often fail to see the motorcycles in approach-turn collisions at intersections (Hurt et al., 1984; Foldvary, 1967) and may not look out for motorcycles (Mannering and Grodsky, 1995) during merging at expressways. Illuminated headlight and bright clothing worn of motorcyclists may be an effective intervention to reduce this type of crash involvement.

4.3. Presence of surveillance camera

The presence of surveillance cameras shows a negative effect for the not-at-fault crash involvement of motorcyclists at intersections. The presence of a red-light camera decreases the probability of not-at-fault crashes by about 12.6% at intersections. Red-light cameras are found to be effective in reducing red running and hence the right-angle collisions (Huang et al., 2006). Haque et al. (in press) have also reported that motorcycles are most exposed to red-light runners due to their accumulation in front of the queue and discharge earlier than other motor vehicles. The presence of cameras effectively reduces not-at-fault crash involvement by discouraging red runners. However, there is also an indication that the presence of a surveillance camera increases the likelihood of at-fault crash involvement. Huang et al. (2006) also reported that presence of a red-light camera may increase rear-end collisions. Quddus et al. (2002) argued that motorcyclists may have difficulties in responding when forward vehicles stop suddenly due to the presence of a red-light camera.

4.4. Wet-road surface

Wet-road surfaces are not found to significantly affect the fault of motorcyclists involved in crashes at intersection and expressways. At non-intersections, there is an increase of likelihood of at-fault crash involvement and a corresponding increase in odds by 1.15 times than on dry road surface. Caliendo et al. (2007) have also reported that wet pavements increase overall number of crashes. While this may be obvious, the indication that such crashes are contributed by motorcyclists fault suggests that motorcyclists need to take more defensive actions while riding on wet surfaces.

4.5. Lane position

The lane position on which the crash occurs is found to significantly affect the fault of motorcyclists on all three location types. Using the curb lane as the reference, the likelihood of the not-at-fault crash involvement significantly increases in single-lane roads and on the median lane at intersections with increased corresponding probabilities of 9.6% and 4.8%, respectively. On single-lane roads, the lane width is wider offering greater freedom for motorcyclists to accumulate near the stop-line and hence more exposed to the conflicting traffic stream (Haque et al., in press) and thus more likely to be victims. Haque et al. (in press) have also reported that motorcyclists use the unoccupied right-turn lane for queuing thereby increasing their exposure to the conflicting stream. In multi-vehicle crashes, the analysis as seen in Table 5 confirms that the odds of being involved in not-at-fault crashes increases by about 24.5% and 11.6% on single-lane roads or median lane of multi-lane roads, respectively.

However, on expressways the median lane is found to increase the likelihood of at-fault crash involvement and the corresponding odds of at-fault crashes is 1.23 times higher. The speed is comparatively higher at median lane of expressways and this increases crash risk (Lin et al., 2003), and may contribute to higher at-fault crash involvement (Elliot et al., 2007). Moreover, in the multi-vehicle crashes (see Table 5) the median lane is not found to be significant. Hence, in single vehicle at-fault crashes on expressways, motorcyclists may be more likely to be involved on the median lane. This is perhaps due to the loss of vehicle control at high speed (Preusser et al., 1995) on expressways. Motorcyclists are also found to be at-fault in crashes at single-lane configuration of the expressway and this corresponds to the slip road or ramp. In this case, the corresponding probability is about 10.1% higher than on the curb lane of the expressways. On the other hand, in multi-vehicle crashes (see Table 5) the corresponding odds of being at-fault are about 1.7 times higher than on the curb lane of the expressways. These suggest that motorcyclists are more likely to make mistakes on the slip road or ramp of expressways and are also likely to implicate other road users.

On the other hand, at non-intersections, results show that the likelihood of not-at-fault crash involvement increases on the median lane by about 16.9%. This may be due to close following of vehicles especially so on the median lane where the speed is comparatively higher than on other lanes. Motorcyclists may be less able to respond well in any interruptions (Quddus et al., 2002). Results in Table 5 also show that in multi-vehicle crashes, their odds of involvement as victims increase by about 25.6%.

4.6. Road speed limit

The speed limit is found to significantly affect the fault of motorcyclists both on expressways and at non-intersections. On expressways, the odds of at-fault crash involvement at roads with speed limit greater than 70 km/h is 66% higher than on roads with

Table 6
Motorcyclists' fault during collisions with pedestrians at non-intersection.

Time of day	Collided with pedestrian	Crash fault		Odds ratio	Chi-square	*P*-value
		At-fault	Not-at-fault			
Night	Yes	237	31	5.335	91.74	<0.001
	No	2,280	1,591	Reference		
Day	Yes	307	71	3.210	83.39	<0.001
	No	3,527	2,618	Reference		

only 70 km/h speed limit. This finding is consistent with those of Elliot et al. (2007) who reported that fast riding increases at-fault crash involvement of motorcyclists. On the other hand, on 40 km/h roads, there is higher not-at-fault crash involvement compared to 70 km/h roads. On lower speed roads away from intersections, motorcyclists tend to be more easily marginalized by other vehicles.

4.7. Rider attributes

Rider age is found to significantly influence the fault of motorcyclists involved at crashes. Generally, rider age is negatively related with the at-fault crash involvement of the motorcyclists (i.e., as age increases the likelihood of at-fault in crashes decreases). Previous research suggests that younger riders have a stronger propensity of risky behavior (Harrison and Christie, 2005; Lin et al., 2003; Rutter and Quine, 1996). Moreover, square of rider age has also found to be significantly associated with fault of motorcyclists. It confirms the existence of a non-linear relationship between the rider age and motorcyclists fault. To capture this, the log-odds of at-fault have been plotted with the rider age and presented in Fig. 2. This indicates that for all the location types the odds of at-fault are higher for those who are at younger and older ends of the age spectrum. Middle-aged (40–60 years) group of motorcyclists are less likely to be found at-fault in crashes. Similar results also have been observed for motorcyclists in motorcycle and motor-vehicle collisions (Kim and Boski, 2001). The plot also indicates that the motorcyclists are more likely to be at-fault at expressways and more vulnerable at intersections. The log-odds of fault graph of motorcyclists at intersections are below zero up to age about 67 years which imply that motorcyclists are more likely to be affected by other road users at intersections.

Motorcycles with pillion riders are also found to be significantly involved in at-fault crashes on expressways. Relative to the case of riding alone, the corresponding probability as the at-fault party is about 50.9% higher. Harrop and Wilson (1982) also reported that pillion passengers contribute to the cause of the crash when they fail to act in unison with the rider and the motorcycle.

The class of rider licence is found to significantly affect the fault of motorcyclists. Relative to the advanced licence rider group, the beginner rider group is more likely to be at-fault during crashes with higher odds of 20% at intersections, 57% on expressways and 23% on non-intersections. Inexperienced riders may not be aware of potentially dangerous locations (Jonah et al., 1982) and are less able to negotiating hazardous situations. While the finding is obvious, it may imply that more needs to be done to make younger and inexperienced riders safer on the roads.

4.8. Motorcycle attributes

Engine capacity of motorcycles is only found to be significant in expressway crashes but not elsewhere. Higher engine capacity gives rise to a higher likelihood of at-fault crash involvement. The probability of each category is plotted with engine size and presented in the Fig. 3. It clearly indicates that the fault of motorcyclists at expressway is increasing with the increase of engine size. This is expected as the motorcycles with larger engine size tend to attain higher speed on expressways and such riders are also more likely to be aggressive and risk takers exhibiting speeding behavior. Speeding has also been found to increase the at-fault crash risk of motorcyclists elsewhere (Elliot et al., 2007).

Foreign-registered motorcycles are more involved in at-fault crashes on expressways with odds about 11.6% higher than Singapore-registered motorcycles. Most riders on foreign-registered motorcycles enter Singapore to work on a daily basis (Quddus et al., 2002). They may have traveled longer distances and are subjected to fatigue in riding. Furthermore, different rider training standards as well as vehicle maintenance requirements may have contributed to the riders being more at-fault in such crashes.

4.9. Collision type

Collisions involving pedestrian significantly contribute to at-fault crash involvement of motorcyclists only at non-intersections, with odds about 43% higher compared to non-pedestrian crashes. Previous research (de Lapparent, 2006) suggests that motorcyclists are less able to anticipate and to response to pedestrians, especially to those who are less conspicuous at night. Results in Table 6 show that the odds of being involved in collisions with pedestrians at night as the at-fault party are 5.33 times higher compared to non-

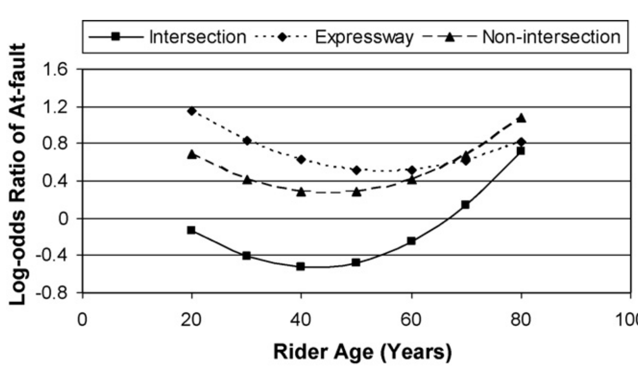

Fig. 2. Log-odds ratio of at-fault of motorcyclists involved in crashes at different location.

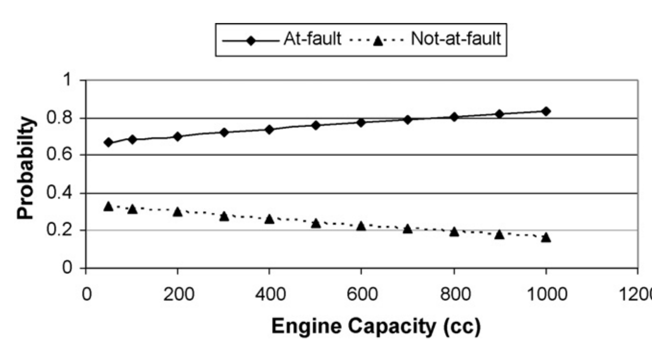

Fig. 3. Relationship of fault with engine capacity of motorcyclists involved in crashes at expressway.

pedestrian collisions while the corresponding odds at day are only 3.2 times higher.

Relative to single-vehicle crashes, the likelihood of not-at-fault crash involvement is found to increase in multi-vehicle crashes. The corresponding odds of multi-vehicle crashes are about 6.1, 3.9, and 5.5 times for intersections, expressways, and non-intersections, respectively. This finding confirms that motorcyclists are more likely to be the victim of other motorists in multi-vehicle collisions. The exposure of motorcycles is very high at intersections (Haque et al., in press). Moreover, the motor vehicles from the conflicting stream often fail to grant the motorcyclist's right of way (Clarke et al., 2007; Preusser et al., 1995; Hurt et al., 1981). Multi-vehicle collisions analysis may help to find the appropriate factors that increase their vulnerability in multi-vehicle crashes.

5. Implications

The study has identified several significant factors for at-fault as well as the not-at-fault crash involvement of motorcyclists. These findings will be helpful in designing corrective programs related to rider education and traffic enforcement for the motorcyclists. The findings related to the not-at-fault crash involvement will also help riders to be more aware of the potential dangerous situations.

Our study has shown that motorcyclists are more likely to be involved in night time crashes as the not-at-fault party both at intersections and expressways due to their reduced conspicuity. A good follow up corrective program is to encourage motorcyclists to increase their visibility by wearing reflective clothing and using illuminated headlight. Using of different retro reflective markings in the motorcycles and helmets may also increase their visibility at night. In Singapore, all riders including pillion passengers generally use helmets throughout their trips due to tough enforcement of laws on mandatory helmet use. This is also true for using the headlight of motorcycles during the daytime. However, there is no legislation for using the reflective clothing or retro reflective signs in motorcycle and helmets. Hence introducing some form of legislation on the use of reflective markers and clothing may help to reduce motorcycle crashes.

The study also shows that the presence of red-light cameras at intersections reduces vulnerability of motorcyclists at intersections. Another corrective program that can be considered is for the road authority to install red-light cameras at sites with high motorcycle traffic. Moreover, the cost benefit analysis for installing red-light cameras should take into account specific input on motorcycle crashes.

The findings of this study also indicate that the excess exposure of motorcyclists at intersections lead them to be victims of other motorists. Rider training or awareness programs should include education on correct movement and queuing at intersections. Currently there are limited practices in the riding schools for guiding the motorcyclists on queuing at junctions.

Our study has shown that the riders are at-fault in a number of critical situations, in particular, high speed riding on expressways, riding with pillion passengers at expressways, and riding on wet-road surface away from intersections. Rider education or safety awareness programs may be designed to deal with these issues. Currently rider training centers in Singapore focus on developing good riding skills on normal road conditions without expose the trainees to these hazardous conditions. The only expose to wet surfaces is in emergency braking. The curriculum should incorporate different maneuvers on wet surfaces as well as riding on expressways.

Collisions involving pedestrians have been found to lead motorcyclists to be involved in at-fault crashes and this effect is higher at night. Rider training programs may be targeted to improve their skills to react quickly in any surprise conditions. The skill of simultaneous application of front and rear wheel brakes in different maneuvering conditions may be helpful in this regard. Currently the riding simulators in the riding centers do not have such scenarios of conflicting with pedestrians for day and night time. Hence this can be simulated in the simulators to make them well prepare to react quickly in this type of surprising situation.

It has been found that the very young and very old riders are more likely to be at-fault in crashes. This is also particularly true for the beginners. Hence this group of riders should be targeted for safety improvement. This can be done by arranging safety talks and programs in motorcycling clubs in colleges and universities as well as community riding clubs with high proportion of elderly riders.

It is recommended that the driving centers may use the findings of this study to include in licensure program to make motorcyclists more aware of the different factors which expose the motorcyclists to crash risks so that more defensive riding may be needed.

6. Conclusion

This study uses the binary logit model to model the fault of motorcyclists involved in crashes. To get a more holistic picture of crash causation, the fault of motorcyclists was analyzed at intersections, on expressways, and at non-intersections. It is found that location types have varying effects on the contributing factors of motorcycle crash-involvement.

Motorcyclists are found to be more vulnerable during night time at both intersections and expressways. The presence of surveillance cameras is found to reduce the not-at-fault crash involvement at intersections. Riding in the median lane, higher engine capacity and riding with a pillion passenger are found to increase the likelihood of at-fault crashes on expressways. Higher speed roads, wet-road surface and collision with pedestrian are found to increase the likelihood of at-fault crashes at non-intersections with the effect of collision involving pedestrians higher at night. The motorcyclists are more likely to be a victim in multi-vehicle crashes at all the locations. Young and older riders are more likely to be at-fault in crashes than middle-aged group of riders. Similarly, the beginner rider licence group of riders is more likely to be at-fault in crashes.

One of the possible extensions of this research is to analyze the fault of both motorcyclists and other motorists or pedestrians, bicycles involved in multi-vehicle collisions at different location types. The understanding of the fault at multi-vehicle collisions may help to design of more effective strategies for improving motorcycle safety. Another possible scope of research is from methodological approach. The model in this study has assumed that the estimated parameters are the same for all observations. However incorporating the possible randomness in the parameter estimation either in the form of mixed logit (Gkritza and Mannering, 2008) or hierarchical formulation (Huang et al., 2007) may improve the model accuracy. An extension of this paper is to incorporate the possible random effects in the parameter estimations.

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