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Motorcyclist injury severity in angle crashes at T-junctions: Identifying significant factors and analysing what made motorists fail to yield to motorcycles

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ABSTRACT

Evidence in literature suggested that motorists' failure to give way to motorcycles at junctions is the main contributory factor to motorcycle–car accidents that involve gap acceptance (i.e., approach-turn and angle crashes). This paper attempts to examine how motorist's failure to give way affects motorcyclist injury severity in angle crashes at T-junctions, while controlling for other factors (demographic, vehicle, crash, and environmental factors). Binary logistic models of motorcyclist injury severity were estimated using the data extracted from the Stats19 accident injury database (1991–2004). Angle collisions were classified into several sub-crashes based on the manoeuvres motorcycles and cars were making prior to the accidents. The modelling results showed that injuries were greatest when a travelling-straight motorcycle on the main road crashed into a right-turn car from the minor road, particularly at stop-/yield-controlled junctions. Such crash pattern was assumed to be an accident involving right-of-way violation. Using binary logistic models, factors determining the likelihood of motorist's failure to yield to motorcycles were also examined. The implications of the research findings of this present study were provided.

1. Introduction

The disparities between injuries sustained by motorcyclists and automobile-occupants in road accidents suggest that it can be much more hazardous to ride a motorbike than to drive an automobile in terms of injury outcome. Motorcyclists' susceptibility to accident injuries in nature may act synergistically with the complexity of conflicting movements and manoeuvres between motorcycles and automobiles to increase motorcyclists' injury severities at junctions (e.g., T-junction or crossroad). For junction accidents, motorcycle–automobile angle accidents were identified as the most common crash type at T-junctions. Following approach-turn crashes and head-on crashes, such crash type was ranked the third in terms of accident severity (see Pai and Saleh, 2007 for details). Unlike automobiles that offer greater crashworthiness to automobile-occupants through metal structure or side airbag in an angle collision, an automobile crashing into a motorcycle (i.e., motorcycle is the struck vehicle) may throw the rider off balance (i.e., ejection) or cause entrapment (if the passenger compartment of the automobile is high). Head and chest injuries, which normally results in severe/fatal consequence, often occur with the rider's ejection (Peek-Asa and Kraus, 1996). Crashing into the side of a car (i.e., hitting the bonnet or the boot area of the car) might cause the rider to tumble, thereby resulting in severe contact with ground if speed is high.

Statistics from the UK Stats19 accident injury database suggested that T-junction is a common place for an angle collision involving motorcycle and car (i.e., more than half of angle collisions occurred at T-junctions between 1991 and 2004). At priority junction where traffic on the minor road is required to stop or has to speed down to identify a wide enough gap in conflicting traffic to permit safe access across the junction, the motorcycle's right-of-way on the priority road can be frequently violated by a turning car, especially by experienced drivers who seem to have problems detecting approaching motorcycles (Hole et al., 1996; Clarke et al., 2007). Factors resulting in motorists infringing upon motorcycles' right-of-way have been documented in several studies (e.g., Woltman and Austin, 1974; Williams and Hoffmann, 1979; Thomson, 1980; Hurt et al., 1981; Peek-Asa and Kraus, 1996; Brown, 2002; Koustanaï et al., 2008; Pai, 2008). These studies argued that motorists may have difficulties in detecting the presence of an approaching motorcycle as a result of motorcycle's poor conspicuity, motorcycle's speed being more difficult to determine, or simply motorists looked but did not see approaching motorcycles. Horswill et al. (2005), together with Caird and Hancock (1994), suggested that a turning motorist that is in a need to identify a gap from the conflicting traffic tends to have the size-arrival illusion which is, smaller objects are perceived to arrive later than larger objects (i.e., drivers may estimate that motorcycles reach

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conflicting points later than cars). Attitudinal factors were also documented in the study of Hancock et al. (1990) who argued that larger automobiles (e.g., trucks) may appear more threatening than approaching motorcycles so drivers waiting on slip roads might be more cautious when intersecting with trucks than motorcycles.

There exists an abundance of research that examined the effect of various junction control measures on the occurrences of car–car angle collisions at intersections. By estimating the negative binomial models and hierarchical logistic models, Poch and Mannering (1996) and Kim et al. (2007) suggested that signalised intersections (i.e., the intersections that are controlled by automatic signals) resulted in a significant decrease in angle collisions. Retting et al. (2003a,b) found that approximately 70% of all angle collisions took place at stop-/give-way controlled junctions. The presence or absence of a traffic signal at junctions did not affect accident involvement of elderly drivers (Stamatiadis et al., 1991), although a recent study by Ulfarsson et al. (2006) reported that elderly drivers experienced more angle collisions when traffic signal measures were present at junctions, relative to unsignalised junctions. An uncontrolled left-turn channels and an increase in signal phases of traffic signals tended to increase angle crashes at four-legged junctions (Mitra et al., 2002). Huang et al. (2006) employing the multinomial logit models found that the presence of a red light camera was effective in reducing angle collisions at signalised four-legged intersections. The finding of Huang et al. is supported by other researchers (e.g., Shin and Washington, 2007; Retting and Kyrychenko, 2002; Retting et al., 2003a,b; Persaud et al., 2005). Songchitruksa and Tarko (2006) indicated that car–car angle collisions at four-legged junctions were often quite severe due to the high impact speed of cars colliding at right angles, and red light running was a contributing factor to such crashes.

Factors affecting injury severities among automobile-occupants, given that angle collisions have occurred, have been regularly examined in literature (e.g., Abdel-Aty and Abdelwahab, 2004). Comparatively consistent findings have been concluded among these extant studies. For instance, occupants seated on the struck-side and occupants of lightweight passenger-vehicles were more likely to be severely injured; struck-side occupants of cars were much more injurious than struck-side occupants of light trucks (i.e., light trucks are much more crashworthy than passenger cars); and perpendicular collision-angle was more severe than oblique collision-angle.

While reviewing together in literature, the abovementioned studies have been insightful into the factors that are associated with the occurrences of car–car or motorcycle–car angle crashes. Nevertheless, prediction models of motorcyclist injury severity resulting from angle collisions at junctions have been rarely developed in literature, let alone a study examining the effects of motorist's failure to yield.

The primary objective of this paper is to examine the determinants of motorcyclist injury severity resulting from motorcycle–car angle crashes, with a focus on the effects of right-of-way violation. A better understanding of the relationship between motorcyclist injury severity and factors such as human, vehicle, weather, and crash characteristics may help facilitate the identification of suitable countermeasures, or at least assist in elucidating a future research direction. Real-life accident data for motorcycle–car angle crashes that occurred at T-junctions (i.e., three-legged perpendicular junctions) in the UK are analysed through the use of appropriate statistical modelling techniques.

The present paper begins with a brief description of the data and a discussion of the proposed statistical model approach. The next section presents the model estimation results, along with a discussion of potential preventive strategies and research limitations. This paper concludes with an overall summary of model findings and recommendations for future research.

2. Data – Stats19 accident injury database

The real-life accident data (Stats19 accident injury database) that are analysed in this study are owned by Department for Transport, Great Britain. Following every road traffic accident which becomes known to the local police and involves personal injury, appropriately qualified and experienced police accident investigators complete the Stats19 forms that comprise three files: accident file, vehicle file, and casualty file. Accident file contains general information on time/date of accident occurrence, weather, road and light conditions, posted speed limit, and road type; vehicle file records vehicle and driver details, such as age and gender of driver/rider, vehicle type, first impact point of vehicle, vehicle's orientation, and vehicle's manoeuvres; and casualty file reports details for each casualty such as injury severity level, age and gender. The injury severity of each casualty is classified into three levels: fatal, serious, and slight injury. Fatal injuries include injuries sustained by casualties who die within 30 days as a result of the accident; serious injuries are defined when accident casualties suffer from fracture, internal injury, severe cuts and lacerations, concussion, or any injury requiring detention in hospital. Slight injuries are classified for victims who sustain sprains, bruises, cuts judged not to be severe and slight shock requiring roadside attention. It should be noted here that it was possible to extract "no injury" data from the Stats19 but these data were considered to be unreliable and issues such as underreporting problems may arise from such data. "No injury" data were therefore not considered in the analysis.

2.1. Categorisation of angle collision

Analysis of an angle crash in this paper is limited to two-vehicle or multi-vehicle crashes. For a two-vehicle accident, it must have involved one motorcycle colliding with an automobile. Such automobile must have been a car, heavy goods vehicle, or bus/coach, but not a motorcycle. For a multi-vehicle accident that involved more than two vehicles, the first vehicle colliding with a motorcycle must have been an automobile, but the second vehicle could have been either an automobile or a motorcycle/bicycle.

Given a T-junction where a minor road meets a major road, an angle crash is defined as a crash that occurs while one motorcycle and one car (we will use "car" to represent all automobile in the rest of paper) travelling from different arms of junctions collide with each other (i.e., a crash that occurs between the through-cross traffic and the merging/conflicting traffic from the slip road). Angle collisions are first categorised into angle perpendicular/oblique collisions: one motorcycle and car colliding with each other at a perpendicular angle and an oblique angle, respectively. From manoeuvre standpoint, an angle perpendicular crash is where the vehicles are turning across each other to travel in different directions, and an angle oblique crash is where they end up travelling in the same direction.

As illustrated in Fig. 1, angle perpendicular/oblique collisions are further classified into several sub-crashes based on the manoeuvres motorcycles and cars were making prior to the crashes: (a) angle perpendicular collision: both turning; (b) angle perpendicular collision: car travelling straight and motorcycle turning; (c) angle perpendicular collision: car turning and motorcycle travelling straight; (d) angle oblique collision: car travelling straight and motorcycle turning; and (e) angle oblique collision: car turning and motorcycle travelling straight. The reason for classifying angle collisions into several sub-crashes was because it is hypothesised in this study that injury levels may be associated with the various manoeuvres of motorcycles and cars in different ways. For instance, the collision-impact received by a motorcyclist

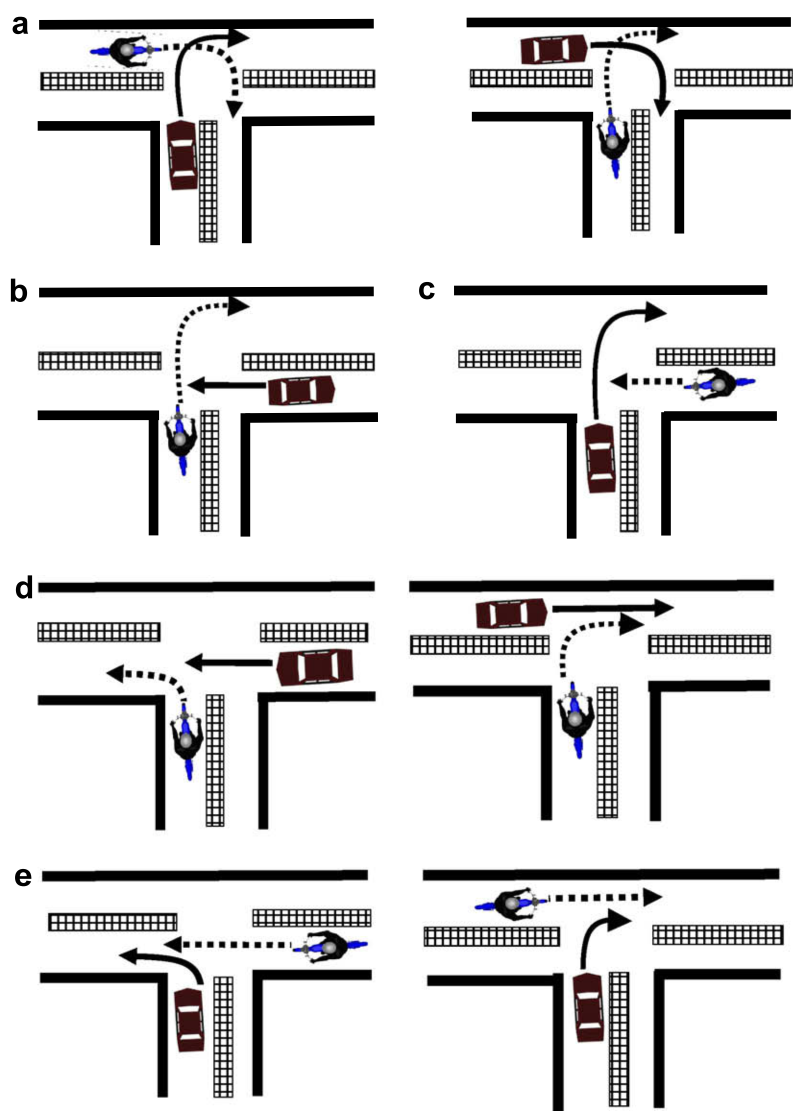

Fig. 1. Schematic diagram of angle collisions at T-junctions. (a) Angle perpendicular collision: both turning; (b) angle perpendicular collision: car travelling-straight and motorcycle turning; (c) angle perpendicular collision: car turning and motorcycle travelling-straight; (d) angle oblique collision: car travelling-straight and motorcycle turning; and (e) angle oblique collision: car turning and motorcycle travelling-straight. (Note: pecked line represents the intended path of a motorcycle; solid line represents the intended path of a car).

in a crash where a turning motorcycle collides with a travelling-straight car may be different from the collision-impact in a collision where a travelling-straight motorcycle collides with a turning car. Note here that a turning manoeuvre used for the classification of an angle crash includes a U-turn manoeuvre by motorcycles or cars. For example, for crash pattern (c), a right-turn car may have attempted to make a U-turn and subsequently collided with a travelling-straight motorcycle on the major road.

2.2. Sample formation and description

The motorcycle–car accident data analysed in this current research were drawn from a 14-year period between 1991 and 2004. Accidents considered for the analyses in this study are limited to the situation where there was at least a car that struck the motorcycle or the car was struck by the motorcycle. Other road users such as a bicyclist or pedestrian might have been involved but the analyses are limited to the accidents in which injuries were sustained by motorcycle users only (including pillion passengers). A total of 34,783 motorcyclist casualties resulting from the motorcycle–car angle accidents that took place at T-junctions were extracted (missing, untraced, and unreliable data were removed). Of these motorcyclist casualties, 27% are classified as KSIs (killed or seriously injured), and 73% are classified as slight injuries.

Tables 1 and 2 provide the information on the distribution of injury severity by the interaction of junction control measures and different crash patterns for angle perpendicular and oblique collisions, respectively. As reported in these two tables, the two crash patterns (i.e., a travelling-straight motorcycle collided with a right-/left-turn car at stop-/give-way controlled junctions) represented a major concern to motorcycle safety and are therefore important to focus on (see the combination of their severity: as much as 28.4% and 24.7% were KSIs, and frequency: 21441 and 5731 casualties).

3. Modelling methodology: the binary logistic model

The binary logistic models are estimated to evaluate the likelihood of KSIs over slight injuries as a function of human, vehicle, weather/temporal, and environment factors. The theoretical

Table 1
Distribution of motorcyclist injury severity by the interaction of junction control measures and various manoeuvres for angle perpendicular collisions.

Manoeuvres * control measures	Injury severity		Total
	Slight	KSI	
Both turning * automatic signal	24 (75.0%)	8 (25.0%)	32 (100%)
Both turning * stop, give-way sign or markings	666 (80.1%)	165 (19.9%)	831 (100%)
Both turning * uncontrolled	89 (77.4%)	26 (22.6%)	115 (100%)
Car straight, motorcycle turning * automatic signal	76 (76.0%)	24 (24.0%)	100 (100%)
Car straight, motorcycle turning * stop, give-way sign or markings	1274 (71.9%)	499 (28.1%)	1773 (100%)
Car straight, motorcycle turning * uncontrolled	188 (76.7%)	57 (23.3%)	245 (100%)
Car turning, motorcycle straight * automatic signal	238 (71.9%)	93 (28.1%)	331 (100%)
Car turning, motorcycle straight * stop, give-way sign or markings	15342 (71.6%)	6099 (28.4%)	21,441 (100%)
Car turning, motorcycle straight * uncontrolled	1833 (75.0%)	610 (25.0%)	2443 (100%)
Total	19,730 (72.2%)	7581 (27.8%)	27,311 (100%)

Table 2
Distribution of motorcyclist injury severity by the interaction of junction control measures and various manoeuvres for angle oblique collisions.

Manoeuvres * control measures	Injury severity		Total
	Slight	KSI	
Car straight, motorcycle turning * automatic signal	62 (89.9%)	7 (10.1%)	69 (100%)
Car straight, motorcycle turning * stop, give-way sign or markings	517 (75.6%)	167 (24.4%)	684 (100%)
Car straight, motorcycle turning * uncontrolled	71 (80.7%)	17 (19.3%)	88 (100%)
Car turning, motorcycle straight * automatic signal	109 (78.4%)	30 (21.6%)	139 (100%)
Car turning, motorcycle straight * stop, give-way sign or markings	4315 (75.3%)	1416 (24.7%)	5731 (100%)
Car turning, motorcycle straight * uncontrolled	587 (77.1%)	174 (22.9%)	761 (100%)
Total	5661 (75.8%)	1811 (24.2%)	7472 (100%)

framework of the binary logistic model including the model specification and method of evaluation is briefly discussed in the current paper. Detailed derivation of this model is provided in several studies (e.g., Long, 1997; Hosmer and Lemeshow, 2000).

The binary logistic models are widely used if the dependent variable is dichotomous (KSI vs. slight in this current study) in the regression equation. This model has many advantages over ordinary least-squares regression models while the dependent variable violates the assumptions of continuous or normal distribution. The logistic regression allows one to predict a binary outcome from a set of explanatory variables that may be continuous, categorical, or a mixture of the two. All explanatory variables are treated as categorical variables in this current research.

In the logistic regression model, a latent variable is formulated by the following expression:

$$g(X) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_j X_j + \ldots \beta_p X_p \tag{1}$$

where X_j is the value of the jth independent variable; and β_j as the corresponding coefficient, for $j = 1, 2, 3, \ldots, p$, and p is the number of independent variables.

With this latent variable, the conditional probability of a positive outcome is determined by

$$\pi(X) = \frac{\exp(g(X))}{1 + \exp(g(X))} \tag{2}$$

The maximum likelihood (ML) method is employed to measure the associations by constructing the likelihood function as follows:

$$l(\beta) = \prod_{i=1}^{n} \pi(X_i)^{y_i} (1 - \pi(X_i))^{1-y_i} \tag{3}$$

where y_i denotes the ith observed outcome, with the value of either 0 or 1, and $i = 1, 2, 3, \ldots, n$, where n is the number of observations. The best estimate of β could be obtained by maximising the log likelihood expression as:

$$LL(\beta) = \ln(l(\beta)) = \sum_{i=1}^{n} \{y_i \ln(\pi(X_i)) + (1 - y_i) \ln(1 - \pi(X_i))\} \tag{4}$$

The effect of attribute k on the likelihood of KSIs could be revealed by the odds ratio (OR):

$$\mathrm{OR} = \exp(\beta_j) \tag{5}$$

An odds ratio that is greater than one indicates that the concerned attribute leads to a higher probability of KSIs, and vice versa. Odds ratios of one or close to one suggest a neutral or weak effect. To assess the goodness-of-fit of the logistic regression model, a Hosmer and Lemeshow goodness-of-fit statistic is provided. A large value of $\chi^2_{\text{Hosmer and Lemeshow}}$ (and small p-value) indicates a lack of fit of the model. A detailed derivation of a $\chi^2_{\text{Hosmer and Lemeshow}}$ statistics, is not provided in this paper – a thorough discussion can be found in the study of Hosmer and Lemeshow (2000).

3.1. Model specification

Several types of variables obtained from the Stats19 were considered in the empirical analysis, including rider/motorist characteristics, vehicle attributes, roadway/geometric characteristics, weather factors, temporal factors, and crash characteristics. This research sought to include as many explanatory variables as possible from the Stats19. Variables that are not statistically significant were removed as these variables were considered to have random and non significant effects on injury outcome. Correlation matrix is also systematically examined among the variables included in the analysis. For the case where one variable is correlated with another variable with a correlation value of 0.5 or above, only one variable is remained in the analysis. Doing this can also avoid multicollinearity that may exists for a model that has a set of explanatory variables. The symptom of multicollinearity (e.g., wildly changing coefficients when an additional variable is included/removed or unreasonable coefficient magnitudes) was examined by observing whether the coefficients of the estimated models have meaningful signs and magnitudes.

All variables in the analysis were transformed into categorical variables for the ease of modelling interpretation. The final model specifications were based on a systematic process of combining categories in one variable when their effects were not significantly different from the reference cases. For example, rider/motorist age is divided into three age groups: teenager (up to 19), middle-aged (20–59), and the elderly (60+). Smaller age groups by, for instance, 20 years, may be desirable. Nevertheless, partitioning the data into smaller sets yielded sample sizes that were too small to analyse. As a result the three age groups presented were decided to be the most reasonable. The models that were most parsimonious and had the best statistical properties (e.g., $\chi^2_{\text{Hosmer and Lemeshow}}$, reasonable parameter magnitudes, and t-statistics) are reported as the final models.

Tables 1 and 2 have identified the most hazardous control measures and crash patterns to motorcyclists involved in angle perpendicular and oblique collisions, respectively. Two binary logistic models (model 1 and model 2) by the most severe combinations are subsequently estimated. These two separate models can be useful for obtaining a disaggregate “picture” of the factors that affect motorcyclist injury severity, conditioned on angle perpendicular/oblique collisions having occurred at stop-/yield-controlled T-junctions. It is worthwhile to mention here that additional models were also estimated for other hazardous combinations (i.e., in angle perpendicular/oblique collision where a car travelling straight collides with a turning motorcycle at stop/yield signs) but a vast majority of the variables were found to be insignificant in explaining injury severity. This is possibly due to relatively few occurrences of these two crash types ($N = 1773$; $N = 684$).

4. Empirical analysis

4.1. Estimation results

Table 3 (model 1) and Table 4 (model 2) present the estimation results for angle perpendicular and oblique collisions respectively where a travelling-straight motorcycle collided with a right-/left-turn car at stop-/yield-controlled junctions. The values of $\chi^2_{\text{Hosmer and Lemeshow}}$ in Tables 3 and 4 reveal that the two models explained the data reasonably well.

Fewer variables appeared to be statistically significant in determining injury levels in model 2 (possibly due to the relatively few occurrences of such crashes: $N = 5731$), and in contrast to model 1, HGVs were found to be the collision partner that posed the greatest risk of KSIs to motorcyclists. Those riding on non built-up roads were generally found to be more injurious for both crash types and specifically the relative parameter magnitudes of non built-up roads between models 1 and 2 indicate a relative increase in injury severity in model 1 (OR = 2.366). This may imply that higher speed limits impose greater collision-impact on a perpendicular collision (model 1) than an oblique collision (model 2).

There is also some evidence that motorcyclists riding on weekends and in early morning were generally more injurious (only for perpendicular crashes). These findings are perhaps reasonable, as it is likely that speeding and alcohol use are greater during these hours and there are more recreational and social activities on

Table 3
Statistics summary and the binary logistic model of the likelihood of KSIs for angle perpendicular crashes where a turning car was in a collision with a travelling-straight motorcycle at stop, give-way signs or markings.

Explanatory variable	Categories of each variable	Frequency (%)	Coefficient – model 1 (p-value)	Odds ratio (OR)
Intercept			−1.913 (<0.001)	
Rider age	1. Up to 19	4378 (20.4%)	−0.028 (0.512)	0.973
	2. Over 60	556 (2.6%)	0.419 (<0.001)	1.521
	3. 20–59	16507 (77.0%)	Reference case	Reference case
Motorist age	1. Up to 19	1378 (6.4%)	0.150 (0.015)	1.162
	2. Over 60	2769 (12.9%)	0.095 (0.040)	1.100
	3. 20–59	17,294 (80.7%)	Reference case	Reference case
Engine size	1. Engine size over 125 cc	15,744 (73.4%)	0.337 (<0.001)	1.401
	2. Engine size up to 125 cc	5697 (26.6%)	Reference case	Reference case
Collision partner	1. HGV (heavy good vehicle)	1122 (5.2%)	0.250 (<0.001)	1.283
	2. Bus/coach	170 (0.8%)	0.348 (0.033)	1.417
	3. Car	20,149 (94.0%)	Reference case	Reference case
Number of vehicle involved	1. $\geqslant 3$	1205 (5.6%)	0.442 (<0.001)	1.556
	2. Two-vehicle crash	20,236 (94.4%)	Reference case	Reference case
Weather condition	1. Fine weather	18,450 (86.1%)	0.146 (0.002)	1.158
	2. Bad weather	2991 (13.9%)	Reference case	Reference case
Accident time	1. Mid-night/early morning (0000–0659)	641 (3.0%)	0.559 (<0.001)	1.750
	2. Evening (1800–2359)	5677 (26.5%)	0.288 (<0.001)	1.333
	3. rush hours (0700–0859; 1600–1759)	8128 (37.9%)	0.055 (0.157)	1.056
	4. Non rush hours (0900–1559)	6995 (32.6%)	Reference case	Reference case
Accident day of week	1. Weekend (Saturday–Sunday)	4190 (19.5%)	0.112 (0.004)	1.119
	2. Weekday (Monday–Friday)	17,251 (80.5%)	Reference case	Reference case
Motorcycle's manoeuvre	1. Going straight	17,965 (83.8%)	0.149 (0.001)	1.161
	2. Traversing	3476 (16.2%)	Reference case	Reference case
Speed limit	1. Non built-up roads (>40 mph)	2972 (13.9%)	0.861 (<0.001)	2.366
	2. built-up roads ($\leqslant$40 mph)	18,469 (86.1%)	Reference case	Reference case
Right-of-way violation	1. Violation cases	17,623 (82.2%)	0.163 (<0.001)	1.177
	2. Non violation cases	3818 (17.8%)	Reference case	Reference case

Summary statistics
Hosmer and Lemeshow test $\chi^2 = 7.226$ (with 8 DF, $p = 0.512$)
Log-likelihood ratio index (ρ^2) = 0.056
The number of KSI that was correctly predicted: 536 (8.8%)
The number of slight injury was correctly predicted: 14899 (97.1%)
Observations: 21441 (KSI: 28.4%; slight: 71.6%)

Table 4
Statistics summary and the binary logistic model of the likelihood of KSIs for angle oblique crashes where a travelling-straight motorcycle was in a collision with a turning car at stop, give-way signs or markings.

Explanatory variable	Categories of each variable	Frequency (%)	Coefficient – model 2 (p-value)	Odds ratio (OR)
Intercept			−1.902 (<0.001)	
Rider age	1. Up to 19	1023 (17.9%)	−0.122 (0.180)	0.885
	2. Over 60	165 (2.9%)	0.338 (0.060)	1.403
	3. 20–59	4543 (79.3%)	Reference case	Reference case
Motorist age	1. Up to 19	363 (6.3%)	0.012 (0.928)	1.012
	2. Over 60	882 (15.4%)	0.212 (0.012)	1.236
	3. 20–59	4486 (78.3%)	Reference case	Reference case
Engine size	1. Engine size over 125 cc	4227 (73.8%)	0.364 (<0.001)	1.439
	2. Engine size up to 125 cc	1504 (26.2%)	Reference case	Reference case
Collision partner	1. HGV (heavy good vehicle)	357 (6.2%)	0.289 (0.018)	1.336
	2. Bus/coach	73 (1.3%)	−0.351 (0.259)	0.704
	3. Car	5301 (92.5%)	Reference case	Reference case
Number of vehicle involved	1. $\geqslant 3$	382 (6.7%)	0.392 (0.001)	1.480
	2. Two-vehicle crash	5349 (93.3%)	Reference case	Reference case
Accident month	1. Spring/summer (March–August)	2792 (48.7%)	0.125 (0.046)	1.133
	2. Autumn/winter (September–February)	2939 (51.3%)	Reference case	Reference case
Accident day of week	1. Weekend (Saturday–Sunday)	1126 (19.6%)	0.204 (0.007)	1.227
	2. Weekday (Monday–Friday)	4605 (80.4%)	Reference case	Reference case
Speed limit	1. Non built-up roads (>40 mph)	815 (14.2%)	0.650 (<0.001)	1.915
	2. Built-up roads ($\leqslant$40 mph)	4916 (85.8%)	Reference case	Reference case
Right-of-way violation	1. Violation cases	4797 (83.7%)	0.270 (0.003)	1.310
	2. Non violation cases	934 (16.3%)	Reference case	Reference case

Summary statistics
Hosmer and Lemeshow test $\chi^2 = 3.501$ (with 8 DF, $p = 0.899$)
Log-Likelihood ratio index (ρ^2) = 0.045
The number of KSI that was correctly predicted: 17 (1.2%)
The number of slight injury was correctly predicted: 4301 (99.7%)
Observations: 5731 (KSI: 24.7%; slight: 75.3%)

weekends (Broughton, 2005). With respect to the effect of engine size on injury severity, heavier motorcycles tended to predispose motorcyclists to more severe injuries (there was a 40.1% and 43.9% increase in KSIs). This is probably because larger motorcycles tend to be ridden on roadways with higher speed limits (Broughton, 2005).

A difference was observed for the effect of motorist age on motorcyclist injury severity in angle perpendicular and angle oblique crashes. Teenaged motorists predisposed riders to a greater risk of KSIs in angle perpendicular crashes (OR = 1.162) than any other age group (but not much different from elderly motorists: OR = 1.100), while injuries to riders were greatest in angle oblique collisions with the elderly motorists (OR = 1.236). These results underscore the need for a further study that examines and compares the crossing behaviours among motorists in different age groups when pulling out in front of the oncoming motorcycles (i.e., angle perpendicular crashes) and merging with the approaching motorcycles (i.e., angle oblique crashes). Crossing behaviours that may be examined in further work include elderly motorists' tendency to underestimate higher speeds (as found in the studies of car–car accidents by for example, Staplin and Lyles, 1991; Ulfarsson et al., 2006; Ryan et al., 1998; Mayhew et al., 2006; Braitman et al., 2007; Murphy, 2005; Retting et al., 2003a,b; Staplin, 1995; Scialfa et al., 1991; Garber and Srinivasan, 1991); the possibility that they cross into and merge with a stream more slowly and have problems detecting approaching motorcycles in urban environments (as found in the studies of car–motorcycle accidents by Clarke et al., 2007; Keskinen et al., 1998), and younger motorists inexperience, inattention, or risky driving behaviours (as found in the studies of car–car accidents by Clarke et al., 1998).

One independent variable deserved further attention here. The variable "right-of-way violation" was incorporated into the models. There are two categorises for this variable: right-of-way violation, and non right-of-way violation, as illustrated in Fig. 2. The

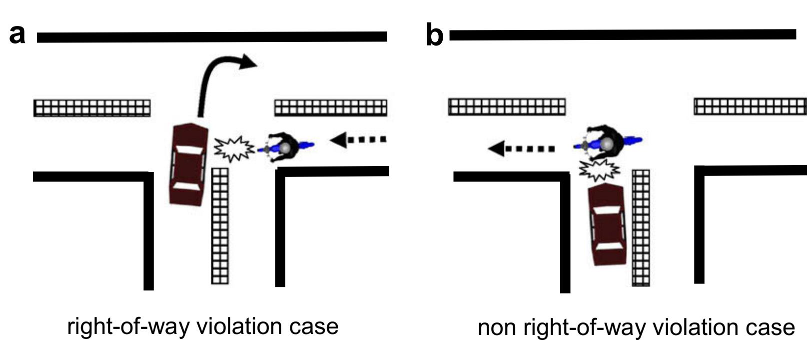

Fig. 2. Schematic diagram of the motorcycle as a striking or struck vehicle in angle collision at T-junctions (note: pecked line represents the intended path of a motorbike; solid line represents the intended path of a car).

definition of right-of-way violation and non right-of-way violation is as follows.

Right-of-way violation is defined as a crash where the car had entered the junction earlier than the approaching motorcycle and such motorcycle crashed into the side of the car. It was assumed that such right-turn car had been in the path of the oncoming motorcycle to which it should have yielded the right-of-way. It merits mention here that the front of the motorcycle does not necessarily have to be the first collision point with which the side of the car collides. The first crash point can be the side of the motorcycle with which the car collides due to the fact that motorcycles are more capable of swerving prior to the crash (Obenski et al., 2007). A crash in which the front of a right-turn car was the first crash point with which the front of an approaching motorcycle collides was also identified as a right-of-way-violation crash. This is because such right-turn car was assumed to have entered the junction as soon as the bike has entered the junction so that its front had struck the front of a motorcycle. A non right-of-way-violation crash was defined as a crash in which the motorcycle was the first vehicle that had entered the junction and the front of the car collided with the motorcycle's offside.

Consistent results were observed between the angle perpendicular crash model and angle oblique crash model with regard to the effect of driver's failure to yield. It was found that injuries were greatest in collisions in which a right-/left-turn car failed to yield to an oncoming motorcycle (an approximately 18% and 31% increased probability of KSI). The frequency data reveal that right-of-way violations resulted in more than 80% of all motorcyclist casualties for both two crash types.

4.2. Likelihood of right-of-way violation

In the course of the investigation of the factors that affect motorcyclist injury severity in angle crashes, it became clear that another problem, that of a right-turn motorist's failure to yield to motorcyclists, needs to be further examined. The binary logistic models were estimated to evaluate the likelihood of motorist's right-of-way violation over non right-of-way violation as a function of human, vehicle, weather, and environment factors. The analyses here are limited to angle perpendicular crashes that occurred at stop-/yield-controlled junctions where a right-turn car collided with an oncoming motorcycle. The binary logistic regression analysis was conducted for angle oblique accidents in which one left-turn car collided with an approaching motorbike. The estimation results of such model appeared to be comparable with those of the model for angle perpendicular crashes. As a result, only the results for angle perpendicular crashes are reported here (Table 5). The values of $\chi^2_{\text{Hosmer and Lemeshow}}$ in Table 5 reveal that the model explained the data reasonably well.

It merits mention here that the analyses were limited to the occurrences of violation and non violation cases in accidents rather than motorcyclist casualties in accidents. It was thought that analyses of motorcyclist casualties in accidents may lead to imprecise results as one individual violation case may result in more than one motorcycle casualty (i.e., a rider and a pillion passenger). A total of 20,644 angle perpendicular accidents were included in the analysis.

The results reveal that the right-of-way of male riders (OR = 1.424; relative to female riders) and younger riders (OR = 1.061; relative to mid-aged riders) was more likely to be violated. Male motorists were more likely to infringe upon motorcyclists' right-of-way (OR = 1.111).

In additional to gender-/age-specific determinants of motorist's failure to yield, other factors such as temporal factors, roadway factors were examined. Motorcycle's right-of-way in dusk lighting conditions (i.e., evening and mid-night/early morning hours, relative to non rush hours) was more likely to be violated. Professional motorists (i.e., HGV or bus/coach driver) were more likely to fail to yield than passenger car drivers. Regarding the effect of speed limit, right-of-way on non built-up roadways was 39% more likely to be violated than that on built-up roadways.

Conspicuity problem that motorcycles have may also arise from the fact that motorcycles being much smaller than other motor vehicles (particularly when viewed from the front of machine)

Table 5
The binary logistic model of the likelihood of motorist's right-of-way violations over non right-of-way violation for angle perpendicular crashes at stop-/give-way controlled junctions.

Variable	Categories of each variable	Coefficient (*p*-value)	Odds ratio (OR)
Intercept		0.872 (<0.001)	
Rider gender	1. Male	0.354 (<0.001)	1.424
	2. Female	Reference case	Reference case
Rider age	1. 60 Above	−0.276 (0.009)	0.759
	2. Up to 19	0.059 (0.198)	1.061
	3. 20–59	Reference case	Reference case
Motorist gender	1. Male	0.105 (0.005)	1.111
	2. Female	Reference case	Reference case
Collision partner	1. Heavy good vehicle	0.210 (0.018)	1.234
	2. Bus/coach	0.313 (0.175)	1.368
	3. Car	Reference case	Reference case
Accident time	1. Midnight; early morning (0000–0659)	0.290 (0.016)	1.337
	2. Evening (1800–2359)	0.196 (<0.001)	1.216
	3. Rush hours (0700–0859; 1600–1759)	−0.021 (0.618)	0.979
	4. Non rush hours (0900–1559)	Reference case	Reference case
Speed limit	1. Non built-up roads (>40 mph)	0.329 (<0.001)	1.389
	2. Built-up roads (⩽40 mph)	Reference case	Reference case
Manoeuvres of the motorcycle	1. Going straight	0.223 (<0.001)	1.424
	2. Traversing	Reference case	Reference case

Summary statistics
Hosmer and Lemeshow test χ^2 = 6.310 (with 8 D.F., p = 0.613)
Log-Likelihood ratio index (ρ^2) = 0.048
The number of right-of-way violation cases that was correctly predicted: 16988 (100%)
The number of non right-of-way violation cases that was correctly predicted: 0 (0%)
Observations: 20644 (16988 violation cases; 3656 non violation cases)

are more likely to be blocked in traffic streams (Olson, 1989). Researchers (e.g., Hurt et al., 1981; Williams and Hoffmann, 1979) suggested that blockages such as larger motor vehicle nearby or a nature obstruction (e.g., tree or curved roadway) may cause motorist's failure to see the oncoming motorcycle or see it in time to avoid the crash. There has been considerable agreement among these researchers – blockages of direct visibility may play a significant role in approximately half of motorcycle–car crashes that involved right-of-way violations. Other researchers (e.g., Preusser et al., 1995; Clarke et al., 1999; Kim and Boski, 2001) suspected that motorcycles' improper overtaking manoeuvres would reduce their visibility because they generally popped out in traffic streams.

In this current paper, the effects of these two factors (i.e., the presence of bend and motorcycles' traversing manoeuvres) on the likelihood of motorists' right-of-way violations were examined. The presence of bend was not significant in explaining the likelihood of motorists' failure to yield and thus was excluded from the final model. Moreover, it was found that the right-of-way of a travelling-straight motorcycle was 42% more likely to be violated than that of a traversing motorbike. The possible explanation for the first result is that the bend data of the Stats19 were thought to be somewhat unreliable – none of traversing manoeuvres (i.e., overtaking or lane changing) was recorded to have occurred on curved roads. The second result could be attributable to the possibility that a travelling-straight motorcycle may travel faster than a traversing motorcycle, allowing less time for a turning motorist to clear the junction in time. It could also be a consequence of an overtaking manoeuvre by a motorcycle that represents the presence of other motorised vehicles nearby, which may act as a visual deterrent to reckless crossing by a turning motorist.

5. Discussions and research limitations

The most hazardous crash patterns identified for angle perpendicular and angle oblique crashes were collisions where one travelling-straight motorbike collided with a right-/left-turn car travelling from the minor road. These two crash patterns that occurred at stop-/yield-controlled junctions appeared to predispose riders to a greater risk of KSIs. Two separate binary logistic models were estimated by these two deadly combinations and one of the main findings was that injuries were greatest in collisions where a right-/left-turn car infringed upon the motorcycle's right-of-way.

The binary logistic model was estimated to examine the factors determining the likelihood of motorists' failure to give-way. The findings could be used to enhance enforcement efforts as well as public information and safety education programmes to curb motorists' failure to yield. For instance, safety education programmes may be directed toward certain drivers such as male motorists or drivers of heavier vehicles. Enforcement efforts may need to be directed towards certain times and locations where the right-of-way was more likely to be violated (e.g., during evening/nighttime hours and on non built-up roads). Several studies have reported that enforcement by police near a junction makes turning motorists more cautious (e.g., Cooper and McDowell, 1977; Storr et al., 1980). It is clear here that such temporal factors (i.e., evening/mid-night/early morning) and location factors (non built-up roads) need to be taken into consideration in the implementation of police-enforcement strategies meant to curb motorcycle–car crashes that result from right-of-way violations.

The result that the right-of-way on non built-up roads was more likely to be violated than that on built-up roads may deserve further discussions. Statistics from DfT (2006) has revealed several phenomenons about the speed distributions by motorcycles and automobiles – it was found that average motorcycle speeds are generally slightly higher than average automobile speeds on the same types of roads. Specifically, about a quarter of motorcyclists exceed the speed limit by more than 10 mph on motorways and dual carriageways, while around one in ten exceed the limit by more than 10 mph on other roads. In the study by Brenac et al. (2006), the mean speed of the motorcycle involved in conspicuity-related accidents was significantly higher than that in non conspicuity-related collisions. Brenac et al. together with Kim and Boski (2001), suggested that motorcycles' poor conspicuity may be exacerbated with higher speed, which may decrease their detectability from a turning motorist's perspective. Peek-Asa and Kraus (1996) specifically discussed speeding effect on the occurrences of approach-turn crashes. They found that for approach-turn crashes, a motorcycle striking a turning car (i.e., a right-of-way violation case) was more prone to be speeding than a motorcycle struck by a turning car (i.e., a non right-way-way violation case). The turning motorist may therefore not be able to correctly judge the speed of the approaching motorcycle and may not clear the junction in time to avoid a crash. They suggested that controlling motorcycle speed may decrease the number of such crash type.

Motorists' higher speeds arising from higher speed limits may also result in themselves failing to yield to motorcyclists. This hypothesis may be supported by Summala and his colleagues (Räsänen and Summala, 2000; Summala et al., 1996) who analysed accidents involving cyclists and motorists at roundabouts. They reported that higher vehicle approach speed contributed to motorists not looking to their right or to not giving way to cyclists at roundabouts. They further pointed out that speed-reducing countermeasures may enable a turning driver to have more time in searching a bicyclist travelling from the right.

Some research limitations in this paper would accrue from analysing police report data. For example, this study is limited to the variables that are available in the Stats19 database, which does not contain other factors that might play a part in influencing injury severity or the likelihood of right-of-way violation. These factors include, for example, speed of motorcycle and its collision partner, helmet and alcohol use, causes to an accident (e.g., speeding, etc.), or more complete geometric factors. Other source of data that is more detailed than the Stats19, or a more in-depth assessment of the accident scene for geometric factors, would allow more precise and conclusive results of model estimation.

6. Conclusions and recommendations for further works

Certain hazards that contribute to severe injuries have been successfully identified in this study. The current research may represent a contribution to the profession through the insight that several pre-crash conditions contributed to more severe injuries sustained by motorcyclists in angle collisions at T-junctions. The main contributions of this present study are threefold. First, motorcyclists were most likely to be KSI in collisions where one travelling-straight motorbike collided with a right-/left-turn car travelling from the minor road. Stop, give-way signs or markings as junction control measures appeared to be associated with greater injury severity resulting from these crash patterns. Second, where stop, give-way signs or markings controlled the junctions, injuries were greatest in the crashes in which the right-/left-turn car infringed upon the motorcycle's right-of-way. Finally, this current study has revealed the factors determining the likelihood of motorists' failure to yield. The results could be used to enhance enforcement efforts as well as public information and safety education programmes to curb motorists' failure to yield.

The analyses in this current research are limited by the variables that are readily available in the Stats19. Clearly there is room for improving the model specification by incorporating additional variables into the models. These additional variables include, for example, headlight use, alcohol use, detailed roadway geometrics data, medical diagnoses records, or detailed motorcycle factors. Analyses of more detailed data than those obtained from the Stats19 would provide more precise and conclusive estimation results.

Overall, the current research contributes to the literature from empirical but not modelling methodological standpoints. The binary logistic models estimated in this research were found to suffer from the same problem of previous studies that estimated traditional discrete-choice models – the less frequent categories of the dependent variable tended to be predicted badly (see a full discussion by Greene, 2003). Although the combination of fatal injury and serious injury as one single KSI category resulted in more accurate prediction capability than two individual categories, the accuracy was still fairly low (8.8% and 1.2% for model 1 and model 2, respectively). It should be noted here that it was not the aim of this study to provide a method to judge success and failure of a random utility model. We leave this to further work that may attempt to identify whether the predictability of the logistic models can be improved by estimating some other non-parametric models such as artificial neural networks.

It merits mention that, although research (see, for example, Hancock et al., 1990; Peek-Asa and Kraus, 1996) has adopted similar approach to define a right-of-way violation, one may still argue that assuming right-of-way violation by the position of the involved vehicle (i.e., whether one automobile has emerged from the junction prior to an oncoming motorcycle) may be somewhat subjective. For instance, a right-turn car crashing into the offside of an approaching motorcycle (such motorcycle was the first vehicle entering the junction) could be classified as a right-of-way violation case rather than a non violation case. This is because such right-turn motorist may be too impatient to wait for the oncoming motorbike to clear the junction (or simply misjudge the time such motorbike needs to clear the junction), thereby deliberately infringing upon such motorcycle's right-of-way and crashing into its offside. It seems reasonable to assume that in both cases the motorcycle has right-of-way. However, it was assumed in the present paper that motorcycle's right-of-way was directly violated by a turning car in an accident where such car has entered the junction earlier than the motorcycle. If the second case (i.e., motorcycle entering the junction earlier than the car) was counted as a right-of-way violation case, there would not be any non violation case. This would not be realistic and as a result, for the current study, it was decided not to define right-of-way violation in this way. It is beyond the scope of this current research to examine whether the approach adopted in previous studies and in this research is robust without any bias. Further studies may seek to obtain more reliable violation data from, for instance, laboratory/computer simulation studies (e.g., Horswill et al., 2005), instead of a police report dataset.

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