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An analysis of motorcyclist injury severity under various traffic control measures at three-legged junctions in the UK

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Abstract

The effects various junction control measures have on accident frequencies among vehicles have been investigated by previous studies through the use of statistical modelling techniques but such effects on motorcyclist injury severity, given that a junction-type accident has occurred, have received little attention in literature. This paper attempts to estimate econometric models of motorcyclist injury severity under different control measures at three-legged junctions in the UK, as a function of demographic, vehicle and environmental factors. Separate ordered probit models were estimated for unsignalised and signalised junctions, using the data extracted from the STATS19 accident injury database (1999–2004). Also examined in the models are collision partners' aggressiveness toward motorcyclists and the impacts various crash configurations have on injury severity. The modelling results uncover several combined factors that were deadly to motorcyclists: for example, injuries tended to be much more severe while motorcyclists involving in approach-turn collisions at signalised junctions than at unsignalised junctions. This study ultimately offers insights into potential countermeasures that could be undertaken to help lessen motorcyclist injury severity at three-legged junctions in the UK.

Keywords: Motorcyclist injury severity at three-legged junction; Traffic control measure; The ordered probit model

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1. Introduction

In the UK motorcyclists' relative risk of being killed or seriously injured (KSI) per kilometre travelled is more than twice that for cyclists and almost 50 times that for car drivers (DfT, 2004). Between years 1999–2004 a majority of motorcycle-related accidents has taken place at three-legged junctions (36%), followed by "non-junction roads" (32.2%), "crossroads" (9.7%), and "roundabouts" (9.1%). These figures suggest that, in terms of mileages travelled and injury severity, motorcyclists are the most vulnerable road users in the UK and three-legged junctions pose the greatest risks to motorcyclists. Motorcyclists tend to expose themselves more to traffic than other road users, which may act synergistically with the complexity of conflicting movements between motorcycles and other vehicles to increase their injury levels resulting from a junction-type accident. A common countermeasure that has been applied for reducing frequent conflicts among road users at junctions is to implement various junction control measures. The effects various junction control measures have on accident frequencies among vehicles have been investigated by previous studies through the use of statistical modelling techniques but their effects on motorcyclist injury severity, given that a junction-type accident has occurred, has received little attention in literature. The multiple factors (e.g., human, environmental or vehicle factors) that influence injury levels could be more complicated in a junction-type crash than in a non junction-type case. A better understanding of such multiple factors could further facilitate the identification of suitable countermeasures which could help prevent/lessen motorcycle-related accidents/injuries. The main purpose of this study was to analyse real-life data and explore the determinants of motorcyclist injury severity under various control measures at three-legged junctions in the UK.

Our paper begins with an outline of relevant literature examining the effects various traffic control measures have on vehicle–accident frequencies and severities. This is followed by a description of the data and a discussion of the econometric model approach proposed for analysing the real-life data. The paper concludes with a summary of model estimation results and directions of future research.

2. Literature review

There exist several studies examining the effects various traffic control measures have on the accident frequencies among various motorised vehicles. A study by Poch and Mannering (1996) investigated the factors that affect intersection-accident occurrences among vehicles by estimating the negative binomial approaches. They concluded that the intersections controlled by signal measures resulted in a significant decrease in both overall-accident and angle-accident frequencies. Signal controls that have different sets of phases were also found to affect the occurrence of specific crash type. Chin and Quddus (2003) have applied the negative binomial model to examine the factors that affect accident frequencies at signalised intersections in Singapore, suggesting that adaptive signal-control measures were more likely to reduce accident occurrence than pre-timed signal-control measures. Mitra et al. (2002) conducting the nero-altered probability models found that there was a decreased occurrence of head-to-rear vehicle accidents by the introduction of adaptive signal controls at four-legged junctions in Singapore but an increase in signal phases tended to result in an increased occurrence of both head-to-rear and head-to-side accidents. The negative binomial model was employed by Wang and Nihan (2004) to estimate the risk of collisions between bicycles and vehicles at signalised intersections in Japan. Their modelling results indicate that four-phase signal-control measures were more effective than two-phase control measures in reducing conflicts between bicycles and right-turn vehicles.

There is clear evidence based on the abovementioned studies documenting the decreased risks of vehicle–accident occurrence as a result of presence of junction control measures. Nevertheless research conducted to investigate their effects on motorcyclist injury severity resulting from a junction-type accident is scant. The most recent and relevant study that has explored such issue, but not for motorcyclist, is by Lee and Abdel-Aty (2005), who concluded that there was an increased pedestrian injury severity at the intersections that were not controlled by any traffic control measure. Another study was by Zhang et al. (2000), who found that elderly drivers were more likely to be severely injured at intersections where there was no traffic control measure.

Other factors that influence injury severities among various road users have been extensively documented in literature, but relatively little for motorcyclists. Among these few studies concerning motorcyclists, several important findings have been concluded: for example, greater motorcycle engine size and motorcycle speed resulted in higher injury severity levels (Quddus et al., 2002; Langley et al., 2000; Shankar and Mannering, 1996; Lin et al., 2003); female riders were more injurious than males (Quddus et al., 2002; Keng, 2005); collisions with stationary objects or heavier vehicles result in more severe injuries (Quddus et al., 2002; Lin et al., 2003; Keng, 2005). Inconsistent results have been found in literature with regard to the effect motorcyclist age has on motorcyclist injury severity (e.g. Shankar and Mannering, 1996; Rutter and Quine, 1996; Elliott et al., 2004). Comparatively little work has been conducted to examine whether a specific collision-type is more injurious to motorcyclists, while a study by Peek-Asa and Kraus (1996) revealed that motorcyclists involving in approach-turn collisions at crossroads had decreased occurrences of head, chest and facial injuries, but were far more likely to suffer from abdominal and lower extremity injuries.

To sum up, the existing studies have provided valuable empirical insights into the relationship between various factors, including control measures, and motorcyclist injury severity. Nevertheless a great majority of these studies focused on accidents that occur along roadway segments rather than at a specific type of junction, where the causes leading to injury severity levels can be complicated by multiple factors. Without a proper understanding of such multiple factors that influence injury outcomes, countermeasures based on the findings of past literature may be ineffective. This study attempts to apply appropriate statistical modelling approach to analyse real-life data, exploring the determinants of motorcyclist injury severity under various junction control measures conditioned on the crash occurrence at three-legged junctions in the UK.

3. Data

The data, known as STATS19 accident injury database, used in this study are owned by Department for Transport, Great Britain. The STATS19 accident injury database for collection of road accident information was established in 1949, and has been periodically reviewed and modernised. The data of STATS19 comprise three files: accident file, vehicle file and casualty file. Accident file records information on crash time and date, weather, road and light conditions, speed limit, and road type of accident; vehicle file contains vehicle and driver details, such as age and gender, vehicle manoeuvres, and vehicle type hit by each individual vehicle; and casualty file includes detail for each casualty. Six-year accident data (1999–2004) were obtained from STATS19 and the data of 45 839 motorcyclist casualties resulting from the motorcycle-related accidents that took place at three-legged junctions were extracted. These motorcyclist casualties include riders and pillion passengers, excluding in cases where an injury has occurred to a pedestrian or occupants in other

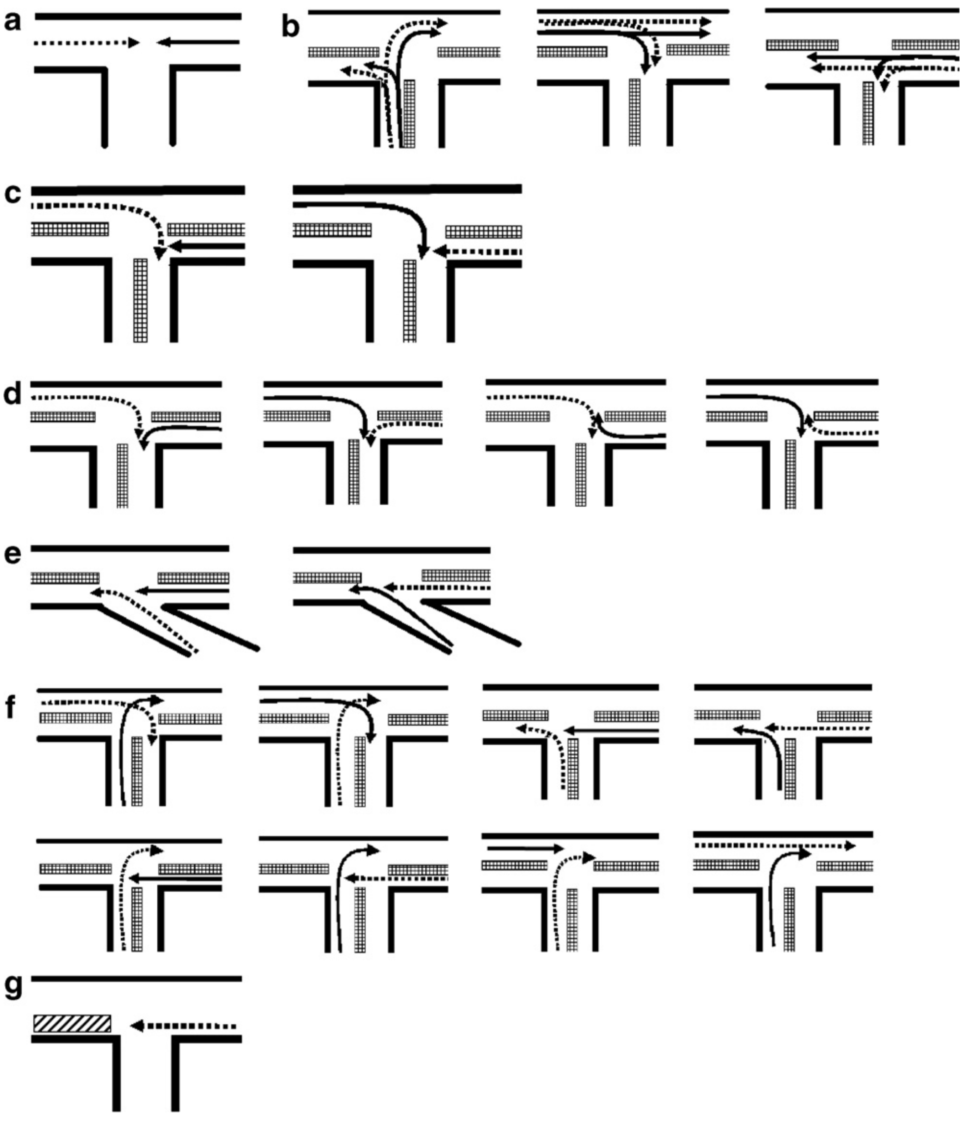

Fig. 1. Schematic diagram of crash configurations at T-junctions. (a) Head-on collision, (b) same-direction collision, (c) approach-turn A/B collision, (d) both-turning A/B collision, (e) merging collision, (f) different-direction A/B collision, (g) collision with a parked/reversing vehicle. *Note*: dotted line represents the path of a motorcycle; black line represents the path of other road user (except pedestrians).

vehicles colliding with motorcycles. 1.4% of these motorcyclist victims are classified as fatal, 21.8% as serious injured, and 76.8% as slightly injured.

A junction-type collision could be more severe than a non-junction case due to the fact that some of the injurious crashes such as angle-collision commonly occur. In this current study, several crash configurations between motorcycles and other road users (excluding pedestrians) are categorised as Fig. 1 illustrates and explained below:

(a) a head-on collision is defined as a collision which takes place when one motorcycle and one vehicle travelling from opposite directions collide with an angle of impact of zero; (b) a same-direction collision is defined as a collision which occurs while one motorcycle and one vehicle travelling from same directions collide each other, including either side-swipe or rear-end crashes; (c) an approach-turn A/B collision is defined as a collision which takes place while one vehicle/motorcycle approaching straight collides with a motorcycle/vehicle travelling from opposite direction and turning right into the path of first vehicle/motorcycle. This includes either a vehicle or motorcycle making a U-turn onto the same street as the approaching vehicle/motorcycle; (d) a both-turning collision is defined as a collision while one vehicle turning right/left/U-turn collides with a motorcycle turning right/left/U-turn and both are from opposite directions. This is further categorised into two crashes: a both-turning A/B collision (mild and acute collision-angle, respectively); (e) merging collisions: one vehicle and motorcycle travelling from different directions collide each other at an angle of impact of less than 90°; (f) a different-direction A/B collision: one vehicle and motorcycle travelling from different directions collide each other at an acute angle and "merging" angle, respectively; and (g) collisions with parked/reversing vehicles: a motorcycle collides with a parked/reversing vehicle.

The collisions in these crash configurations are based on the first vehicle colliding with a motorcycle for the cases where there were multi-vehicle crashes. Several collisions that have small number of occurrences are combined with other crashes that have greater occurrences so that variability caused by random effects when statistical models are applied can be reduced. For example, "both-turning collision A" and "merging collision" are combined with "different-direction collision B" as these three types of crash have mild collision-angle. "Both-turning collision B" is combined with "different-direction collision A" as these two crashes have acute angle of impact.

4. Modelling methodology: the ordered-discrete choice model

Several econometric models have been adopted in literature to isolate factors that affect injury severities sustained by various road users. Long (1997) suggested that unordered multinomial or nested logit or probit models, while accounting for categorical nature of the dependent variable, disregard the ordinal nature of injury severity levels and are associated with undesirable properties, such as the independence of irrelevant alternatives (IIA) in the case of a multinomial logit model (Ben-Akiva and Lerman, 1985). The lack of a closed-form likelihood can also be problematic in the case of a multinomial probit model (Greene, 2000). Several researchers (see, for example Duncan et al., 1998; Quddus et al., 2002) have proposed the ordered-discrete choice models (i.e., the ordered probit/logit models: OP/OL) for modelling injury severities and suggested that an ordered-discrete choice model is able to account for unequal differences between categories in the dependent variable, as well as being able to relax the restriction of the IIA.

The OP/OL models are usually in a latent (i.e., unobserved) variables framework and the general specification is:

$$y_i^* = \beta' x_i + \varepsilon_i \tag{1}$$

where y_i^* is the latent and continuous measure of injury severity faced by an accident victim i in an accident; β' is the vector of estimated parameters; x_i is the $(K \times 1)$ vector of observed non-stochastic (i.e., non-random) explanatory variables, and ε_i is the normally distributed error term with zero mean and unit variance for the OP model, but logistically distributed for the OL model. Note here that the error terms for different accident victims are assumed to be uncorrelated (i.e., disturbance term is assumed to be heteroskedastic, representing the variance of the disturbance term can vary from one victim to another). Standard regression techniques can not be applied to calculate Eq. (1) because the dependent variable y_i^* is unobserved. Instead the data used in this study include the observed data y_i, a coded discrete variable measuring the injury level sustained by an accident victim, i: $y_i = 1$ for slight injury; $y_i = 2$ for serious injury and $y_i = 3$ for fatality. The observed and coded discrete injury severity,y_i, can be determined from the following formulae:

$$y_i = \begin{cases} 1 & \text{if } -\infty < y_i^* \leqslant \mu_1 \text{ (slight injury)} \\ 2 & \text{if } \mu_1 < y_i^* \leqslant \mu_2 \text{ (serious injury)} \\ 3 & \text{if } \mu_2 < y_i^* < +\infty \text{ (fatal injury)} \end{cases}$$

where the threshold values $\mu 1$ and $\mu 2$ are unknown parameters to be estimated. The predicted probabilities of the three coded injury severity levels by a victim i, for given x_i are:

$$\begin{aligned} P(y_i = 1|\text{accident}) &= \Phi(\mu_1 - \beta' x_i) \\ P(y_i = 2|\text{accident}) &= \Phi(\mu_2 - \beta' x_i) - \Phi(\mu_1 - \beta' x_i) \\ P(y_i = 3|\text{accident}) &= 1 - \Phi(\mu_2 - \beta' x_i) \end{aligned}$$

where $\Phi(u)$ denotes the cdf (cumulative density function) of the random error term ε_i evaluated at u. The method of maximum likelihood is used for estimating parameters of the OP/OL models. For the OP model, ε_i is normally distributed with mean 0 and variance 1 and the cdf is:

$$\Phi(\varepsilon) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\varepsilon} \exp\left(-\frac{t^2}{2}\right) \mathrm{d}t$$

For the OL model, ε_i is logistically distributed with a mean of 0 and a variance of $\pi^2/3$ and the cdf is:

$$\Lambda(\varepsilon) = \frac{\exp(\varepsilon)}{1 + \exp(\varepsilon)}$$

A measure of model goodness-of-fit ρ^2 (McFadden, 1973) can be calculated as:

$$\rho^2 = 1 - [\ln(L_b)/\ln(L_0)]$$

where $\ln(L_b)$ is the maximised likelihood and $\ln(L_0)$ is the likelihood assuming all the model slope coefficients are equal to 0. This measure is bounded by 0 and 1 and as it approaches 1, model fit improves.

In practice the OP and OL formulations give very similar results and therefore only the estimation results of the OP models are reported in the following section. It is worth noting that the logistic regression model could also be applied if fatal injury and serious injury were to be combined as one category (i.e., KSI), resulting in a total of two categories in the dependent variable: slight and KSI. However such model may not be able to examine the whole spectrum of motorcycle injury severity (i.e., the probabilities of sustaining slight, serious or fatal injuries separately) due to the combination of serious and fatal injury.

4.1. Model specification

Three OP models are estimated in this study for the junctions controlled by three different control measures – model 1: stop, give-way signs or markings; model 2: uncontrolled; and model 3: signal measures. Estimation of these three unrestricted models is preferable to employing one restricted model since such separate models allow us to separately investigate the effects of the explanatory variables on injury severity levels under different control measures. Theoretically the impacts human, vehicle, and environmental factors have on motorcyclist injury severity are expected to vary across three-legged junctions that are controlled by various traffic measures. For example, one would expect a speed limit to have a different impact on injury levels at uncontrolled junctions than it would at signalised junctions but such information may be obscured by conducting a pooled model that restricts the variable "junction control measures" in one model. From a statistical standpoint, such separate models may also avoid the complicated interpretations resulting from several interaction terms (e.g., interaction effects of control measures and other variables) that have to be included in one restricted model specification, and may overcome the potential collinearity problems. Table 1 presents a summary of the exploratory variables examined and hypothesised in this study to be associated with the dependent variable and the modelling estimation results were reported in Table 2.

5. Model estimation results

5.1. Overall results

Overall results are reported in this section. A positive sign of the estimated parameters implies increased injury severities sustained by motorcyclists with increase in the value of the explanatory variables. Significance value (P-value) for each category of variable is reported in parentheses.

5.1.1. Model 1

Model 1 examines the factors that affect injury severity levels resulting from accidents where stop, give-way signs or markings controlled the junctions. Factors found to be most significantly associated with the increased injury levels include: male or elderly rider; greater motorcycle engine size; riding in early morning, on weekend, in spring/summer month, and under fine weather; street lights unlit; riding on non built-up road (speed limit over 40 mph); collisions with bus/coach or HGV (heavy good vehicle); and involving in a head-on or approach-turn B collision.

Table 1
Statistics summary by three separate models

Explanatory variable	Categories of each variable	Frequency (%) – model 1	Frequency (%) – model 2	Frequency (%) – model 3
Dependent variable	1. Slight	28567 (76.3%)	4295 (77.3%)	2351 (83.1%)
	2. Serious	8332 (22.2%)	1194 (21.5%)	457 (16.2%)
	3. Fatal	553 (1.5%)	69 (1.2%)	21 (0.7%)
Gender of rider	1. Male	34580 (92.3%)	5148 (92.6%)	2608 (92.2%)
	2. Female	2872 (7.7%)	410 (7.4%)	221 (7.8%)
Age of rider	1. Up to 19	9017 (24.1%)	1667 (30.0%)	482 (17.0%)
	2. 20–59	27636 (73.8%)	3749 (67.5%)	2301 (81.3%)
	3. 60 above	799 (2.1%)	142 (2.6%)	46 (1.6%)
Engine size	1. Moped	6630 (17.7%)	1123 (20.2%)	441 (15.6%)
	2. Motorcycle up to 125 cc	11154 (29.8%)	1603 (28.8%)	794 (28.1%)
	3. Motorcycle with 125 cc above	19668 (52.5%)	2832 (51.0%)	1594 (56.3%)
Collision partner	1. Pedal cycle	242 (0.6%)	52 (0.9%)	31 (1.1%)
	2. Motorcycle	721 (1.9%)	161 (2.9%)	82 (2.9%)
	3. Heavy good vehicle	2753 (7.4%)	396 (7.1%)	273 (9.7%)
	4. Bus/coach	495 (1.3%)	59 (1.1%)	73 (2.6%)
	5. Car	33241 (88.8%)	4890 (88.0%)	2370 (83.8%)
Accident month	1. Spring/summer (March–August)	19096 (51.0%)	2960 (53.3%)	1476 (52.2%)
	2. Autumn/winter (September–February)	18356 (49.0%)	2598 (46.7%)	1353 (47.8%)
Light condition	1. Darkness: street lights unknown	217 (0.6%)	43 (0.8%)	19 (0.7%)
	2. Darkness: street lights lit	8796 (23.5%)	1127 (20.3%)	827 (29.2%)
	3. Darkness: street lights unlit	731 (2.0%)	147 (2.6%)	22 (0.8%)
	4. Daylight	27708 (74.0%)	4241 (76.3%)	1961 (69.3%)
Weather condition	1. Other/unknown	684 (1.8%)	138 (2.5%)	65 (2.3%)
	2. Bad weather	4521 (12.1%)	636 (11.4%)	318 (11.2%)
	3. Fine weather	32247 (86.1%)	4784 (86.1%)	2446 (86.5%)
Accident time	1. 0000–0659	1193 (3.2%)	147 (2.6%)	161 (5.7%)
	2. 0700–0859	5118 (13.7%)	606 (10.9%)	332 (11.7%)
	3. 0900–1559	13361 (35.7%)	2072 (37.3%)	1014 (35.8%)
	4. 1600–1759	7632 (20.4%)	1241 (22.3%)	491 (17.4%)
	5. 1800–2359	10148 (27.1%)	1492 (26.8%)	831 (29.4%)

(*continued on next page*)

Table 1 (*continued*)

Explanatory variable	Categories of each variable	Frequency (%) – model 1	Frequency (%) – model 2	Frequency (%) – model 3
Accident day of week	1. Weekday (Monday–Thursday)	23090 (61.7%)	3293 (59.2%)	1814 (64.1%)
	2. Weekend (Friday–Sunday)	14362 (38.3%)	2265 (40.8%)	1015 (35.9%)
Speed limit	1. Built-up roads	33159 (88.5%)	4757 (85.6%)	2737 (96.7%)
	2. Non built-up roads	4293 (11.5%)	801 (14.4%)	92 (3.3%)
Crash configuration	1. Head-on	1217 (3.2%)	301 (5.4%)	40 (1.4%)
	2. Same-direction	12504 (33.4%)	5061 (37.1%)	1564 (55.3%)
	3. Approach-turn A	309 (0.8%)	28 (0.5%)	99 (3.5%)
	4. Approach-turn B	5422 (14.5%)	880 (15.8%)	543 (19.2%)
	5. Different-direction A	12314 (32.9%)	1437 (25.9%)	322 (11.4%)
	6. Different-direction B	4460 (11.9%)	522 (9.4%)	180 (6.4%)
	7. Collided with parked/reversing vehicle	1226 (3.3%)	329 (5.9%)	81 (2.9%)
	Observations	37452	5558	2829

Table 2
Estimation results of three separate models

Explanatory variable	Categories of each variable	Coefficients – model 1	Coefficients – model 2	Coefficients – model 3
Gender of rider	1. Male	0.132 (<0.001)	−0.008 (0.948)	0.283 (0.024)
	2. Female	Reference case	Reference case	Reference case
Age of rider	1. Up to 19	−0.232 (<0.001)	−0.307 (0.091)	−0.153 (0.509)
	2. 20–59	−0.281 (<0.001)	−0.111 (0.516)	−0.105 (0.632)
	3. 60 Above	Reference case	Reference case	Reference case
Engine size	1. Moped	−0.375 (<0.001)	−0.657 (<0.001)	−0.194 (0.051)
	2. Motorcycle up to 125 cc	−0.217 (<0.001)	−0.179 (0.018)	−0.136 (0.053)
	3. Motorcycle with 125 cc above	Reference case	Reference case	Reference case
Collision partner	1. Pedal cycle	−0.164 (0.084)	−0.673 (0.101)	−0.354 (0.273)
	2. Motorcycle	−0.032 (0.549)	−0.048 (0.789)	−0.008 (0.964
	3. Heavy good vehicle	0.197 (<0.001)	0.336 (<0.001)	0.185 (0.053)
	4. Bus/coach	0.194 (0.001)	0.397 (0.119)	0.347 (0.031)
	5. Car	Reference case	Reference case	Reference case
Accident month	1. Spring/summer (March–August)	0.030 (0.049)	0.066 (0.296)	0.031 (0.609)
	2. Autumn/winter (September–February)	Reference case	Reference case	Reference case
Light condition	1. Darkness: street lighting unknown	0.104 (0.274)	0.152 (0.651)	0.252 (0.498)
	2. Darkness: street lights lit	0.081 (<0.001)	0.170 (0.080)	0.005 (0.952)
	3. Darkness: street lights unlit	0.101 (0.043)	0.409 (0.007)	−0.155 (0.636)
	4. Daylight	Reference case	Reference case	Reference case
Weather condition	1. Other/unknown	−0.158 (0.005)	−0.485 (0.033)	−0.931 (0.004)
	2. Bad weather	−0.095 (<0.001)	−0.102 (0.297)	−0.215 (0.028)
	3. Fine weather	Reference case	Reference case	Reference case
Accident time	1. 0000–0659	0.212 (<0.001)	0.004 (0.980)	0.098 (0.436)
	2. 0700–0859	−0.080 (0.003)	−0.106 (0.362)	0.029 (0.802)
	3. 0900–1559	−0.111 (<0.001)	−0.044 (0.608)	−0.069 (0.468)
	4. 1600–1759	−0.086 (<0.001)	−0.194 (0.029)	0.068 (0.470)
	5. 1800–2359	Reference case	Reference case	Reference case
Accident day of week	1. Weekday (Monday–Thursday)	−0.089 (<0.001)	−0.036 (0.547)	0.016 (0.796)
	2. Weekend (Friday–Sunday)	Reference case	Reference case	Reference case

(*continued on next page*)

Table 2 (*continued*)

Explanatory variable	Categories of each variable	Coefficients – model 1	Coefficients – model 2	Coefficients – model 3
Speed limit	1. Built-up roads (up to 40 mph)	−0.611 (<0.001)	−0.783 (<0.001)	−0.465 (<0.001)
	2. Non built-up roads (over 40 mph)	Reference case	Reference case	Reference case
Crash configuration	1. Head-on	0.200 (<0.001)	0.071 (0.649)	−0.062 (0.831)
	2. Same-direction	−0.286 (<0.001)	−0.392 (0.002)	−0.302 (0.076)
	3. Approach-turn A	−0.134 (0.130)	0.027 (0.945)	*0.316 (0.140)*
	4. Approach-turn B	0.141 (0.001)	0.117 (0.368)	0.290 (0.098)
	5. Different-direction A	−0.048 (0.235)	−0.223 (0.080)	*0.279 (0.123)*
	6. Different-direction B	−0.159 (<0.001)	−0.426 (0.006)	−0.203 (0.321)
	7. Collided with parked/reversing vehicle	Reference case	Reference case	Reference case
	μ_1	−0.247	0.191	0.569
	μ_2	1.318	3.262	2.144
	McFadden Pseudo R Square ρ^2	0.051	0.056	0.058

5.1.2. Model 2

Model 2 shows the results of the OP model of motorcyclist injury severity at uncontrolled junctions. In this model factors that appear to most significantly contribute to more severe injuries include elderly rider, greater engine size of motorcycle, riding in early morning, on weekend and under fine weather; street lights unlit; riding on non built-up road; collisions with bus/coach or HGV; and involving in a head-on and approach-turn B collision. Some variables such as gender of rider, accident month and accident day of week were found to be insignificant in the determination of motorcyclist injury severity.

5.1.3. Model 3

Model 3 explores the determinants of injury severity resulting from accidents at signalised junctions. A majority of the independent variables examined was found to be statistically insignificant in explaining motorcyclist injury severity, which could be attributable to the comparatively few accident occurrences at such junctions ($N = 2829$). Estimation results here indicate that male riders tended to be more injurious than females and other significant factors (or marginally significant relative to reference cases) associated with greater injury levels are heavier engine size of motorcycle; collisions with bus/coach or HGV; riding under fine weather and on non built-up road; and involving in an approach-turn A/B or different-direction A crash.

5.2. Comparisons among model 1, 2 and 3

Comparing the parameter magnitudes among the separate models may provide further insights into the determinants of injury severity under three different traffic control measures. The comparison results are provided below.

5.2.1. Gender of rider

Male riders were found to be more injurious than females according to model 1 and 3 (but not model 2) and in model 2 such effect is not statistically significant. Specifically the relative parameter magnitudes of male rider among these three models indicate a relative increase in injury severity in model 3. This implies that male riders, given an accident has occurred, were more likely to be severely injured at signalised junctions than at unsignalised junctions (model 1 and model 2). Given that other factors that influence motorcyclist injury level are controlled for, this interesting result is likely due to some other unmeasured factors: for example, male riders might be more prone to violate signal-control measures than females, thus increasing injury levels once an accident has occurred.

5.2.2. Age of rider

Generally elderly riders had greater tendency to sustain more severe injuries, although age effect is not statistically significant in model 3. An interesting result was that teenaged riders were more prone to be severely injured than those aged 20–59 in accidents where stop, give-way signs or markings controlled the junctions but there was an opposite result in accidents at uncontrolled junctions. A likely explanation for this is that those aged between 20 and 59 tend to be more experienced motorcyclists and possibly due to their over-confidence in motorcycling at uncontrolled junctions, injuries were more severe once an accident has occurred. In other words, this superior skill in motorcycling may be offset by insufficient risk compensations to neutralise the increased risk of injury at such junctions.

5.2.3. Engine size

Heavier motorcycles were generally found to more severely injury motorcyclists regardless of what control measure was adopted. Such effect appears to be somewhat larger at unsignalised junctions. There might be two possible explanations for this. First, owing to greater performance and engine power of heavier motorcycles, motorcyclists might have less reaction time for last-minute braking in response to the sudden presence of approaching vehicles which tend to be less attentive to motorcycles at unsignalised junctions. Second, those riding heavier motorcycles tend to be more experienced in motorcycling, and therefore they might be unwilling to yield to other traffic as a result of their overconfidence at unsignalised junctions.

5.2.4. Collision partner

With regard to collision partners' aggressiveness toward motorcyclists, heavier crash partners appear to predispose motorcyclists to more severe injuries. Specifically, motorcyclists colliding with HGVs or bus/coach were more injurious at uncontrolled junctions and bus/coach was also found to be fatal to motorcyclists at signalised junctions. The first result is likely because drivers of heavier vehicles might perceive themselves to have more priorities to travel in their desired directions at uncontrolled junctions, hereby being less attentive to the presence of motorcycle. The latter result is possibly attributable to more bus/coach operations at signalised junctions (that tend to be located in urban areas), thereby increasing the occurrence of a deadly bus/coach-collision.

5.2.5. Light conditions

Riding in darkness without street lighting was found to injury motorcyclists more severely in model 1 and 2 (but not in model 3) and such effect does appear to be particularly larger at uncontrolled junctions. This is likely because there tends to be poor maintenance and installation of street lights at uncontrolled junctions, leading to decreased visibility for road users to more readily take evasive action in response to a sudden conflict with other traffic.

5.2.6. Weather conditions

Riding under fine weather appears to result in more severe injuries regardless of what control measure was employed and such effect is larger in model 3 than in model 1 and 2. A likely explanation for this interesting result, but needs to be further examined, is that while bad weather might be acting as a deterrent to speeding and inconsiderate road behaviours, motorcyclists and drivers might drive more recklessly and incautiously under fine weather at signalised junctions (which provide them with absolute rights to cross the junctions under green phases), hereby exacerbating collision-impact once a crash has taken place.

5.2.7. Accident time

Injuries resulting from early morning riding in general appear to be greatest, notwithstanding statistical insignificance in model 2 and 3. Such effect is inflated in model 1, suggesting that the combined effect (i.e., early morning and the junctions controlled by stop, give-way signs and markings) was indeed deadly to motorcyclists. This result here is possibly attributable to some other unobserved factors that have an influence on the increased injury forms. For example, more occurrences of speeding and drink-riding/driving in early morning may lead to negligence of stop, give-way signs and markings, hereby magnifying collision-impact once a crash has taken place.

5.2.8. Speed limit

Motorcyclist injury severity in general appears to increase with an increase in speed limit and specifically this effect is intensified at unsignalised junctions. An increased speed limit may result in excessive speed and in turn greater speed limits posted at unsignalised junctions may exacerbate injury levels since road users would perceive less restricted freedom to travel in their desired directions at unsignalised junctions than they would at signalised junctions. This combined effect would further result in the inability of motorcyclists and other traffic to visually detect each other, thereby enlarging the crash-impact once they have collided with each other.

5.2.9. Crash configuration

Motorcyclists involving in head-on and approach-turn B collisions were in general more severely injured and an exception is head-on collisions in model 3, predisposing motorcyclists to milder injury forms. This could be explained by better geometrics design at signalised junctions, hereby reducing occurrence of a deadly head-on crash.

Three somewhat surprising results were observed in model 3. First, injuries were greatest in approach-turn A crashes whereas there was a negative value of coefficients in model 1 and such effect is statistically insignificant in model 2. This result here is likely attributable to the lack of risk compensations: while signalised junctions provide definite rights to motorcyclists and other motorists travelling from opposite directions to cross the junctions, they probably did not compensate as sufficiently as they normally did at unsignalised junctions to neutralise the higher risks in involving in approach-turn A collisions. Some other unmeasured factors such as excessive speed of the vehicle approaching straight could further exacerbate the crash-impact resulting from an approach-turn A collision. Second, injuries resulting from approach-turn B collisions appear to be more severe than those at unsignalised junctions (model 1 and 2). Likewise this could be attributable to the lack of risk compensation in an accident where a signal measure provides both road users travelling from opposite directions with absolute rights to cross the junction. Finally despite different-direction A collisions were found to be negatively associated with the increased injury severity at unsignalised junctions, such collisions surprisingly resulted in greater likelihoods of severe injuries at signalised junctions. Such collisions in practice should not have occurred at signalised junctions and violation to the signal-control measures by either motorcyclists or their crash partners is a possible explanation.

6. Discussions

Results of three OP models in our study uncover crucial determinants of motorcyclist injury severity under different control measures, and may offer insights into potential prevention strategies that could be undertaken to reduce injury levels. Possible countermeasures and intervention points are discussed below.

There are at least two possible engineering measures that can be applied for our estimation result that approach-turn A/B collisions were more injurious to motorcyclists at signalised junctions than at unsignalised junctions. First, at a signalised junction where there are high volumes of motorcycles or vehicles, signal-control measures that contain priority phases or a longer duration of green phase can be provided to either motorcycles or vehicles while both travelling from opposite directions have definite rights to cross the junction at same time so that the occurrence of an approach-turn A/B collision would be possibly reduced. Second, in order to reduce the occurrence of an approach-turn A collision, wait-and-turn areas which require motorcyclists to temporarily wait at such areas and then turn right to cross the junction in their desired directions could also avoid conflicts with oncoming traffic. These two engineering measures could eliminate the need for either motorcyclists or vehicles to interact with oncoming traffic during the turn/approach, thereby avoiding a deadly conflict.

Our modelling result suggests that the combined effect of riding in darkness without street lights and uncontrolled junctions was deadly to motorcyclists. Installation of street lights can be considered as a countermeasure to lessen injury severity resulting from an accident at such locations. Education schemes could be beneficial for some of our estimating results regarding demographic factors: for instance, educating male riders to be more vigilant of their high risks in being severely injured at signalised junctions.

Signal-control measures with priority phases for bus/coach at signalised junctions where there tend to be higher volumes of bus/coach could be an effective intervention point, hereby reducing possible collisions between bus/coach and motorcycle. An early warning sign that alerts motorcyclists to high volumes of HGVs ahead at an uncontrolled junction could be advantageous.

With regard to accident-time effect, stricter police enforcement on speeding and drink-riding/driving in early morning at junctions controlled by stop, give-way signs and markings, as well as education schemes, might be an effective prevention policy. A reduction of speed limit at unsignalised junctions could be particularly effective in moderating injury severity, allowing more reaction time for last-minute manoeuvring and braking in moments before impacts.

7. Conclusions and recommendations for further works

The OP models are employed in this study using disaggregated dataset extracted from STATS19 accident injury database to investigate the factors that contribute to more severe motorcyclist injury severity at three-legged junctions in the UK. Estimation of three separate models enables us to separately explore the effects of the explanatory variables on injury severity under different control measures and indicates several combined factors that were deadly to motorcyclists. Based on the model estimation results, this study ultimately offers insights into potential prevention strategies that may help to lessen motorcyclist injury level.

In terms of future works, further studies that examine the comparisons of parameter magnitudes among the separate models are warranted. For example, further exploration is needed to investigate what factors act synergistically with the combination of signalised junctions and approach-turn collisions to increase motorcyclist injury severity. Does excessive speed of motorcycle/vehicle as a result of greater speed limit play a part? In addition to this, further research into our finding that collisions with bus/coach at signalised or uncontrolled junctions were deadly to motorcyclists could also be worthwhile. Is that possibly attributable to more involvements of bus/coach in a specific crash-type (e.g., approach-turn collision) at such junctions?

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