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Exploring motorcyclist injury severity in approach-turn collisions at T-junctions: Focusing on the effects of driver's failure to yield and junction control measures

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Abstract

Research has suggested that motorcyclists involved in approach-turn crashes were much more injurious than any other crash-type. This paper investigates the determinants of motorcyclist injury severity resulting from such crash types that occurred at T-junctions, with emphasis on the effects of driver's failure to give way and various junction control measures. The ordered probit models of motorcyclist injury severity were estimated using the data extracted from the STATS19 accident injury database (1991–2004). Approach-turn collisions are categorised into two sub-crashes based on the manoeuvres motorcycles and vehicles were making prior to the collisions. The modelling results uncover several important determinants of injury severity: for example, injuries appeared to be greatest when an approaching motorcycle collided with a turning-right vehicle, and such effect was found to exacerbate injury severity when stop, give-way signs and markings controlled the junction. A turning-right driver that was identified to fail to yield to an approaching motorcyclist was also found to severely injure the motorcyclist. The findings of this study may offer guidelines for further research and provide some important preliminary evidence for the development of countermeasures that may help prevent the specific hazards from occurring.

Keywords: Motorcyclist injury severity; Approach-turn collision; T-junction; Driver's failure to yield; Junction control measure

1. Introduction

The fact that motorcycle users are more vulnerable to injuries than those using other motorised vehicles may act synergistically with the complexity of conflicting movements between vehicles and motorcycles at junctions to increase their injury severities. A junction-type collision could be more injurious than a non-junction case to motorcyclists as some of the deadly crashes such as angle collisions commonly occur. A research programme that investigates whether a particular crash-type that takes place at junctions is more serious to motorcyclists may help provide potential countermeasures regarding motorcyclist's safety.

Existing literature has attempted to estimate crash prediction models that predict occurrence of different crash types among motorised vehicles using roadway geometric variables, environmental factors and traffic conditions as predictors and whether a certain crash-type is more severe to vehicle-drivers has been extensively documented in literature (see, for example, Abdel-Aty and Keller, 2005; Chang and Mannering, 1999; O'Donnell and Connor, 1996; Shankar and Mannering, 1996; Kockelman and Kweon, 2002). However, a study that specifically explores whether a particular crash-type in a junction-type accident is more deadly to motorcyclists has been surprisingly scant in literature. Two exceptions are the studies by Pai and Saleh (2007a) and Peek-Asa and Kraus (1996). Pai and Saleh examining accidents at T-junctions, together with Peek-Asa and Kraus investigating crashes at four-legged intersections, have consistently concluded that motorcyclists involved in approach-turn crashes were more likely to be severely injured than those involved in any other crash-type.

An approach-turn collision 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. Statistics from UK STATS19 accident injury database suggested that T-junction

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is a common place for an approach-turn collision involving motorcycle and vehicle (i.e., more than half of approach-turn collisions occurred at T-junctions between 1991 and 2004). Several researchers (e.g., Peek-Asa and Kraus, 1996; Clarke et al., 2007; Hole et al., 1996; Williams and Hoffmann, 1979) have suggested that the principal factors in this crash-type could be the failure of a turning driver to see the approaching vehicle (e.g., look but did not see), to adequately judge the time available to clear the intersection, or to yield right of way to an approaching motorcycle. These studies may provide general insight into the factors affecting the occurrence of approach-turn crashes. However, the contributing causes to motorcyclist injury severity resulting from such crash-type have been rarely investigated in literature. These contributing causes may be complicated by the presence of multiple factors (e.g., junction control measures, right of way violation, speed of the involved vehicle, or speed limits, etc.). A better understanding of such multiple factors could further facilitate the identification of suitable countermeasures which may help prevent the hazards from occurring. This paper attempts to analyse real-life data through the use of appropriate statistical modelling techniques to explore the determinants of motorcyclist injury severity resulting from approach-turn collisions at T-junctions in the UK, with emphasis on the effects of vehicle's failure to yield and various junction control measures.

Our paper begins with a description of the data and the proposed econometric model approach adopted in this study. The next section discusses the model estimation results and potential protective policies and strategies. This paper concludes with an overall summary of model findings and recommendations for future research.

2. Data—STATS19 accident injury database

The data, known as the 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 with which each individual vehicle collides; and casualty file includes detail for each casualty such as injury-severity level, age and gender of the victim. The severity of each casualty is classified into three levels: killed or seriously injured (KSI), slight injury, and no injury. KSI includes casualties who either die within 30 days as a result of the accident or suffer from fracture, internal injury, severe cuts and lacerations, concussion, or any injury requiring detention in hospital. Slight injury is classified for those victims who sustain sprains, bruises, cuts judged not to be severe and slight shock requiring roadside attention. Accident data over the period of years 1991–2004 were obtained from the STATS19 and the data of 17,716 motorcyclist casualties resulting from vehicle–motorcycle approach-turn crashes that took place at T-junctions were extracted. These casualties include riders and pillion passengers, excluding in cases where an injury has occurred to a pedestrian or occupants in other vehicles that were involved in such crashes. Of these motorcyclist casualties, 31.3% are classified as KSI, 67.8% are classified as slight injury, and 0.9% are classified as no injury.

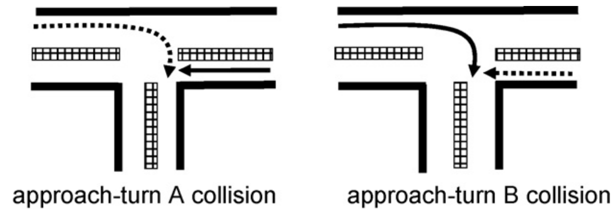

Fig. 1. Schematic diagram of approach-turn A/B collisions at T-junctions. *Note*: Pecked line represents the intended path of the vehicle; solid line represents the intended path of the motorcycle.

2.1. Approach-turn collision

In this study an approach-turn crash is classified into two sub-crashes—approach-turn A: a motorcycle approaching straight collides with a vehicle travelling from opposite direction and turning right into such motorcycle's path; and approach-turn B crash: an approaching vehicle is in a collision with a motorcycle travelling from opposite direction and turning right into such vehicle's path (this categorisation includes either a vehicle or motorcycle making a U-turn onto the same street as the approaching vehicle/motorcycle). The categorisation is schematically illustrated in Fig. 1.

3. Modelling methodology: the ordered–discrete choice model

Several econometric models (e.g., unordered multinomial; nested logit or probit models) have been adopted in literature to isolate factors that affect injury severities sustained by various road users. Borooah (2001) suggested that these models, while accounting for categorical nature of the dependent variable, disregard the ordinal nature of injury-severity levels (i.e., from least severe to the most severe) 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, 2003). To overcome these problems, several researchers (see, for example, O'Donnell and Connor, 1996; Pai and Saleh, 2007a, 2007b) proposed the ordered–discrete choice models (i.e., the ordered probit/logit model: OP/OL) for modelling injury severities. Borooah (2001) suggested that an ordered–discrete choice model is able to account for unequal differences between categories in the dependent variable (i.e., the distance between no injury and slight injury is not the same as that between slight injury and KSI in our study), as well as 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 a motorcyclist victim i; β' the vector of parameters to be estimated; x_i 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 and logistically distributed for the OL model. 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 cannot 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 no injury; $y_i = 2$ for slight injury and $y_i = 3$ for KSI. The observed and coded discrete injury severity, y_i, can be determined from the following formulae:

$$y_i = \begin{cases} 1, \text{ if } -\infty < y_i^* \le \mu_1 & \text{(no injury)} \\ 2, \text{ if } \mu_1 < y_i^* \le \mu_2 & \text{(slight injury)} \\ 3, \text{ if } \mu_2 < y_i^* < +\infty & \text{(KSI)} \end{cases} \tag{2}$$

where the threshold values $\mu_1 < \mu_2$ are unknown parameters to be estimated. The predicted probabilities of the three coded injury-severity levels by a victim i, for given x_i can be illustrated as:

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

where $\Phi(u)$ denotes the cumulative density function (cdf) 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. In practice the OP and OL formulations produce very similar results (O'Donnell and Connor, 1996) and therefore only the estimation results of the OP models are reported in the following section.

3.1. Model specification

An overall model (model 1) is first estimated to identify whether a certain junction control measure is more severe and whether one specific type of approach-turn crash is more hazardous to motorcyclists than another one, while controlling for other confounding factors. Since junction control measures are of interest in this paper, one frequency table is created for investigating the distribution of injury severity across the observations and by the interaction of junction control measures and approach-turn A/B collisions. This table is to identify the most hazardous control measure in approach-turn A and B collisions, respectively. One additional model by the deadliest combination is subsequently estimated. Such separate model can be useful for obtaining a disaggregate "picture" of motorcyclist injury severity, conditioned on approach-turn A/B collisions having occurred under a specific "hazardous" control measure.

4. Modelling results

The model estimation results for the overall model are first reported in this section. A positive value of coefficients indicates that the category increases the propensity of the most serious injury level (i.e., KSI) with an increase in its magnitude and vice versa, relative to its reference category. Significance value (p-value) for each category is reported in parentheses. It is noteworthy that multicollinearity might be a concern for a model that calibrates multiple independent variables. The symptom of multicollinearity (e.g., wildly changing coefficients when an additional variable is included/removed or unreasonable coefficient magnitudes) was not observed in the developed models and the coefficients of the estimated models had meaningful signs and magnitudes. In addition no variable was found to be correlated to each other (i.e., correlation that is over 0.5 can cause multicollinearity). As a result there is no need to concern about collinearity in the models.

4.1. Overall model

Estimation results for the overall model (model 1) are presented in Table 1. Junctions controlled by stop, give-way signs or markings appeared to be more severe to motorcyclists. Motorcyclists involved in approach-turn A crashes were found to be more injurious than those involved in approach-turn B collisions. Table 1 also shows that motorcyclists were about 16-times more likely to be involved in approach-turn A collisions than approach-turn B crashes (94% and 6%). The results here regarding the frequency and severity of approach-turn A and approach-turn B are consistent with the conclusions drawn in the study by Peek-Asa and Kraus (1996). Other factors found to be most significantly associated with more severe injures include: male or elderly rider; heavier motorcycle; more than three vehicles were involved in collisions; collisions with heavier vehicles (bus/coach or HGV); riding in midnight and early morning, on weekend, in spring/summer month, and under fine weather; street lights were unlit in darkness; and riding on non-built-up road (speed limit over 40 mph).

Table 2 shows the relationship between junction control measures, approach-turn A/B crashes, and injury severity. It was found that those involved in approach-turn A crashes at stop, give-way signs or markings were most likely to be severely injured (i.e., as much as 32.5% were KSI). In order to gain a further understanding of factors contributing to more severe injuries resulting from this deadliest combination, one additional OP model was estimated and the results are reported in the next section. Additional models were also estimated for some other hazardous combinations (e.g., approach-turn A crashes that occurred at uncontrolled junctions and approach-turn B collisions that took place at signalised junctions) but most of the variables were found to be insignificant in explaining injury severity. This is possibly due to comparatively few occurrences

Table 1
Statistics summary and estimation results of the overall OP model

Explanatory variable	Categories of each variable	Frequency (%)	Coefficients—model 1
Dependent variable	1. No injury	164(0.9%)	
	2. Slight injury	12,005(67.8%)	
	3. KSI	5,547(31.3%)	
Gender of rider	1. Male	16,562(93.5%)	0.101 (0.012)
	2. Female	1,154(6.5%)	Reference case
Age of rider	1. Over 60	366(2.1%)	0.180 (0.010)
	2. 20–59	13,725(77.5%)	0.011 (0.657)
	3. Up to 19	3,625(20.5%)	Reference case
Engine size	1. Engine size over 125 cc	12,692(71.6%)	0.150 (<0.001)
	2. Engine size up to 125 cc	5,024(28.4%)	Reference case
Number of vehicle involved	1. ≥3	903(5.1%)	0.187 (<0.001)
	2. Two-vehicle crash	16,813(94.9%)	Reference case
Collision partner	1. Heavy good vehicle (HGV)	1,087(6.1%)	0.172 (<0.001)
	2. Bus/coach	178(1.0%)	0.231 (0.015)
	3. Car	16,451(92.9%)	Reference case
Light condition	1. Darkness: street lights unknown	186(1.1%)	0.160 (0.094)
	2. Darkness: street lights lit	6,057(34.2%)	0.062 (0.030)
	3. Darkness: street lights unlit	372(2.1%)	0.119 (0.089)
	4. Daylight	11,101(62.7%)	Reference case
Accident month	1. Spring/summer (March–August)	8,517(48.1%)	0.018 (0.384)
	2. Autumn/winter (September–February)	9,199(51.9%)	Reference case
Weather condition	1. Other or unknown	337(1.9%)	0.027 (0.722)
	2. Fine weather	15,472(87.3%)	0.131 (<0.001)
	3. Bad weather	1,907(10.8%)	Reference case
Accident time	1. Midnight/early morning (00:00–06:59)	604(3.4%)	0.211 (<0.001)
	2. Rush hours (07:00–08:59; 16:00–17:59)	5,462(30.8%)	0.033 (0.195)
	3. Evening (18:00–23:59)	6,172(34.8%)	0.136 (<0.001)
	4. Non-rush hours (09:00–15:59)	5,478(30.9%)	Reference case
Accident day of week	1. Weekend (Saturday–Sunday	3,659(20.7%)	0.070 (0.003)
	2. Weekday (Monday–Friday)	14,057(79.3%)	Reference case
Speed limit	1. Non-built-up roads (>40 mph)	1,631(9.2%)	0.620 (<0.001)
	2. Built-up roads (≤40 mph)	16,085(90.8%)	Reference case
Junction control	1. Uncontrolled	2,274(12.8%)	0.037 (0.402)
	2. Stop, give-way signs or markings	14,038(79.2%)	0.086 (0.018)
	3. Automatic signal measures	1,404(7.9%)	Reference case
Crash configuration	1. Approach-turn A	16,654(94.0%)	0.279 (<0.001)
	2. Approach-turn B	1,062(6.0%)	Reference case
	μ_1	−1.549 (<0.001)	
	μ_2	1.357 (<0.001)	
	−2 log–likelihood at zero	6325.382	
	−2 log–likelihood at convergence	5649.461	
	Log–likelihood ratio index (ρ^2)	0.11	
	Observations	17,716	

of such crashes ($N = 2169$ and 189, respectively). These additional models were therefore not reported in this current paper.

4.2. Separate model for approach-turn A crashes at stop, give-way signs and markings

Table 3 presents the modelling results for the factors that affect motorcyclist injury severity resulting from approach-turn A collisions where stop, give-way signs or markings controlled the junctions. The directions of the coefficient signs of the explanatory variables in this model appear to be identical to those in model 1, except for light conditions being found to be insignificant in determining injury severity.

One new variable (striking or struck role of the motorcycle) was added into this model. This variable is to examine whether a turning vehicle can be identified as a determining crash factor. There are three categorises for this variable: motorcycle is the struck vehicle, motorcycle is the striking vehicle, and unknown, as illustrated in Fig. 2. A motorcycle is defined as the struck

Table 2
The relationship between approach-turn crashes, junction control measures, and injury severity

Crash	Control measure	No injury	Slight injury	KSI	Total
Approach-turn A	Uncontrolled	15 (0.7%)	1,501 (69.2%)	653 (30.1%)	2,169 (100%)
	Stop, give-way signs or markings	99 (0.7%)	8,864 (66.8%)	4307 (32.5%)	13,270 (100%)
	Automatic signals	16 (1.3%)	868 (71.4%)	331 (27.2%)	1,215 (100%)
	Total	130 (0.8%)	11,233 (67.4%)	5291 (31.8%)	16,654 (100%)
Approach-turn B	Uncontrolled	3 (2.9%)	75 (71.4%)	27 (25.7%)	105 (100%)
	Stop, give-way sighs or markings	29 (3.8%)	563 (73.3%)	176 (22.9%)	768 (100%)
	Automatic signals	2 (1.1%)	134 (70.9%)	53 (28.0%)	189 (100%)
	Total	34 (3.2%)	772 (72.2%)	256 (24.1%)	1,062 (100%)

Table 3
Statistics summary and estimation results of the OP model for approach-turn A crashes that occurred at stop, give-way signs or markings

Explanatory variable	Categories of each variable	Frequency (%)	Coefficients—model 2
Dependent variable	1. No injury	99(0.7%)	
	2. Slight injury	8,864(66.8%)	
	3. KSI	4,307(32.5%)	
Gender of rider	1. Male	12,429(93.7%)	0.091 (0.052)
	2. Female	841(6.3%)	Reference case
Age of rider	1. Over 60	258(1.9%)	0.192 (0.020)
	2. 20–59	10,381(78.2%)	−0.005 (0.872)
	3. Up to 19	2,631(19.8%)	Reference case
Engine size	1. Engine size over 125 cc	9,588(72.3%)	0.145 (<0.001)
	2. Engine size up to 125 cc	3,682(27.7%)	Reference case
Number of vehicle involved	1. ≥3	706(5.3%)	0.238 (<0.001)
	2. Two-vehicle crash	12,564(94.7%)	Reference case
Collision partner	1. Heavy good vehicle (HGV)	811(6.1%)	0.154 (0.001)
	2. Bus/coach	127(1.0%)	0.252 (0.025)
	3. Car	12,332(92.9%)	Reference case
Light condition	1. Darkness: street lights unknown	138(1.0%)	0.152 (0.170)
	2. Darkness: street lights lit	4,547(34.3%)	0.037 (0.262)
	3. Darkness: street lights unlit	287(2.2%)	0.025 (0.759)
	4. Daylight	8,298(62.5%)	Reference case
Accident month	1. Spring/summer (March–August)	6,384(48.1%)	−0.015 (0.550)
	2. Autumn/winter (September–February)	6,886(51.9%)	Reference case
Weather condition	1. Other or unknown	238(1.8%)	0.063 (0.488)
	2. Fine weather	11,605(87.5%)	0.130 (<0.001)
	3. Bad weather	1,427(10.8%)	Reference case
Accident time	1. Midnight/early morning (00:00–06:59)	416(3.1%)	0.201 (0.004)
	2. Rush hours (07:00–08:59; 16:00–17:59)	4,126(31.1%)	0.023 (0.446)
	3. Evening (18:00–23:59)	4,662(35.1%)	0.150 (<0.001)
	4. Non-rush hours (09:00–15:59)	4,066(30.6%)	Reference case
Accident day of week	1. Weekend (Saturday–Sunday)	2,674(20.2%)	0.074 (0.009)
	2. Weekday (Monday–Friday)	10,596(79.8%)	Reference case
Speed limit	1. Non-built-up roads (>40 mph)	1,257(9.5%)	0.639 (<0.001)
	2. Built-up roads (≤40 mph)	12,013(90.5%)	Reference case
Striking/struck role	1. Motorcycle was the struck vehicle (motorcycle entered the junction first)	1,246(9.4%)	0.154 (0.032)
	2. Motorcycle was the striking vehicle (vehicle entered the junction first)	11,577(87.2%)	0.189 (0.003)
	3. Unknown	447(3.4%)	Reference case
	μ_1	−1.823 (<0.001)	
	μ_2	1.123 (<0.001)	
	−2 log–likelihood at zero	4366.947	
	−2 log–likelihood at convergence	3864.497	
	Log–likelihood ratio index (ρ^2)	0.12	
	Observations	13,270	

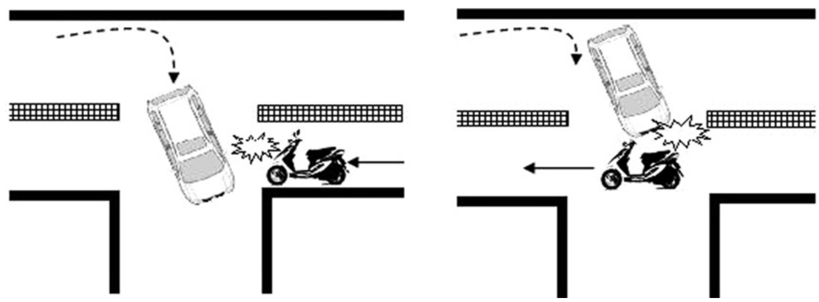

Fig. 2. Schematic diagram of the motorcycle as a striking or struck vehicle in an approach-turn A collision at T-junctions. *Note*: Pecked line represents the intended path of a vehicle; solid line represents the intended path of a motorcycle.

vehicle in a collision where the motorcycle was the first vehicle that had entered the junction and the front of the car collided with the motorcycle's offside. A motorcycle is defined as the striking vehicle in a crash where the car had entered the junction earlier than the motorcycle and the motorcycle made contact with the side of the car. It merits mention here that the front of the motorcycle does not necessarily have to be the contact point with which the side of the car collides due to motorcycles being more capable of swerving before impact (i.e., it can be the side of the motorcycle with which the car collides). It is reasonable to assume that such turning driver may have violated the motorcycle's right of way by entering the junction earlier than the motorcycle, and the motorcycle therefore struck the vehicle. Similar definition of striking/struck role was adopted by Peek-Asa and Kraus (1996). Results here show that in such crash, the vehicle that had entered the junction earlier was much more frequently the right-turning vehicle than the approaching motorcycle (87.2% vs. 9.4%), and such effect was indeed a hazard to motorcyclists in terms of its impact on injury severity.

Several noteworthy results from the estimated model may also deserve further explanations. There is some evidence that motorcyclists riding on weekends were generally more injurious than riding on weekdays, and riding during early morning appeared to be a deadly factor to motorcyclists. These findings are perhaps reasonable, as it is likely that speeding and alcohol use are more common during these hours and there are probably more recreational and social activities on weekends (Broughton, 2005), thereby resulting in greater collision-impact. With respect to the impact engine size has on injury severity, motorcycles with larger engine capacity generally appeared to predispose motorcyclists to more severe injuries. There are at least two possible explanations for this: first, larger motorcycles tend to be ridden on roadways with higher speed limits; and second, drinkers are more likely to be on bigger motorcycles. Given the increasing kinetic energy and greater impact at higher speed, the result here regarding the impact engine size has on injury severity is logic and as expected. This reasoning can be supported by Pai and Saleh (2007a) and Broughton (2005).

5. Discussions and research limitations

The estimated overall model has revealed that stop, give-way signs or markings was indeed a deadly factor and motorcyclists were more injurious in approach-turn A crashes. One frequency table was created and it was found that several combined factors (i.e., approach-turn A crashes that occurred at stop, give-way signs or markings; and approach-turn B crashes that took place at signalised junctions) appeared to predispose motorcyclists to more severe injuries. One additional OP model was further estimated by the deadliest combination (i.e., a turning-right vehicle collided with an approaching motorcycle at stop, give-way signs or markings) and one of the main findings was that injuries were greatest in collisions where the vehicle failed to give way to the motorcycle. Based on the modelling results some of the possible engineering countermeasures and intervention points are discussed below.

At least two possible engineering measures could be applied for our estimation results that motorcyclists were more severely injured in approach-turn A collisions at stop, give-way signs or markings, and in approach-turn B crashes at signallised junctions. First, for approach-turn A crashes that take place at stop, give-way controlled junctions with high volume of motorcycles or vehicles, an early warning sign that alerts motorcyclists to the presence of right-turning vehicles could be advantageous. Second, for approach-turn B collisions that occur at signallised junctions with high volumes of motorcycles or vehicles, priority signal-phases or a longer duration of green phase for either motorcycles or vehicles could be a good intervention point. A wait-and-turn area that requires motorcycles to temporarily wait at such area and then turn right to cross the junction in their desired directions could also avoid conflicting with oncoming traffic. These engineering countermeasures could help eliminate the needs for either motorcyclists or vehicle-drivers to detect oncoming traffic during the turn/approach, thereby avoiding a deadly conflict.

The modelling results suggested that severe injuries were associated with higher speed limits. Statistics from DfT (2007) has revealed that the percentage of motorcycles travelling at more than 10 mph above the speed limits on all road types was higher than that of other motorised vehicles. This suggests that motorcycles are more likely than vehicles to be speeding. Peek-Asa and Kraus (1996) found that for approach-turn collisions, a striking motorcycle in a collision with a turning vehicle was more likely to be speeding than a motorcycle struck by a turning car. They suggested that controlling motorcycle speed may decrease the number of approach-turn crashes, and could also decrease injury severity when such collisions do occur. Excessive speed of motorcycle may also reduce motorcycle's conspicuity (Kim and

Boski, 2001). Controlling motorcycle speed by reducing speed limits may enable motorcycle's speed to be less difficult to determine so that a turning vehicle-driver would be more capable of seeing an approaching motorcycle, and adequately judging the time available to clear the junction. Our hypothesis on the relationship between higher speed and vehicle's failure to give way can perhaps be supported by Räsänen and Summala (2000) and Summala et al. (1996) in their bicycle–vehicle crash studies. Räsänen and Summala suggested that higher vehicle approach speed contributed to drivers not looking to their right or to not giving way to bicyclists at roundabouts, while Summala et al. found that speed-reducing countermeasures may enable a turning driver to have more time in searching a bicyclist travelling from the right. Reduced speed limits may also allow motorcyclists to have more reaction time for swerving and braking in moments before impacts if one turning vehicle does violate motorcycle's right-of-way, thereby reducing collision-impact.

In addition to these engineering measures, increasing conspicuity of motorcycles or motorcyclists (e.g., daytime headlights or bright clothing worn by motorcyclists) may be a potential countermeasure to help a turning driver to be more attentive to motorcycles. Being able to virtually detect motorcycle may prevent vehicle-drivers from making a turn recklessly, or at least, help to allow more chances to brake abruptly before a collision. Wells et al. (2004) and Muller (1984) have pointed out that improving motorcycles' conspicuity by increasing the use of reflective or fluorescent clothing, white or light coloured helmets, and daytime headlights may be beneficial in reducing serious injuries or deaths to motorcyclists. Their findings regarding the benefit of the use of headlight at daytime have been supported by Yuan (2000). A future study may attempt to validate whether their findings are applicable in this current study (especially for the deadly approach-turn A crashes).

Some research limitations arise in this paper whilst analysing police report data. For example, this study is limited to the variables that are available in the STATS19, which does not contain other factors that might play a part in influencing injury severity. These factors include, for example, speed of motorcycle and its collision partner, helmet and alcohol use, or causes to an accident (e.g., speeding, etc.). Other source of data that is more detailed than the STATS19 would allow more precise and conclusive results of model estimation.

6. Conclusions and recommendations for further works

Specific hazards that contribute to severe injuries have been successfully identified in this study. This current research represents a contribution to the profession through the insight that several pre-crash conditions were significantly associated with motorcyclist injury severity in approach-turn A/B crashes at T-junctions. The main conclusions to be drawn from this study include: first, approach-turn collisions in which the vehicle was right-turning were more likely to result in motorcyclists being severely injured when the stop, give-way signs or markings controlled the junction; second, when the motorcycle was the turning vehicle (i.e., approach-turn B crash), the motorcyclist was most likely to be seriously injured when an automatic signal controlled the junction; and third, where stop, give-way signs or markings controlled the junctions, injuries were greatest in the crashes where the motorcycle's right of way was violated by a turning vehicle. Based on the modelling results, this study may offer guidelines for future research and provide some important preliminary evidence for the development of countermeasures that may help prevent these specific hazards from occurring.

In terms of future works, studies that continue to further explore the estimation results in the additional model are warranted. For instance, further exploration should seek to examine what factors act synergistically with the combined effects (e.g., a turning-right vehicle collides with an approaching motorcycle at stop, give-way signs or markings) to increase injury severity. Peek-Asa and Kraus (1996) suggested that an approach-turn A crash in which a turning vehicle was struck by a motorcycle, the motorcyclist was much more likely to be speeding. A turning vehicle therefore may not correctly judge the speed of the oncoming motorcycle and clear the junction in time to avoid a crash. The conclusion drawn by Peek-Asa and Kraus cannot be supported from our current study due to the lack of data on whether a motorcycle is speeding. However, what has been known in our work was that injuries were more severe on roadways with higher speed limits. Possible direction of a future work may identify whether motorcycle speed plays a part in affecting injury outcome. Studies (e.g., Thomson, 1980; Peek-Asa and Kraus, 1996; Williams and Hoffmann, 1979) have also indicated that motorcycles being less conspicuous than other motorised vehicles may result in motorcycles being disproportionately involved in approach-turn crashes, especially in diminished lighting conditions. It would therefore be worthwhile to examine whether motorcycle's poor conspicuity determines not only the accident occurrence but also accident outcome. The further works recommended here, however, require data that are more detailed than the STATS19. Such studies may provide further insight into the contribution of other important factors to more severe injuries resulting from approach-turn A/B crashes.

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