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HOW SIMILAR ARE TWO-UNIT BICYCLE AND MOTORCYCLE CRASHES?

Narelle Haworth[1], Ashim Kumar Debnath[2*]

[1] Centre for Accident Research and Road Safety-Queensland
K Block, Queensland University of Technology
130 Victoria Park Road, Kelvin Grove, QLD 4059
AUSTRALIA
Phone: 61 7 3138 8417
Fax: 61 7 3138 0111
Email: n.haworth@qut.edu.au

[2] Centre for Accident Research and Road Safety-Queensland
K Block, Queensland University of Technology
130 Victoria Park Road, Kelvin Grove, QLD 4059
AUSTRALIA
Phone: 61 7 3138 8423
Fax: 61 7 3138 0111
Email: ashim.debnath@qut.edu.au

* Corresponding author

ABSTRACT

This paper explores the similarities and differences between bicycle and motorcycle crashes with other motor vehicles. If similar treatments can be effective for both bicycle and motorcycle crashes, then greater benefits in terms crash costs saved may be possible for the same investment in treatments. To reduce the biases associated with under-reporting of these crashes to police, property damage and minor injury crashes were excluded. The most common crash type for both bicycles (31.1%) and motorcycles (24.5%) was intersection from adjacent approaches. Drivers of other vehicles were coded most at fault in the majority of two-unit bicycle (57.0%) and motorcycle crashes (62.7%). The crash types, patterns of fault and factors affecting fault were generally similar for bicycle and motorcycle crashes. This confirms the need to combat the factors contributing to failure of other drivers to yield right of way to two-wheelers, and suggest that some of these actions should prove beneficial to the safety of both motorized and non-motorized two-wheelers. In contrast, child bicyclists were more often at fault, particularly in crashes involving a vehicle leaving the driveway or footpath. The greater reporting of violations by riders and drivers in motorcycle crashes also deserves further investigation.

Keywords: Two wheeler crash, Bicycle safety, Motorcycle safety, At-fault crash, Binary logistic model, Child bicyclist crash.

1. Introduction

Bicyclists, motorcyclists and pedestrians are often referred to as vulnerable road users in the road safety literature because the likelihood that they will be seriously injured if a collision occurs is higher than for motor vehicle occupants. Vulnerable road users comprise the majority of traffic fatalities in most low and middle-income countries (Naci et al., 2009) and in 2010 accounted for about a quarter to a half of traffic fatalities in high income countries such as the United States (28.6%) (NHTSA, 2012), Australia (32.0%) (DIT, 2012b) and Great Britain (49.7%) (DFT, 2012). In these three countries, motorcyclists and pedestrians make up the bulk of vulnerable road user fatalities, with pedal cyclists comprising only 3-6% of fatalities. However, pedal cyclists represent between a quarter (US) (NHTSA, 2012) and a third (Australia) (Henley and Harrison, 2012) of all vulnerable road users with non-fatal traffic injuries.

There are many similarities among the three groups of vulnerable road users as well as real differences. All three modes serve as both recreation and transport, have poor data and similar contributing factors to injury. In addition, most adult pedestrians, pedal cyclists and motorcyclists are also car drivers for whom walking, cycling or motorcycling is not their main mode of transport.

In common with pedestrians, injuries to bicycle and motorcycle riders result in higher injury costs (Hitchens and Palmer, 2012) than injuries to car occupants. The vulnerability of bicycle riders is particularly evident in crashes with motor vehicles. For bicyclists, only 6 to 8% of Emergency Department presentations result from collisions with vehicles (Scott et al., 2005) compared with at least 22% of hospital admissions for on-road crashes (Henley and Harrison, 2012) and more than 80% of on-road fatalities (DIT, 2012a). The higher travel speeds of motorcycles mean that they are vulnerable in single-vehicle crashes as well as in collisions with motor vehicles. Thus, while 80% of Australian on-road bicycle fatalities involved motor vehicles, only 58% of on-road motorcycle rider fatalities involved other motor vehicles (DIT, 2012a). In a German study, Otte et al. (2012) compared injury outcomes in multi-vehicle crashes involving pedestrians, pedal cyclists and motorized two-wheelers. Overall, pedestrians were the most severely injured, followed by motorized two-wheelers then bicyclists. The lower injury severity of bicyclists was related to the lower speed of the collision partner, compared to pedestrian crashes. They comment that the higher speeds of the motorcyclists contributed to the severity of their injuries.

Bicycle and motorcycle crashes have generally been analyzed in isolation, but it is expected that similar factors may be important for both types of crashes because both are minority road users in comparison with dual track vehicles, physically smaller, less visible, lack physical protection, are less stable, and more affected by road surface irregularities. The limited conspicuity of bicycles and motorcycles and consequently drivers failing to see them or give-way to them have been identified as contributing factors in many studies (e.g., Haque et al., 2012; Horswill et al., 2005; Pai, 2011b; Pai et al., 2009), which implies that there might be similarities between bicycle and motorcycle crashes, particularly at give-way situations. Other authors have suggested that drivers' perception of motorcycles as less threatening than other large vehicles may also contribute to them failing to give way (see Pai, 2011a). Since bicycles are physically smaller and have limited conspicuity, these factors could be true for bicycles as well.

Poor availability of data is a problem for understanding both bicycle and motorcycle crashes. The numerators of crash risk (numbers of persons in crashes or injured) are substantially under-reported for bicyclists and motorcyclists. US and European studies indicate that only 11% (Stutts et al., 1990) to 13% (Veisten et al., 2007) of bicycle crashes are recorded in police statistics and the data are skewed to serious injury crashes and those that involve motor vehicles (Stutts et al., 1990). US, European and Australian comparisons show about twice as many hospitalized motorcyclists in health data as in police data (Henley and Harrison, 2012; NCIPC, 2012; NHTSA, 2012). The extent of under-reporting is greater in less serious bicycle crashes in many countries (see ITF, 2012). The denominators used in risk calculations often relate to per head of population, per license or registration or per distance travelled. Distance travelled appears to be conceptually a better denominator, but the availability of this data for motorcycles is patchy at best and its accuracy is sometimes disputed (see Haworth, 2003). Data regarding the distances travelled by bicyclists and pedestrians, and the extent to which this travel occurs on roadways, are very sparse (Aultman-Hall et al., 2012).

The aim of this paper is to explore the similarities and differences between bicycle and motorcycle crashes with other motor vehicles in order to assess the extent to which similar treatments may be effective for both bicycle and motorcycle crashes. If so, greater benefits in terms crash costs saved may be possible for the same investment in treatments. The comparisons focus on two-unit crashes of higher severity levels, given that single-vehicle crashes are less likely to be similar because of the much higher travels speeds of motorcycles than bicycles, and crashes of lower severity levels are prone to greater under-reporting, as discussed earlier. This paper proceeds to outline the four-stage methodological approach involving crash data filtering, descriptive analyses of crash and controller characteristics, modeling probabilities of bicycle and motorcycle crashes, and modeling at-fault characteristics of riders and drivers using regression models. Results from the descriptive analyses and regression models are then presented, followed by a discussion of the findings and their implications in developing targeted countermeasures. Limitations and conclusions of the research are finally presented.

2. Method

2.1 Setting

This research was conducted in the State of Queensland, Australia. Queensland has 4.3 million inhabitants and a climate that varies from sub-tropical to tropical, allowing year-round bicycle and motorcycle riding. A recent national population survey estimated that about 26% of the Queensland population rode a bicycle in the previous month (ABC, 2012). However, in the 2011 Australian Census, only 1.2% of Brisbane residents travelled to work by bicycle (ABS, 2012). There were 162,000 motorcycles registered in Queensland at 30 June 2011, comprising 3.7% of registered vehicles (TMR, 2012). Most urban roads have signed 60 km/h speed limits. Vehicles drive on the left side of the road and cycling on the footpath is legal for riders of all ages unless there are signs prohibiting riding.

2.2 Study approach

A comprehensive comparison of bicycle and motorcycle crashes requires understanding the similarities and differences between them in terms of 1) characteristics of crashes, 2) characteristics of controllers involved, and 3) involvement of controllers as the at-fault party.

The first component provides insights into where and how the crashes occurred; the second describes who were involved in the crashes; whereas the third can suggest potential targets for safety measures based on enforcement or education.

To understand the similarities and differences, a four-stage analysis approach is undertaken in this study. In the first stage, police-reported crash data are filtered to select the crashes involving a bicycle or a motorcycle and a motor vehicle. The resulting data set is then further carefully examined to check its reliability, i.e., finding missing or unknown data fields, correlations among data groups, and any seemingly unusual high or low crash numbers. The second stage involves descriptive analyses of the selected dataset to understand the general characteristics of crashes and controllers involved. Frequencies of crashes for different characteristics of controllers (e.g., gender, age, license status), crashes (e.g., crash type, time of crash), and roadway features (e.g., road type, traffic control type, speed limits) are analyzed. In the third stage, a regression model is developed. Conditional on there having been a two-unit two-wheeler crash, it models the probability that it is a motorcycle rider who was involved rather than a bicycle rider. The probability values are estimated for different characteristics of crashes, roadways, riders, and drivers involved. The final stage involves examining the at-fault characteristics of bicyclists and motorcyclists using regression models. A substantial amount of research has examined fault in multi-vehicle bicycle and motorcycle crashes, with the general finding that the other driver is more often at fault than the two-wheeler (e.g., ACEM, 2008; Haque et al., 2009; Hurt et al., 1981) but none has compared the patterns of fault in bicyclist and motorcyclist crashes.

Crash severities were not compared in this study, because only the more severe crashes were included in the analyzed dataset. Thus any differences in the overall severity patterns could not be detected. From a practical point of view, all of the crashes included in the data set are sufficiently severe to be legitimate targets for treatment.

2.3 Data

A dataset of police-reported crashes involving a bicycle (n=4015) or a motorcycle (n=8978) from 1 January 2005 to 31 December 2009 in Queensland was supplied by the state department of Transport and Main Roads. Crashes that occur on private roads or on public paths that are not within the road reserve (e.g., off-road bicycle paths through public parks) are excluded from the official records. Of the reported crashes, 3698 two-unit crashes involved a bicycle and 5370 involved a motorcycle. A two-unit crash is one which involves two controllers, e.g., a two-wheeler and a car. Pedestrians are not counted as units in the dataset. Crashes involving more than two units (n=488) were omitted from the dataset to keep the analysis focus on two-unit crashes. Furthermore, two-unit crashes involving one bicycle and one motorcycle (n=35) were excluded to simplify the analyses. After crashes where the outcome was reported as minor injury or property damage were excluded, the final dataset contained 6761 two-vehicle crashes: 2790 involving a bicycle and a motorized vehicle (car, bus, truck, utility or panel van) and 3971 involving a motorcycle and another motorized vehicle, where the maximum level of severity of injury to anyone in the crash was coded as fatality, hospitalization or medical treatment. The unit judged by police to be most at fault was labeled “Unit 1”.

There were substantial levels of missing data for some variables of interest. Helmet use was coded as unknown for 10.6% of bicycle riders and 9.0% of motorcyclists. Seat belt use was coded only for injured drivers, so it was not available for 97.8% of drivers in the bicycle crashes and 92.4% in the motorcycle crashes. License status was unknown for 10.8% of drivers in bicycle crashes and 7.0% of drivers in motorcycle crashes. License status was unknown for 3.2% of motorcycle riders in crashes and was not recorded for bicycle riders.

Gender and age were unknown for less than 0.5% of bicyclists and motorcyclists. However, driver gender and age were recorded as “Not applicable” in the 1.4% of bicycle crashes and 1.5% of motorcycle crashes where there was no controller present at the time of the crash (e.g., a parked car with no driver present). In these crashes, the bicycle or motorcycle rider was coded as most at fault. Gender was coded as “unknown” for 5.3% of drivers in bicycle crashes and 2.8% of drivers in motorcycle crashes. Age was coded as “unknown” for 8.5% of drivers in bicycle crashes and 3.6% of drivers in motorcycle crashes. Driver gender or age was more commonly unknown when the driver was most at fault. This is consistent with some of the crashes being reported to the police at a later time in order to facilitate third-party injury insurance claims against the driver at fault.

Alcohol/drug involvement was coded if the controller was attributed with the contributing circumstances “Violation - Over prescribed concentration of alcohol”, “Condition - Under influence of liquor or drug”, or “Violation - Tested for drugs only”. There is no “Violation - Over prescribed concentration of alcohol” for bicycle riders and riders are often not tested, so alcohol/drug involvement may be underestimated for bicycle riders. Unfortunately, the official records show only whether alcohol/drug was present with no distinction made between “no alcohol/drug” and “unknown”, so there is no clear indication of the extent of missing data for this variable.

None of the high risk behaviors automatically led to the controller being coded as at fault. Among motorcyclists where alcohol/drug involvement was coded as a contributing factor, 76.6% were at fault. The corresponding proportions of being at fault for speeding, helmet non-use, unlicensed riding were 80.4%, 90.9%, and 70.9%, respectively. Among bicyclists, the proportions at fault when alcohol/drug involved and helmet non-use were identified were 80.6% and 82.9%. For other drivers, 74.8% of those with alcohol/drug involved, 66.2% of those unlicensed and 76.9% of those speeding were coded as at fault.

Given that previous research have shown that high risk behaviors co-occur in motorcycle crashes (FORS, 1997, 1999; NHTSA, 2008) in the US (Hurt et al., 1981) and Australia (Haworth et al., 1997), both on the part of the rider and the other driver (Schneider et al., 2012), analyses of their associations were undertaken. All of the high risk behaviors were found to be significantly related. Significant associations were detected between helmet non-use and alcohol/drug involvement for both motorcycle and bicycle riders (motorcycle: $\chi^2(1) = 125.8$, $p < 0.001$; bicycle: $\chi^2(1) = 31.25$, $p < 0.001$). Helmet non-use was associated with both speeding and unlicensed riding for motorcycle riders (speeding: $\chi^2(1) = 7.4$, $p < 0.01$; unlicensed riding: $\chi^2(1) = 247.9$, $p < 0.001$). Speeding was associated with unlicensed riding by motorcyclists ($\chi^2(1) = 61.7$, $p < 0.001$). For motorcycle riders and other vehicle drivers, alcohol/drug involvement was associated with speeding (motorcycle: $\chi^2(1) = 87.1$, $p < 0.001$; other drivers: $\chi^2(1) = 11.2$, $p = 0.001$) and with unlicensed riding (motorcycle: $\chi^2(1) = 154.2$, $p < 0.001$; other drivers: $\chi^2(1) = 40.4$, $p < 0.001$). Speeding was also associated with unlicensed driving by other drivers ($\chi^2(1) = 41.3$, $p < 0.001$). Schneider et al. (2012) note that the inter-relationship between high risk behaviors makes it difficult to untangle their specific effects.

Age group and license status were correlated for drivers, with most of the youngest drivers having learner or provisional licenses. To remove this correlation, license status was recoded to “licensed”, “unlicensed” and “unknown”.

The original dataset included 20 categories of contributing circumstances with up to six contributing circumstances noted for each unit in a crash. For modeling purposes, the analysis in this paper excluded categories which were coded as present for less than 2% of units in crashes. The contributing circumstances that remained were: alcohol/drug, speeding (for motorcycle riders only), fail to give way/stop, disobey traffic sign/light, illegal maneuver, and dangerous driving. Illegal maneuver was coded if the controller was attributed with “Violation – improper overtaking”, “Violation – cross double lines”, “Violation - fail to signal intention”, “Violation – improper turn other than U-turn”, “Violation – fail to keep left”, “Violation – unsafe lane change”, “Violation – improper U-turn”, “Violation – overtaking stationary vehicle at pedestrian crossing”, “Violation – illegally parked” or “Violation – turn in the face of oncoming traffic”.

2.4 Regression models

As noted in Section 2.2., a regression model was formulated to compare the relative involvement of different factors in bicycle-motor vehicle and motorcycle-motor vehicle crashes. Conditional on there having been a two-wheeler crash, the analysis models the probability that it is a bicyclist who was involved rather than a motorcyclist (or conversely - it is symmetrical). As explained earlier in Section 2.3, crashes involving both types of two-wheelers were omitted from the analysis because of relatively low number of these crashes. The remaining two outcomes can be well formulated as a binary logistic model by using the binary outcomes motorcycle crash (= 1) and bicycle crash (= 0) as the response variable. A set of explanatory variables describing the characteristics of crashes, riders, and drivers (see Table 3) which were assumed to be associated with the likelihood of crashes involving motorcycles and bicycles was included in the model.

The influence of the explanatory variables on the at-fault status of riders and drivers was examined by formulating separate models for bicycle and motorcycle crashes. By using the binary outcomes rider-at-fault (= 1) and rider-not-at-fault (= 0) as response variables in corresponding models of bicycle and motorcycle crashes, the models were formulated as binary logistic models. Separate models for bicycle and motorcycle riders were necessary because some of the explanatory variables (e.g., license status of rider, speeding rider) were not available or relevant in both sets of crashes.

To select the explanatory variables to be included in the models, each variable was carefully examined for different observation groups (e.g., bicycle crashes) and its association with being at-fault. Given the low numbers of motor vehicle drivers for whom speeding was coded as a contributing circumstance (0.3% in bicycle crashes, 0.4% in motorcycle crashes), other driver speeding was not included in the models. Since no bicycle riders were coded as speeding, rider speeding was excluded from the crash and the bicycle-at-fault models. Similarly, since license status of all bicycle riders was reported as Not Applicable, rider license status was excluded from these two models.

Dangerous driving as a contributing circumstance predicted being at-fault perfectly for riders and drivers and so was excluded from the at-fault models. Circumstances where a bicycle rider failed to give way/stop or a driver disobeyed traffic light/sign at the time of crash also predicted fault perfectly in bicycle crashes, and thus were not included in the bicycle-at-fault model.

The contributing circumstances “other driver conditions” and “other circumstances” covered a wide variety of individual circumstances, some of which were already included as crash characteristics (e.g., wet road), and therefore these variables were excluded from all models.

In all models, to identify the subset of explanatory variables which yield the best fitted model, a backward elimination procedure was employed to eliminate the non-significant variables one by one so that the Akaike Information Criteria (AIC) was minimized. Significance of the explanatory variables was examined by using the z-test. To evaluate if the models have sufficient explanatory power, likelihood ratio statistics (G^2) were computed.

3. Results

3.1 Descriptive statistics

The characteristics of the 6761 two-wheeler crashes are summarized in Tables 1 and 2. Riders were more likely to be male (79.1% bicycle, 89.3% motorcycle) than the drivers in these crashes (57.6% drivers in bicycle crashes, 59.4% drivers in motorcycle crashes). Almost a quarter (22.6%) of the bicycle riders were children. About 10-13% of motorcycle riders and drivers were novices (learner, provisional or restricted licenses). Almost 8% of motorcycle riders were unlicensed.

Drivers of other vehicles were coded most at fault in the majority of bicycle (57.0%) and motorcycle crashes (62.7%). Helmet wearing rates were lower for bicycle riders than motorcycle riders (79.1% versus 89.5%). Alcohol or drug involvement was highest among motorcycle riders (4.0%), although the extent of missing data could not be identified. Motorcycle riders were also more involved in speeding (5.0%) than others. Drivers of other vehicles failed to give way/stop at the time of crash more often than bicycle riders (26.2% versus 5.8%) and motorcycle riders (25.6% versus 3.3%). A similar trend was observed for drivers performing an illegal maneuver during bicycle (10.4% versus 3.7%) and motorcycle crashes (25.0% versus 10.0%).

Almost 80% of other vehicles in bicycle and motorcycle crashes were cars. About 20% of crashes occurred on weekends and 16-18% happened at night. More than half of the bicycle and motorcycle crashes occurred at intersections and more than 60% of crashes occurred on roads with a 60 km/h speed limit. Bicycle crashes occurred more often (30% in comparison with 18.6% of motorcycle crashes) on roads with 50 km/h or less speed limits. The most common crash type was intersection from adjacent approaches (31.1% bicycle crashes, 24.5% motorcycle crashes) among which the most common types were right turn (34.3% bicycle crashes, 57.1% motorcycle crashes), right angle (27.6% bicycle crashes, 31.8% motorcycle crashes), and left turn (23.3% bicycle crashes, 9.4% motorcycle crashes).

3.2 Regression model results

The parameters of the formulated models were derived using the maximum likelihood estimation method in the software STATA 11.2. The parameter estimates, odds ratios (O.R.), and their statistical significance, are presented in Table 3. The AIC values of the best-fitted crash-type-comparison-model, bicycle-at-fault-model, and motorcycle-at-fault-model are

6780.6, 1605.9, and 1689.7 respectively. The corresponding likelihood ratio statistics are 2500.8 (57 *df*), 2300.6 (46 *df*), and 3652 (47 *df*). The values are well above the corresponding critical values for significance at the 1% significance level, implying that the models have sufficient explanatory power. The significant variables of the models are discussed in the subsequent sections.

3.2.1 Results from crash type comparison model

The regression model comparing motorcycle and bicycle crashes found a significant time trend in which the number of motorcycle crashes dropped relative to bicycle crashes (beta = -0.004) over the five-year period (see Table 3). In terms of crash characteristics, motorcycle crashes were more likely than bicycle crashes to occur at "other intersections" relative to mid-block locations (O.R. = 1.9) and at stop signs relative to locations with no traffic control (O.R. = 1.5), many of which were mid-block locations. Not surprisingly, motorcycle crashes were less likely (18% lower odds) than bicycle crashes to occur in speed zones of 50 km/h or less and more likely to occur in speed zones of 80-90 km/h (122% increase in odds) and 100-110 km/h (259% increase in odds) compared to 60 km/h speed zones. The odds of motorcycle crashes occurring in darkness with street lighting were 22% higher than those of bicycle crashes and were 32% lower to occur in dawn/dusk. Motorcycle crashes were more likely (O.R. = 2.1) to occur on curves where the view was obstructed (but not where the view was open) than bicycle crashes (relative to straight road sections). Motorcycle crashes were more likely to occur on crests (52% higher odds) and less likely to occur on dips (52% lower odds) and grades (29% lower odds) than bicycle crashes (relative to level road sections). Relative to crashes at intersections from adjacent approaches, motorcycle crashes were more likely than bicycle crashes to be head on (O.R. = 5.8), involve opposite vehicles turning (O.R. = 1.4), be rear-end collisions (O.R. = 8.9), and involve lane changes (O.R. = 1.7).

In terms of rider characteristics, motorcycle riders in crashes were less likely than bicycle riders to be female (56% lower odds), or to be aged 0-15 years (95% lower odds) or over 50 years (35% lower odds), but were more likely (48% higher odds) to be aged 21-24 years (relative to 25-39 years of age). Motorcycle riders were less likely than bicycle riders to not be wearing a helmet (82% lower odds) or for helmet status to be unknown (23% lower odds). Motorcycle riders were more likely to violate road rules than bicycle riders. While motorcycle riders had about twice the odds of bicycle riders to be influenced by alcohol/drug, fail to give way/stop, and disobey traffic light/sign, their odds were much higher when illegal maneuver (5.9 times) or dangerous driving were recorded (27.3 times).

The other drivers were more likely to be female (17% higher odds) or of unknown gender (277% higher odds) or 60 years and older (21% higher odds) in motorcycle compared to bicycle crashes. The other drivers in motorcycle crashes were also more likely to fail to give way (O.R. = 3.1), disobey traffic light/sign (O.R. = 6.4), perform an illegal maneuver (O.R. = 4.7) or be charged with dangerous driving (O.R. = 2.7) than in bicycle crashes.

3.2.2 Results from at fault models

Time of day, day of week and wet or dry road surface did not affect the likelihood of the rider being at fault in either the bicycle or the motorcycle model. For both bicycle and motorcycle crashes, the odds of riders being at fault at roundabouts were about half those at mid-block locations. Crashes at traffic lights were less likely to be the fault of the bicycle (O.R. = 0.27) or motorcycle (O.R. = 0.43) rider than crashes at locations with no traffic control (which were mostly mid-block). Compared with locations with no traffic control, motorcycle riders were less likely to be at fault at give-way and stop signs with corresponding 45% and 83% reductions in odds.

Speed limit did not affect the likelihood of the motorcycle rider being considered at fault, but bicycle riders had 53% lower odds to be at fault in 70 km/h zones than in 60 km/h zones. Conversely, the odds of motorcycle riders to be at fault in crashes at dawn/dusk were 2.3 times those in daylight, but this was not true for bicycle riders. Horizontal alignment did not affect likelihood of the rider being at fault in either bicycle or motorcycle crashes, but bicycle riders were less likely (78% lower odds) to be at fault in crashes occurring on crests than those on a level road.

Bicycle riders were less likely to be at fault in most types of crashes that did not occur at intersections with vehicles from adjacent approaches (with the exception of vehicle leaving from driveway where they had 105% higher odds to be at fault and head on where there was no significant difference). Motorcycle riders were less likely to be at fault when there were opposing vehicles turning (66% lower odds) and where there were lane changes (72% lower odds) than at intersections with vehicles from adjacent approaches. Drivers of utilities and panel vans were more likely to be at fault (compared to car drivers) in bicycle crashes with corresponding increase in odds by 95.4%.

The effects of the characteristics of bicycle and motorcycle riders on at fault status were also examined in the models. The odds of male motorcycle riders to be at fault were 1.8 times the odds for females, but this was not true for bicycle riders. All of the younger age groups were more likely to be at fault than bicycle riders aged 25-39 years, as were riders aged 50 and over and riders whose age was unknown. Interestingly, riders aged below 15 years, who are relatively inexperienced on roads, had the highest odds ratios (8.43) of being at fault and the odds ratios showed a decreasing trend with increase in rider age. The only effect of age on at fault status for motorcycle riders was that riders aged 16-20 years were more likely (O.R. = 2.06) to be at fault than riders aged 25-39 years.

Riders not wearing helmets were significantly more likely to be at fault in both bicycle (310% higher odds) and motorcycle (766% higher odds) crashes, and riders whose helmet status was unknown were more likely to be at fault in bicycle crashes (56% higher odds). Unlicensed motorcycle riders were more likely to be at fault than licensed riders with an increase in odds by 174%. Not surprisingly, the likelihood of the rider being coded at fault was greater where alcohol/drug involvement (bicycle: O.R. = 8.5; motorcycle: O.R. = 3.0), speeding (motorcycle: O.R. = 20.2), fail to give way/stop (bicycle: all observations were associated with rider at fault; motorcycle: O.R. = 437), disobey traffic light/sign (bicycle: O.R. = 148; motorcycle: O.R. = 185), illegal maneuver (bicycle: O.R. = 49.7; motorcycle: O.R. = 177) and dangerous driving (all observations were associated with rider at fault) were recorded.

Regarding other driver characteristics, bicycle riders were more likely (46% higher odds) to be considered at fault when the other driver was female. Motorcycle riders were less likely (55% lower odds) to be at fault when the other driver was aged 16-20 years (relative to 40-59 years). Both bicycle and motorcycle riders were less likely to be at fault when the age of the other driver was unknown and bicycle riders were more likely to be at fault when the gender of the other driver was unknown. This probably reflects crashes where the driver of the other vehicle was not present.

License status of the other driver had no significant effect on fault status in bicycle or motorcycle crashes. The likelihood of the bicycle or motorcycle rider being coded at fault was lower where the other driver was recorded as being alcohol/drug influenced (bicycle: 73% lower odds; motorcycle: 88% lower odds), failing to give way/stop (99.6% lower odds for both), performing an illegal maneuver (99% lower odds for both), disobeying traffic light/sign (bicycle: all observations associated with rider not at fault; motorcycle: 99.7% lower odds) or charged with dangerous driving (all observations associated with rider not at fault).

Given that 22.6% of the bicycle riders in crashes were aged 0-15 years and their odds of being at fault were eight times higher than for riders aged 25-39 years, further analyses of these crashes were undertaken to better identify countermeasures relevant to this group. Of the 630 child bicyclist crashes, the most commonly coded crash types were 'vehicle leaving driveway' (n=255) and 'intersection from adjacent approaches' (n=186). The children were coded as at fault in about 90% of both of these types of crashes, while the at fault rate was much lower for adult bicyclists. Of the 'vehicle leaving driveway' crashes, 214 involved a controller (presumably a cyclist) riding out from the footpath and colliding with a vehicle travelling along the road. There were no traffic controls at the location of about 50% of the crashes at intersections from adjacent approaches. Most of the child cyclist crashes occurred during the day on 0-60 km/h speed limit roads.

Since intersection from adjacent approaches was the most common type of crash and drivers failed to give way in about a quarter of these crashes, further analyses were undertaken to explore the crash scenarios where drivers failed to give way. The proportion of drivers failing to give way was highest at roundabouts (58.2%) and locations with give-way (68.8%) or stop signs (66.5%). The corresponding proportion at signalized intersections was as little as 2%. In general, drivers were more likely to fail to give way to motorcyclists than to bicyclists. Drivers were most likely to fail to give way in 'intersection from adjacent approaches' crashes (bicycle crashes: 55.6% of drivers, motorcycle crashes: 75.3% of drivers) and in 'vehicle leaving driveway' crashes with motorcycles (74.9% of driver, but not bicycles: 17.1% of drivers). Among the former type of crashes, the corresponding proportions of drivers failing to give way in bicycle and motorcycle crashes were correspondingly 63.3% and 75.2% (right angle crashes), 61.1% and 78.6% (right turn crashes), and 66% and 48.9% (left turn crashes). The right angle crashes commonly occurred at cross intersections, whereas the turning crashes tended to occur at T intersections.

Drivers performed illegal maneuvers mostly in crashes at intersections with no traffic control (bicycle crashes: 74.4%, motorcycle crashes: 76.5%) and operating traffic lights (bicycle crashes: 18.6%, motorcycle crashes: 21.4%). The highest proportions of drivers performing illegal maneuvers were found in turning related crashes: 'opposing vehicle turning' (bicycle crashes: 69.4%, motorcycle crashes: 68%), and 'parallel lanes turning' (bicycle crashes: 20.8%, motorcycle crashes: 51.4%). Motorcycle crashes involving lane changes also contributed 55.4% of cases of drivers performing illegal maneuvers.

4. Discussion

This paper explored the degree of similarity of two-unit bicycle and motorcycle crashes to assess whether the same treatments might be effective for both types of crashes. The analyses revealed general similarities in the road characteristics and crash types, with intersection from adjacent approaches being the most common crash type for both bicycles and motorcycles. Consistent with earlier research (ACEM, 2008; Comelli et al., 2008; Haque et al., 2009; Hurt et al., 1981; Johnston et al., 2008; Räsänen and Summala, 1998; Wells et al., 2004), drivers of other vehicles were coded most at fault in the majority of bicycle (57.0%) and motorcycle crashes (62.7%). This implies that two-wheeler safety improvement treatments need to focus not only on riders but also on drivers. The successive paragraphs discuss the common driver actions that led to being at fault in bicycle and motorcycle crashes: failure to give way and illegal maneuvers.

The results of this study support earlier research showing that a very large proportion of multi-vehicle bicycle (Räsänen and Summala, 1998) and motorcycle crashes involve right-of-way violations by other vehicles (ACEM, 2008; Comelli et al., 2008; Hurt et al., 1981; Johnston et al., 2008; Wells et al., 2004). Many of these crashes fall into the category of 'looked but failed to see' (LBFTS) or 'sorry mate I didn't see you' (SMIDSY) crashes (Broughton and Walker, 2009; Brown, 2005).

Driver failure to see two-wheelers, difficulty in determining motorcycle speeds, and reduced conspicuity of two-wheelers have been identified as important causes of 'failure to give way' type crashes in many studies (e.g., Haque et al., 2012; Horswill et al., 2005; Pai, 2011b; Pai et al., 2009). While driver attention is important, improving conspicuity of riders by using illuminated lights, wearing reflective clothing, and using retro-reflective marking on helmets and two-wheelers could potentially improve rider safety. Limited conspicuity of two-wheelers, particularly bicycles, is a more serious issue at night (Wood et al., 2009). Smaller size and less intensity of bicycle lights could explain why drivers failed to give way to bicyclists more often at night than motorcyclists. Increasing the conspicuity of riders and two-wheelers to improve safety has been recommended in a number of studies (Haque et al., 2012; Pai et al., 2009; Thornley et al., 2008; Wood et al., 2009; Yuan, 2000). In addition to headlight (static or blinking), reflective vest, and reflective markings on two-wheelers, researchers (Wood et al., 2012) have suggested use of ankle and knee reflectors for bicyclists. Enforcement of mandatory bicycle lights at night by imposing fines, as practised in the Netherlands (Wegman and Aarts, 2006), could discourage bicycle riding at night without lights. Introducing minimum requirements for lights and reflective elements of bicycles and motorcycles could further encourage conspicuous riding and improve uniformity in conspicuity of particular type of two-wheelers so that drivers perceive them correctly.

The effectiveness of the conspicuity improvement treatments has been the subject of considerable research. Mandatory use of daytime motorcycle headlights was found effective in reducing motorcycle crashes (Elvik et al., 2009; Yuan, 2000). However, night-time conspicuity improvement treatments, such as retro-reflective vests and markers, were found to produce mixed findings for motorcycles, as identified in Haque et al. (2012). For bicycles, on the other hand, use of reflective vests and markers (Thornley et al., 2008; Wood et al., 2009) and ankle and knee reflectors (Wood et al., 2012) were found to be generally effective. Bicycle lights were also found to reduce crashes by increasing their visibility during daylight and twilight periods, but no such effects seen for night time (Madsen et al., 2013). However, effectiveness of bicycle lights in enhancing conspicuity was found to be over-estimated by bicyclists compared to drivers (Wood et al., 2009). A systematic review of randomized controlled trials (Kwan and Mapstone, 2004) concluded that bicycle visibility aids influence drivers' reaction, detection, and recognition; however, their effects on cyclist crashes were considered to be unknown.

The majority of the crashes where the driver failed to give way occurred at intersections with two-wheelers from adjacent approaches or when a vehicle was leaving a driveway. Often vehicles leave driveways in the reverse direction and the presence of parked vehicles along roads could restrict drivers' sight distance and therefore contribute to the failure to see and give way to oncoming riders.

Signalized intersections have shown better performance in reducing driver failure to give way crashes in comparison with uncontrolled, give-way, and stop controlled intersections. While traffic lights should reduce such failure to give way cases, signalization of most intersections could be economically infeasible.

Drivers performed illegal maneuvers mostly in turning and lane changes crashes at intersections with no traffic control and traffic lights. Motorists violating right of way of motorcycles (i.e., performing illegal maneuver) has been found as contributing factor of motorcycle crashes in many studies (see Pai, 2011a for a discussion). The likely causes identified were the reduced conspicuity of motorcycles and the perception that approaching motorcycles are less threatening than large vehicles. While improving conspicuity could make motorcycles better visible to drivers, driver awareness of violating right of way and its potential consequences is important. Separating motorcycles from other traffic has been found to be effective in reducing motorcycle crashes in Malaysia (Radin Sohadi et al., 2000). Separation of bicycles from other traffic has also been suggested (e.g., Bíl et al., 2010) and is more common than separation of motorcycles. However, Aultman-Hall and Kaltenecker (1999) showed that such separation does not necessarily reduce the number of cycling crashes. Lower speed limits provide a cheaper alternative to the construction of separated two-wheeler paths (Bíl et al., 2010), but the benefits may be greater for mid-block sections than for intersections.

Intelligent transportation system (ITS) technologies, such as blind zone alert, obstacle detection systems, intelligent speed assistance, in-vehicle driver behavior monitoring etc. could be effective in reducing two-wheeler crashes (Pai, 2011a; Steriu, 2012). However, there has been limited research in developing ITS measures specifically targeted to car-motorcycle and car-bicycle crashes and challenges in market introduction of these measures are the major obstacles to their use. The European Union funded SafeCycle project has been developing ITS technologies for bicycle safety (e.g., avoiding red light running, bicycle detection by cars, blind spot signaling for trucks), but these are not yet widely known or used (Steriu, 2012).

Similarities in driver and rider exposure patterns (e.g., young males drive/ride more at night than others, reduced riding during rain) could underpin some of the similarities in crash involvement characteristics. Conversely, some differences in driver and rider exposure patterns (e.g. more recreational bicycle riding during dawn and dusk) might lead to differences in crash involvement characteristics. However, lack of exposure data restricts the ability of this study to analyze such relationships. Nevertheless, it can be seen that the differences between bicycle and motorcycle crashes identified by the crash-type-comparison-model related largely to differences in usage patterns (fewer bicycle crashes in high speed zones, more in low speed zones, and fewer in darkness with street lighting) and travel speeds (more motorcycle crashes on curves where the view was obstructed and on crests; more bicycle crashes on dips and grade sections). More bicycle crashes in low speed zones (0-50 km/h) probably reflect more bicycle usage in the Brisbane city and surrounding areas which are hilly. It could be argued that higher speeds and restricted visibility caused more motorcycle crashes on curves with obstructed views and on crests. Rider awareness of hazards at these locations and installation of signage to warn motorists of restricted view could potentially improve rider safety.

Violations of road rules by both drivers and riders (and consequently being at-fault) were more common in motorcycle than bicycle crashes. This rather surprising finding warrants further investigation. It might reflect more driver failure to see motorcyclists (Haque et al., 2012) and more common failure by motorcyclists to react to drivers because motorcyclists are travelling more quickly than bicycle riders. Alternatively, police may be more likely to identify violations in motorcycle crashes because they perceive that sanctions would be easier to apply to drivers and motorcycle riders than bicycle riders (who do not have the threat of losing their license).

One of the important differences between bicycle and motorcycle crashes is the greater involvement of children in bicycle crashes. Almost a quarter of the bicycle riders were aged under 16, and 80% were at fault in the crash. Similar findings were also found in Ontario, where 79% of bicycle riders aged under 10 and 55% aged 10 to 19 years were at-fault (Rowe et al., 1995). Analyses showed that child bicyclists are mostly involved in leaving driveway/footpath and ‘intersection from adjacent approaches’ types of crashes which occurred mainly during daytime and in 0-60 km/h roads. Since children are mostly at fault in these scenarios and adults are generally not, educational approaches such as improving child riding awareness (e.g., education from school or parents) are needed for the children. Structured educational programs like the Bikeability scheme (UK) and Cycling certificates and Great Cycling Exam (Belgium) could improve the skills of children as well as older cyclists (Steriu, 2012). Furthermore, since the severity levels of these child bicyclist crashes were high, implementing measures to reduce injury severity (e.g., helmet use, lower speed limits or traffic calming measures to reduce travel speeds) could be beneficial for them (as well as adults). It may be more effective to adapt the riding environment to the needs of children, particularly in the low speed areas where children usually access roads from footpaths, rather than attempting to make children behave more like the adults.

Child bicyclists are inexperienced not only with riding but also with the functioning of the road system. In addition, significant numbers of adult cyclists are lacking in (at least recent) cycling experience. A survey of adult Queensland cyclists found that 26% of respondents had only been riding regularly in the last two years (Haworth and Schramm, 2011). Inexperience has also been shown to be a major factor in motorcycle crashes (Mullin et al., 2000; Rutter and Quine, 1996). Inexperience appears to contribute to crash risk by means of lower levels of vehicle control skill and lower levels of hazard perception and responding (Bellet and Banet, 2012; Habibovic and Davidsson, 2012; Hosking et al., 2010), both leading to poorer ability to avoid crashes.

Many of the bicyclist crashes involving children occurred at intersections with no traffic control on roads with speed limits of 60 km/h or less. Arguably, these are areas of low traffic volume (as evidenced by the lack of traffic controls) and therefore the economic value of installing on-road treatments or separated facilities at each of these sites is likely to be low. Therefore, measures that have a more area-wide effect, such as lower speed limits, and potentially rider or driver education, may be more appropriate than intersection improvements. It has been recommended that speed limits on access roads, which are shared by bicycles and motorized traffic, should be set at 30 km/h to minimize the risk of death and serious injury (Steriu, 2012). Enforcement of the speed limits and supplementing the signs by installing low-cost traffic calming measures were recommended to improve driver compliance with speed limits.

While motorcyclists were more likely to be involved in crashes than bicyclists when under the influence of alcohol or drugs, bicyclists were more likely to be at-fault than motorcyclists under such influence. This may reflect under-reporting of alcohol and drug information for bicycle riders because of a lower likelihood of bicyclists being tested for alcohol or drugs.

A number of findings of the current research which contrast with previous studies may reflect the particular subset of crashes analyzed here. The current study found no effects of weekday/weekend or wet road on the likelihood of it being a bicycle or motorcycle crash or of the rider being at fault. In contrast, Haque et al. (2009) reported that wet roads increased at-fault crash involvement at intersections. However, their analysis included single vehicle crashes which may have shown a greater effect of wet road than the two-unit crashes examined here. The motorcycle riders in the current study are more likely to be at fault than in Schneider et al.'s study (Schneider et al., 2012). One of the differences between the two studies is that Schneider et al. (2012) included crashes of all severities whereas minor injury and property damage crashes were excluded from the current study. This may have affected the likelihood of riders being at fault, assuming that lower severity crashes would be less likely to be reported if the rider was at fault.

5. Limitations

The dataset did not include information on some factors which have previously been shown to be significant predictors of at fault status in motorcycle crashes, including seat belt use by the other driver (Schneider et al., 2012) and estimated vehicle speed (Kim et al., 2007). The lack of data for some of the high-risk behaviors may have prevented identifying relationships between them (as in Schneider et al., 2012), which may have resulted in effects being attributed to the wrong variable.

While the comparisons were limited to two-unit crashes with an outcome of at least medical treatment to limit the recognized effects of under-reporting of low severity bicycle and motorcycle crashes, it may be that there was more complete reporting of crashes where the other vehicle was at fault than where the two-wheeler was at fault. In addition, the exclusion of property damage only and minor injury crashes precluded any useful analyses of factors influencing the severity of bicycle and motorcycle crashes. It should be noted that some judgments of fault may have been incorrect, because they were made by general police, rather than specialist investigators.

The explanatory variables included in the regression models were limited to those features of the road system that are recorded in Police crash data, including characteristics of crashes, roadway features, riders, and drivers. Broader aspects of the road system, such as details of road design (e.g., turning radius, presence of exclusive turning lanes), training of riders and drivers, and road rules are also likely to affect the likelihood and at-fault characteristics of bicycle and motorcycle crashes. For example, whether bicycles and motorcycles are being used for recreation, rather than transportation, may well affect crash characteristics, but this is not recorded in Police crash data.

Care should be taken in generalizing the effects of helmet use or fault status to other jurisdictions where bicycle or motorcycle helmet wearing is not mandatory or wearing rates are significantly lower. Helmet non-wearing by motorcyclists may be a stronger marker of risk taking in Australia than elsewhere.

6. Conclusions

The crash types, patterns of fault and factors affecting fault are generally similar for two-unit bicycle and motorcycle crashes. This confirms the need to combat the factors contributing to failure of other drivers to yield right of way to two-wheelers, and suggests that some of these actions should prove beneficial to the safety of both motorized and non-motorized two-wheelers. The limited conspicuity of two-wheelers might have resulted in drivers failing to see and yield right of way to two-wheelers, thus highlighting the need of enhancing two-wheeler conspicuity. Child bicyclists were over-represented as the at fault party, particularly in crashes involving a vehicle leaving driveway or footpath, potentially indicating the need for rider education and awareness. In general, safety improving treatments need to focus on both drivers and riders. The greater reporting of violations by riders and drivers in motorcycle crashes deserves further investigation, however.

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TABLE 1 Descriptive Statistics for the Two-Wheeler Controllers and Other Drivers

Variable name	Bicycle crashes (n=2790)		Motorcycle crashes (n=3971)	
	Two-wheeler %	Other vehicle %	Two-wheeler %	Other vehicle %
Gender				
Male	79.1	57.6	89.3	59.4
Female	20.9	35.8	10.7	36.3
Not applicable/Unknown	0.0	6.6	0.1	4.3
Age				
0-15	22.6	0.0	0.9	0.0
16-20	11.0	8.2	9.0	10.6
21-24	7.9	8.2	13.5	10.1
25-39	27.6	27.6	39.4	29.0
40-59	23.9	34.1	33.0	31.6
60+	6.6	12.0	3.9	13.6
Not applicable/unknown	0.4	9.8	0.3	5.1
License status				
Learner		0.9	3.0	1.3
Provisional or restricted		9.0	7.0	11.5
Open		75.1	79.0	75.8
Unlicensed*		2.8	7.8	2.9
Not applicable	100.0	1.4	0.1	1.5
Unknown		10.8	3.2	7.0
At-fault	43.0	57.0	37.3	62.7
Wearing a helmet				
Worn	79.1	-	89.5	-
Not worn	10.3	-	1.4	-
Unknown**	10.6	-	9.1	-
Alcohol/drug	2.2	1.7	4.0	2.4
Speeding	0.0	0.3	5.0	0.4
Failure to give way/stop	5.8	26.2	3.3	25.6
Disobey traffic sign/light	3.9	1.1	3.5	3.2
Illegal maneuver	3.7	10.4	10.0	25.0
Other driver condition	2.9	2.4	3.2	2.2

* includes unlicensed, cancelled/disqualified, expired, inappropriate class, never held a license, not licensed in Australia
** includes 5 uninjured motorcyclists for which helmet status was not recorded

TABLE 2 Descriptive Statistics for the Two-Unit Bicycle and Motorcycle Crashes

Variable name	Bicycle crashes (n=2790) %	Motorcycle crashes (n=3971) %
Other vehicle		
Car	77.1	79.7
Utility/panel van	16.3	15.3
Truck	4.1	3.9
Bus	2.5	1.1
Day		
Weekday	80.1	77.2
Weekend	19.9	22.8
Time period		
00.00am-5.59am	5.2	3.9
6am-11.59am	41.6	30.9
12.00pm-5.59pm	42.0	50.3
6.00pm-11.59am	11.3	14.9
Road type		
Midblock	41.0	40.1
Cross intersection	15.3	17.4
Roundabout	10.5	8.3
T junction	30.1	29.4
Other intersections	1.3	2.3
Others	1.8	2.4
Traffic control type		
No control	62.9	62.3
Operating traffic lights	13.0	10.4
Give way sign	18.4	21.1
Stop sign	5.2	4.3
Others	0.5	1.9
Road condition		
Dry	92.5	93.0
Wet	7.4	7.0
Horizontal alignment		
Curve	11.2	16.5
Straight	88.8	83.5
Vertical alignment		
Crest	3.1	5.9
Dip	3.1	2.1
Grade	17.0	14.6
Level	76.9	77.4
Speed zone (km/h)		
0-50	29.9	18.6
60	61.3	62.7
70	4.5	5.2
80-90	2.8	7.2
100-110	1.5	6.2
Crash type		
Intersection from adjacent approaches	31.1	24.5
Head-on	1.8	6.3
Opposing vehicles turning	10.2	18.9
Rear-end	3.9	16.6
Lane changes	6.9	7.5
Parallel lanes turning	7.9	7.8
Vehicle leaving driveway	19.7	7.6
Hit parked vehicle	3.2	1.6
Other	15.3	9.1

TABLE 3 Explanatory Variables Included in Models and Regression Estimates

Explanatory variables	Crash type comparison model			Bicycle at fault model			Motorcycle at fault model		
	Beta	O.R.	p	Beta	O.R.	p	Beta	O.R.	p
Constant	-0.362		0.040	0.375		0.211	1.508		<.001
Time trend #	-0.004	0.996	0.012	-			-		
Crash characteristics									
Weekday crash	-0.116	0.890	0.128	-			-		
Night time crash ^	-			-			-0.530	0.588	0.108
Wet surface	-			-			-		
Roadway type									
Cross intersection	0.016	1.016	0.899	0.414	1.512	0.178	-0.116	0.891	0.671
Roundabout	-0.091	0.913	0.520	-0.709	0.492	0.033	-0.714	0.490	0.038
T junction	-0.078	0.925	0.423	0.198	1.219	0.341	-0.240	0.786	0.189
Other intersections	0.643	1.903	0.012	-1.104	0.332	0.128	-0.296	0.744	0.467
Midblock *									
Others	0.391	1.478	0.080	-0.205	0.815	0.643	-0.609	0.544	0.133
Traffic control type									
No control *									
Operating traffic lights	0.058	1.060	0.646	-1.308	0.270	<.001	-0.837	0.433	0.001
Give way sign	-0.037	0.964	0.749	0.166	1.181	0.552	-0.605	0.546	0.037
Stop sign	0.408	1.503	0.012	0.297	1.345	0.534	-1.755	0.173	0.001
Others	-1.148	0.317	0.005	0.232	1.262	0.707	-0.997	0.369	0.089
Speed limit									
0 - 50 km/h	-0.193	0.825	0.008	-0.178	0.837	0.243	-		
60 km/h *									
70 km/h	0.079	1.082	0.583	-0.763	0.466	0.011	-		
80-90 km/h	0.798	2.222	<.001	0.148	1.160	0.695	-		
100-110 km/h	1.279	3.592	<.001	-0.448	0.639	0.302	-		
Lighting condition									
Daylight *									
Darkness - lighted	0.198	1.219	0.037	-			0.007	1.007	0.985
Darkness - not lighted	-0.218	0.804	0.316	-			0.184	1.202	0.711
Dawn/dusk	-0.388	0.678	0.001	-			0.817	2.264	0.006
Horizontal alignment									
Curve (view obstructed)	0.721	2.056	<.001	-			-		
Curve (view open)	0.185	1.203	0.074	-			-		
Straight *									
Vertical alignment									
Crest	0.419	1.520	0.008	-1.508	0.221	<.001	-		
Dip	-0.740	0.477	<.001	0.680	1.974	0.069	-		
Grade	-0.339	0.713	<.001	-0.070	0.932	0.691	-		
Level *									
Type of crash									
Head on	1.758	5.801	<.001	-0.014	0.986	0.980	-0.183	0.832	0.679
Opposing vehicles turning	0.354	1.424	0.008	-0.950	0.387	0.021	-1.082	0.339	0.010
Rear end	2.182	8.865	<.001	-1.962	0.141	<.001	-0.239	0.788	0.471
Lane changes	0.499	1.646	0.002	-1.916	0.147	<.001	-1.284	0.277	0.001
Parallel lanes turning	0.311	1.365	0.038	-1.718	0.179	<.001	-0.781	0.458	0.059
Vehicle leaving driveway	-0.102	0.903	0.431	0.717	2.049	0.005	-0.050	0.951	0.915
Intersection from adjacent approaches *									
Others	0.033	1.033	0.817	-1.396	0.248	<.001	-0.586	0.557	0.111

Four wheeler type									
Bus and Truck	-			0.405	1.500	0.108	-		
Utility and Panel van	-			0.670	1.954	<.001	-		
Car and Station wagon *									
Rider characteristics									
Female rider	-0.814	0.443	<.001	-			-0.562	0.570	0.005
Age									
0-15 years	-2.924	0.054	<.001	2.132	8.429	<.001	0.983	2.673	0.338
16-20 years	-0.197	0.821	0.066	1.196	3.306	<.001	0.721	2.056	0.006
21-24 years	0.392	1.479	<.001	0.586	1.797	0.021	0.241	1.272	0.243
25-39 years *									
40-49 years	-0.047	0.954	0.572	0.021	1.021	0.923	-0.275	0.760	0.101
50+ years	-0.425	0.654	<.001	0.620	1.860	0.002	-0.208	0.813	0.278
Unknown	-0.109	0.897	0.821	2.072	7.944	0.040	-0.462	0.630	0.728
License status									
Licensed *	NA			NA					
Unlicensed	NA			NA			1.008	2.740	0.001
Unknown	NA			NA			0.001	1.001	0.997
Helmet use									
Worn *									
Not worn	-1.732	0.177	<.001	1.410	4.097	<.001	2.159	8.660	0.012
Unknown	-0.261	0.771	0.010	0.443	1.557	0.031	0.103	1.108	0.640
Drug/Alcohol influenced	0.732	2.079	<.001	2.144	8.538	<.001	1.091	2.976	0.003
Speeding	NA			NA			3.008	20.242	<.001
Fail to give way/stop	0.899	2.456	<.001	a			6.081	437.29	<.001
Disobey traffic light/sign	0.764	2.147	<.001	4.995	147.63	<.001	5.221	185.03	<.001
Illegal maneuver	1.781	5.934	<.001	3.905	49.672	<.001	5.178	177.35	<.001
Dangerous driving	3.307	27.297	<.001	a			a		
Driver characteristics									
Gender									
Male *									
Female	0.158	1.171	0.015	0.376	1.457	0.017	0.106	1.112	0.451
Unknown	1.328	3.773	<.001	0.876	2.401	0.044	1.392	4.022	0.059
Age									
16-20 years	0.197	1.218	0.082	0.019	1.019	0.946	-0.806	0.447	0.001
21-24 years	0.130	1.139	0.251	0.232	1.261	0.370	-0.434	0.648	0.061
25-39 years	0.100	1.106	0.196	0.136	1.146	0.429	0.021	1.021	0.897
40-59 years *									
60+ years	0.193	1.213	0.049	-0.339	0.713	0.145	-0.077	0.926	0.747
Unknown	-1.730	0.177	<.001	-1.417	0.242	<.001	-1.860	0.156	0.009
License status									
Licensed *									
Unlicensed	0.013	1.013	0.953	-			-		
Unknown	0.360	1.433	0.043	-			-		
Drug/Alcohol influenced	-			-1.292	0.275	0.011	-2.118	0.120	<.001
Fail to give way/stop	1.146	3.144	<.001	-5.530	0.004	<.001	-5.636	0.004	<.001
Disobey traffic light/sign	1.856	6.400	<.001	b			-5.881	0.003	<.001
Illegal maneuver	1.539	4.662	<.001	-4.584	0.010	<.001	-4.908	0.007	<.001
Dangerous driving	0.975	2.651	0.009	b			b		
Summary Statistics									
Number of observation	6761			2790			3971		
Log-likelihood (at zero)	-4582.69			-1906.25			-2622.88		
Log-likelihood (model)	-3332.29			-755.97			-796.87		
AIC	6780.57			1605.94			1689.74		
G^2	2500.81 (57 *df*), p<.001			2300.56 (46 *df*), p<.001			3652.03 (47 *df*), p<.001		

\# Assuming that January 2005 = 1 to December 2009 = 60
^ Crashes occurred between 1800-0559 hours
* Reference category
\- Not found significant

NA Not present in model
a Predicts At fault perfectly, variable not present in model
b Predicts Not at fault perfectly, variable not present in model