Differences in Motorcycle Conspicuity-related Factors and Motorcycle Crash Severities in Daylight and Dark Conditions

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ABSTRACT

Previous studies in the United States and internationally suggest that low motorcycle conspicuity, or the inability of the motorcyclist to be seen by other road users, is an important factor associated with the risk of motorcycle crashes. However, there has been limited research on motorcycle conspicuity in the United States in the past two decades, while at the same time, there has been a renewed interest from states in increasing motorcycle conspicuity and motorist awareness. Using motorcycle crash data for Iowa from 2001 to 2008, this paper examines the distribution of conspicuity related factors that could potentially relate to a collision between a motorcycle and another vehicle in daylight and dark conditions using contingency table analysis.

This paper further examines the distribution of collision configurations (such as “non-motorcycle” being “at-fault” in rear-end collisions, angle crashes, and sideswipe crashes) and factors (related to “non-motorcycle” vehicle drivers) potentially related to not seeing motorcyclists for different motorcycle crash severity outcomes using contingency table analysis. Finally, this paper develops a multinomial logit model to investigate the effect of potential motorcycle-conspicuity related factors on motorcycle crash severity outcomes. The results from the model show that angle crashes (“non-motorcycle” turning left), rear end crashes (“non-motorcycle” hitting “motorcycle”), light conditions, failure to yield ROW (right of way) by non-motorcycle drivers, light conditions and other variables played significant roles in motorcycle crash-injury outcome. The limitations of examining motorcycle conspicuity by analysis of crash data are also discussed.

Keywords: motorcycle safety, conspicuity, daylight, dark, multinomial logit model.

INTRODUCTION

Previous studies in the United States and internationally suggest that low motorcycle conspicuity, or the inability of the motorcyclist to be seen by other road users is thought to be an important factor associated with the risk of motorcycle crashes (Cercarelli, 1992; Hurt et al., 1981; Williams and Hoffmann, 1979; Wulf et al., 1989). This may be due to several factors including the size of motorcycle, irregular outline of the vehicle, low luminance or contrast with the background environment, and the ability to maneuver in the traffic stream. Additional measures to enhancing conspicuity include wearing reflective or fluorescent clothing, wearing white or light colored helmets, using headlights during daytime, and using headlamp modulators (Jenkins and Wigan, 1985; Muller, 1984; Olson et al., 1981; Rumar, 1980; Thomson, 1980; Torrez, 2008; Well et al., 2004). Safety campaigns also advocate the importance of conspicuity to motorcycle drivers. Baer et al. (2010) mentioned that most states in the United States have implemented conspicuity and/or motorist awareness campaigns. In addition, there are recommendations in place encouraging states to initiate public awareness efforts that are focused on the use of high visibility riding gear and daytime running lights; take steps to alert motorists about motorcyclists, using strategies such as incorporating “Share the Road” messages as part of driver’s education classes; and amplify public information and outreach efforts” (Baer and Skemer, 2010).

However, it is not an easy task to motivate all motorcyclists to wear the proper type of reflective gear, especially when there is no law enforcing it. To date, twenty states and the District of Columbia have universal motorcycle helmet laws that require all riders to wear helmet. Twenty-seven states require only some riders to wear helmet, and three states (Illinois, Iowa and New Hampshire) do not have a motorcycle helmet law. Baer et al. (2010) stated that while the majority of states promote helmet use, only just over half of the states emphasize the use of eye and face protection.

Motorcycle safety concerns and renewed interest from states in increasing motorcycle conspicuity and motorist awareness make the present moment an opportune time to revisit the problem of motorcycle conspicuity. First, this paper reviews previous studies on motorcycle conspicuity with a focus on the effectiveness of proposed measures for enhancing conspicuity.

Then, using motorcycle crash data for Iowa from 2001 to 2008, this paper identifies those motorcycle-conspicuity factors that could potentially relate to a collision between a motorcycle and another vehicle. This paper also develops a multinomial logit model to examine the effect of these factors (with a focus on the "non-motorcycle" driver contributing factors) on two vehicle motorcycle crash severity outcomes.

LITERATURE REVIEW

Clothing and Gear

The injury reduction benefits of motorcycle rider clothing have been well established in the literature (de Rome, 2006). Rider clothing and gear have also been associated with the risk of being involved in motorcycle collisions. A case study in New Zealand (Wells et al., 2004) showed that there was a 37-percent lower risk of motorcyclists getting into a severe traffic collision if the driver was wearing any reflective or fluorescent clothing and a 24-percent lower risk if the driver was wearing a white helmet instead of a black one. However, the color of the driver's frontal clothing and motorcycle was not as important. Seasonal variations in conspicuity of high-visibility garments have been also investigated through a naturalistic, daytime field study of pedestrians (Buonarosa and Sayer, 2007). The results showed that the distances at which pedestrians were first detected depended on the season and the amount of background material (jacket or vest). The researchers did not find any significant differences in daytime conspicuity if pedestrians were wearing either fluorescent yellow-green or fluorescent red-orange clothing. However, they found that the conspicuity of fluorescent red-orange garments might depend primarily on color contrast, while the conspicuity of fluorescent yellow-green garments might depend primarily on luminance contrast. A similar experimental study on motorcyclists (Hole et al., 1996) confirmed that the brightness contrast between the motorcyclist and the surroundings may be a more important conspicuity-related factor than bright clothing and headlight use alone.

Daytime Running Lights

National and international studies have shown that legislation mandating motorcycle headlight-use during daytime has been effective in reducing the number of multi-vehicle motorcycle collisions (Rumar, 1980; Rudin et al., 1996; Thomson, 1980), and the number of fatal and serious injury accidents (Muller, 1984; Yuan, 2000; Zador, 1985). However, not all previous work has shown positive benefits of motorcycle daytime light laws. For example, the change in the number of minor injury accidents after the implementation of similar legislation in Singapore was insignificant (Yuan, 2000). Interestingly, a study of fatal crashes in the United States from 1975 to 1980 (Muller, 1985) found no statistical significant differences between states with and without daytime headlight laws. The safety benefits of motorcycle daytime headlight laws have also been questioned in (Perlot and Prower, 2003). The discrepancies in the results on the estimated effectiveness of motorcycle headlight laws are likely attributed to the study design and estimation methods used (Muller, 1985; Perlot and Prower, 2003). In addition, enhanced conspicuity might lead to risk perception and risk-compensating (or offsetting) behavior, in which drivers adjust their driving behavior in response to situations that can be perceived as comparatively dangerous or safe. For example, drivers in Norway perceived comparatively safe having the headlights on during daytime (Elvik, 1993). Turning to the specifications of daytime running lights, two lamps and lamps over 180mm diameter have been shown to offer a greater conspicuity advantage than single or smaller lamps (Donne and Fulton, 1985).

Motorcycle Actions and Driver Awareness

Previous research has argued that there is a conspicuity problem associated with motorcycles, as other vehicles in the traffic stream that make a left turn are unable to recognize them in the daylight, in comparison to other vehicles (Olson et al., 1979; Williams and Hoffmann, 1979). This might be due to the difference in frontal surface area and low visibility of the motorcyclist. For example, riders who were wearing fluorescent clothing and riding with headlamp lights during daytime were less likely to be involved in this type of collisions. This could be also attributed to the complexity of the situation. For example, making a left turn significantly increases a driver’s head movements, eye movements, and mental workload in comparison to driving straight through an intersection (Wulf et al., 1989). Interestingly, in a comparison of motorcycle-car crashes to car-car crashes (Cercarelli et al., 1992), no statistical significant differences in the day and night distributions of car-car and car-motorcycle crashes were found. As such, the argument, according to which drivers have more trouble seeing motorcycles in the daylight in comparison to other vehicles, due to the difference in frontal surface area, needs to be revisited.

Public Information and Outreach Efforts

Campaigns or interventions have also been claimed to be successful in reducing conspicuity-related motorcycle crashes. A report by road safety committee in Victoria, Australia mentioned that public information campaigns in Victoria, Australia to increase the voluntary use of colored and fluorescent clothing and daytime running lights were found to be effective, but their effect tapered off after about nine months. In a survey of state motorcycle safety programs (Baer et al., 2010), 96% of the 44 states that responded to the survey stated that have implemented conspicuity and/or motorist awareness campaigns, and one-half of the states indicated that they have programs at schools to educate students about motorcycle safety. However, voluntary action countermeasures such as motorcycle education and training courses, motorcycle helmet use promotion programs, and education to encourage motorcyclists to increase their conspicuity have not been proven effective yet; and some evidence suggest that these countermeasures are unlikely to be effective (Preusser et al., 2008). Also, public awareness campaigns are increasingly reaching out to both manufacturers of rider’s clothing and motorcyclists in order to encourage the producing and wearing of highly reflective materials to improve the visibility of motorcyclists on the road (Wells, 2004).

DATA AND DESCRIPTIVE STATISTICS

Data on reported motorcycle crashes were collected for the 8–year period from 2001 to 2008 from the crash database maintained by the Iowa Department of Transportation. The data collected included information on two vehicle motorcycle crashes where one vehicle was motorcycle and the other was a non-motorcycle vehicle. Attributes included: year, month, day and time of crash; crash location (urban or rural area); road surface and environmental conditions; manner of crash, crash severity, major cause of the crash, and events contributing to the crash; and other information about the motorcycle driver and the driver of the "non-motorcycle" vehicle involved in the crash (such as helmet use). However, potential conspicuity-related factors such as rider clothing, color of motorcycle, helmet color, and motorcycle type could not be collected from the crash database. The crashes occurring within one mile of the corporate city limits were defined as urban, while the crashes occurring outside the city boundaries were defined as rural. It should be noted that property damage crashes of less than $1,000 are not included in the crash database maintained by the Iowa Department of Transportation. Table 1 shows the summary statistics for select variables for two-vehicle motorcycle (MC) crashes.

Table 1 Summary statistics for select variables for two-vehicle motorcycle crashes

Variable	***Mean or Percentage (Standard Deviation)***
Number of crashes	3,693
Average number of crashes/year	461.6 (46.1)
Crash severity Fatal/ major injury/minor injury/possible or unknown/ PDO	4.5/18.0/34.1/22.8/20.7
Year: 2001 to 2008	11.0/10.7/11.5/12.2/13.7/ 13.4/12.8/14.7
Month of year Jan/Feb/Mar/Apr/May/Jun /Jul/Aug/Sep/Oct/Nov/Dec	0.6/0.6/2.7/8.8/12.1/17.0/ 16.6/15.8/13.6/8.0/3.5/0.5
Day of week Mon/Tue/Wed/Thu/Fri/Sat/Sun	13.8/11.5/11.9/12.4/ 12.8/18.5/19.1
Time of day 0-7/7-9/9-11/11-13/13-16/16-18/18-24	4.3/4.2/5.6/10.4/25.0/22.7/27.9
Weather conditions Clear/Partly cloudy/cloudy/other	72.1/18.4/5.5/4.0
Light conditions Daylight/ dusk/ dawn/dark-roadway lighted/ dark-roadway not lighted/dark-unknown roadway lighting/other	78.9/3.2/0.5/12.8/3.1/ 0.4/1.1
Road surface conditions Dry/ Wet, snow or slush/Other	92.5/1.0/6.5
Rural/Urban	19.0/81.0
Non-intersection/intersection	42.4/57.6
Speed limit (mph) Under 25/ 25-35/40-50/55-65/ over 65	*Motorcycle:* 2.7/69.2/11.9/16.0/0.2 *"Non-motorcycle" vehicle:* 3.5/69.4/11.6/15.3/0.2

Manner of crash/collision Head-on/rear-end, non-MC hitting MC/rear-end, MC hitting non-MC/angle, non-MC turning left and MC moving straight/ angle, MC turning left and non-MC moving straight/ broadside/sideswipe, same direction/sideswipe, opposite direction/other	3.8/11.7/13.1/10.7/2.3/37.8/6.8/ 2.1/11.7
Driver contributing factor	*Motorcycle*: Lost control/ followed too closed / exceeded authorized speed 3.13/3.2/2.7 *"Non-motorcycle" vehicle*: FTYROW*: Making left turn/ FTYROW*: from stop sign 10.7/9.2
Vehicle Action Moving straight/turning left/turning right/other	*Motorcycle:* 75.0/4.4/2.4/18.1 *"Non-motorcycle" vehicle:* 36.8/35.1/4.1/24.2
Age of the motorcycle driver under 20/ 21 to 30/31 to 40/ 41 to 50/ 51 to 60/ over 60 years old	39.8 (17.3) 11.2/23.1/19.1/23.7/ 14.7/8.2
Age of the driver of the "non-motorcycle" vehicle under 20/ 21 to 30/31 to 40/ 41 to 50/ 51 to 60/ over 60 years old	43.3 (24.0) 19.9/20.3/13.9/12.9/10.3/22.7
Helmet use Driver without helmet/ driver with helmet	85.0/15.0

* *Failed to yield right of way*

A total of 7,325 motorcycle crashes were reported during the 8–year analysis period (2001–2008). In 2008, 1,108 motorcycle crashes were reported in Iowa, compared to 782 crashes that were reported in 2001, which represents a 42% increase. Note that from 2001 to 2008, motorcycle registrations increased from 120,961 to 162,662 (34%). The analysis presented herein focuses on two-vehicle crashes (one motorcycle collided with a "non-motorcycle" vehicle), which represented half of the total number of crashes that were reported during the study period.

Overall, 50% of the fatal two-vehicle motorcycle crashes occurred on high-speed roads (of 55 mph-speed limit or higher). As expected, the majority of crashes involving motorcycles occurred between May and September, with a higher number occurring in June and July. Turning to the distribution of crashes by day of week, two-vehicle crashes involving motorcycles were more likely to occur on a weekend, which suggests that more recreational trips than work trips were made by motorcycles. The temporal distribution of crashes during a day shows an increasing trend of two-vehicle crashes occurring from 1 p.m. to 12 a.m. and a decreasing trend thereafter.

More than two-third of the two-vehicle motorcycle crashes reported were under clear weather (as clear conditions encourage motorcycle riding), and one-quarter were reported under cloudy or partly cloudy conditions. Approximately 80% of the crashes occurred in daylight, while almost one fifth of the crashes occurred under dark conditions. These findings are likely attributed to the higher exposure of motorcycles in daylight compared to nighttime and the greater associated probability of getting involved in a crash.

Table 1 also shows that most two-vehicle crashes occurred on urban roads (81%). More than half of the two-vehicle crashes occurred on an intersection (of which 67% occurred on four-way intersections and 20% on T-intersections). The "non-motorcycle vehicle" was reported as the major driving contributing factor in the majority of the non-intersection and intersection crashes. The two primary driver-contributing factors by "non-motorcycle" vehicles were "failing to yield right of way to motorcycles when making left turn", and "failing to yield right of way to motorcycles at intersections from the stop sign". The three primary driver-contributing factors by motorcycles involved in two-vehicle crashes were "lost control" (same as in single vehicle crashes), "following too close", and "exceeded authorized speed". The majority of two-vehicle crashes occurred on roads with low speed limit (25 mph – 35 mph).

In addition, if the major driving contributing factor by motorcycles involved in two-vehicle crashes was "no improper action", it was assumed that the "non-motorcycle" vehicle was "at-fault". Likewise, if the major driving contributing factor by "non-motorcycle" vehicles involved in two-vehicle crashes was "no improper action", it was assumed that the motorcycle was "at-fault". In more than half (56%) of two-vehicle crashes, the driver of the "non-motorcycle" vehicle was imputed "at-fault", while in a quarter of two-vehicle crashes motorcyclists were imputed "at-fault". This is consistent with previous work that stated that in multi-vehicle crashes motorcyclists are more likely to be victims than "at-fault" (Haque et al., 2009). Turning to the vehicle actions that led to a crash, one-quarter of crashes involved a motorcycle and another vehicle moving straight, while one-third of crashes involved one vehicle turning left and the other going straight. The analysis of crashes where one vehicle was turning left and the other was going straight showed that in 91.4% of the cases the motorcycle was going straight and the "non-motorcycle" vehicle was turning left—a finding consistent with previous work (Olson, 1989). In addition, one-quarter of two-vehicle crashes were rear-end crashes with broadside crashes having the highest percentage.

Half of the two-vehicle crashes involved motorcycle drivers between 21 and 30 years old or between 41 and 50 years old. The distribution of crashes by the age of the "non-motorcycle" vehicle's driver showed that a high percentage of older drivers (over 60 years old), followed by young drivers (under 30 years old) were involved in a crash with the motorcycle. Helmet use rates of motorcycle drivers involved in two-vehicle crashes during the analysis period were very low (15%), as there is no mandatory helmet law in Iowa.

METHODOLOGY

Contingency Tables

Contingency tables were created and chi-squared test statistics were estimated to examine the relationship between manner of crash, helmet use and light conditions, as well as that between potentially conspicuity-related factors and crash severity outcomes in two-vehicle crashes.

Contingency tables are often used to record and analyze the relationship between two or more categorical variables, such as between light conditions (daylight or dark) and crash categories (two-vehicle crashes). Contingency tables display the frequency distribution of the variables in a matrix format (Pearson, 1904). When the two variables are independent in a two-dimensional contingency table, the frequencies are estimated using Equation 1

$$E_{ij} = \frac{n_{i.} n_{.j}}{N} \quad (1)$$

where:
$n_{i.}$:the total number of observations in the *i*th category of the row variable
$n_{.j}$:the total number of observations in the *j*th category of the column variable
N: the total number of observations in the sample

The χ^2 test statistic for a two-way contingency table is as follows (Washington et al., 2010)

$$\chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \quad (2)$$

where, the differences between observed (O_{ij}) and expected (E_{ij}) frequencies are summed over all rows and columns (r and c, respectively). The test statistic shown in Equation 2 is approximately χ^2 distributed with degrees of freedom, $df = (r-1)(c-1)$.

Multinomial Logit Model

Previous studies (Abdel-Aty et al., 1998; Farmer et al., 1997; O'Donnell and Connor, 1996; Kockleman and Kweon, 2002; Carson and Mannering, 2001; Ulfarsson and Mannering, 2004) have attempted to investigate influential factors on crash-injury severity outcome with an emphasis on car and truck crashes. Nevertheless, research efforts employing prediction models of motorcycle injury severity resulting from different conspicuity related factors have been surprisingly scant in the literature. Among the extant literature, one of the studies was found where Shanker and Mannering (1996) focused exclusively on motorcycle crash severity. They performed multinomial logit analysis of single-vehicle motorcycle crash severity and showed the multinomial logit formulation is a promising approach to evaluate the determinant of motorcycle crash severity. Quddus et al. (2002) utilized ordered probit models to analyze motorcycle damage and injury severity resulting from crashes. But there is found to be no studies regarding prediction models of motorcycle conspicuity related factors. That is why this study dedicated effort to develop a prediction model to investigate the effect of conspicuity related factors on motorcycle crash injury outcome.

The review of the literature shows that two preferred approaches have emerged in the statistical modeling of crash severity data, ordered probability models (ordered logit and probit) and unordered probability models (multinomial and nested logit). As injury levels are typically progressive, ordered probability models would seem to be natural choice to account for the ordinal nature of injury severities. In the literature, there are examples (O'Donnell and Connor, 1996; Duncan et al., 1998; Renski et el., 1999; Khattak, 2001; Kockleman and Kweon, 2002; Abdel Aty, 2003; Yamamoto and Shankar, 2004) of using this technique. However, there are at least two concerns with applying ordered probability models on injury-severity analysis. The first relates to the fact that non-injury crashes may be under-represented in the police-reported crash data. The presence of underreporting in an ordered probability model can result in biased and inconsistent result model coefficient estimates. In contrast, the coefficient estimates of an unordered multinomial logit probability model are consistent except for the constant term (Washington et.el, 2011).

The second problem is more difficult to correct and relates to the restriction that ordered probability models place on variable influences. To understand better, readers are encouraged to follow the air-bag deployment example used in Washington et el., 2011. Unordered probability models do not impose this constraint and such models have been applied in crash-injury severity analysis by numerous researchers (Shanker et el., 1996; Chang and Mannering, 1999; Carson and Mannering, 2001; Lee and Mannering, 2002, Ulfarsson and Mannering, 2004; Khorashadi et al., 2005). So, this approach will be adopted to investigate the effects of motorcycle conspicuity related factors on crash-injury severity outcomes in this study.

A multinomial logit model (MNL) was estimated in this paper for relating potentially conspicuity-related factors to five motorcycle injury severity outcomes: fatal, major, minor, possible/unknown, and property damage only (PDO). The factors considered in the MNL estimation included: manner of crash with "non-motorcycle" drivers "at-fault" (rear end crashes with "non-motorcycle" drivers hitting motorcycle, angle crashes where motorcycle moved straight and "non-motorcycle" vehicle turned left, sideswipe crashes with same direction); "non-motorcycle" driver contributing factors (failing to yield right to motorcycle when making left turn, failing to yield right of way to motorcycle at intersections from stop signs); helmet use; crash location (urban or rural); speed limit; road surface conditions; light conditions; and "non-motorcycle" driver vehicle action (if "non-motorcycle" drivers turned left or not). For modeling purposes, all these factors were considered as indicator variables, taking the value of one or zero.

The MNL model is built on the assumption that the choice between any pair of alternatives of the response variables is independent of the availability of other alternatives. It implies that the random part of the utility function is independent among the alternatives. The multivariate response variable in a MNL model is unordered. For motorcycle injury severity outcomes, the MNL defines a function that determines injury severity outcome as follows

$$W_{in} = \beta_i X_{in} + \epsilon_{in} \tag{3}$$

where:

W_{in}: the function that determines the probability of discrete injury outcome i for crash n

X_{in}: vector of measurable characteristics (conspicuity-related factors, other injury outcome related factors) that determine the injury outcome for crash *n*

β_i :a vector of estimable coefficients, and ε_{in} is an error term accounting for unobserved effects influencing the injury outcome of crash *n*

In this study *i* = 1, 2, 3, 4, and 5

where:

W_{1n} :fatal injury crash,

W_{2n} :major injury crash,

W_{3n} :minor injury crash,

W_{4n} :possible/unknown injury crash,

W_{5n} :property damage only (PDO) crash.

It can be shown that if ε_{in} are assumed to be extreme value distributed, then a standard multinomial model results

$$P_n(i) = \frac{EXP[\beta_i X_{in}]}{\sum EXP[\beta_I X_{In}]} \tag{4}$$

where:

$P_n(i)$: the probability that crash *n* will have injury outcome *i*

I: is the set of possible injury outcomes.

Note that elasticities are not applicable to indicator variables (those variables taking on values of 0 or 1). As all the variables discussed in the current model are indicator variables, a pseudo-elasticity can be calculated in this case as

$$E_{xki}^{P(i)} = \left[\frac{EXP(\beta_{kI})\sum_{i=1}^{I} EXP(\beta_i X_i)}{\sum_{i=1}^{I} EXP[\Delta(\beta_i X_i)]} - 1\right] \times 100 \tag{5}$$

where *I* is the set of all possible injury outcomes. $\Delta(\beta_i X_i)$ is the value of the utility function determining the satisfaction level after x_{ki} has been changed from zero to one and $\beta_i X_i$ is the value when $x_{ki} = 0$. The pseudo-elasticity of a variable with respect to an injury outcome represents the percent change in the probability of that injury severity when the variable is changed from zero to one. Thus a pseudo-elasticity of 33.0 for a variable in the fatal injury outcome means that the probability of a crash being fatal would increase by 33%.

RESULTS

Contingency Table Analysis

Table 2 presents the chi-squared test estimation results for the differences in potential conspicuity-related factors in light and dark conditions in two-vehicle crashes that could potentially relate to a collision between a motorcycle and another vehicle. Differences in helmet use under light and dark conditions for two-vehicle motorcycle crashes were examined. Higher helmet use was found during daytime than under dark conditions ($\chi^2 = 5.6, df = 1, p < 0.05$). The difference in helmet use rates in two-vehicle crashes is 5.1%. Additional information on helmet color would provide better insights as to whether the statistically significant lower helmet use rate in dark conditions suggests lower motorcycle conspicuity as well. If this hypothesis proves accurate, then the motorcycle conspicuity problem would be more severe under dark conditions than in daylight.

Table 2 Contingency table between potential conspicuity-related factors and light conditions

Test #	*Factor*	*Daylight*	*Dark*	*Estimated chi-squared value*	*Standard chi-squared value at alpha=0.05*
1	*Helmet use*			5.6	3.8
	Driver without helmet	1531 (75.4%)	395 (80.4%)		
	Driver with helmet	500 (24.6%)	96 (19.6%)		
2	*Crash Location*			3.81	3.8
	Rural	480 (82.5%)	102 (17.5%)		
	Urban	2101 (79.5%)	563 (20.5%)		
3	*Manner of crash/collision*			6.8	7.8
	Rear-end	645 (78.5%)	177 (21.5%)		
	Angle, oncoming left turn	493 (76.1%)	155 (23.9%)		
	Broadside	777 (82.4%)	166 (17.6%)		
	Sideswipe, same direction	316 (82.7%)	66 (17.3%)		
4	*Rear-end crash*			4.1	3.8
	Motorcycle hit “non-motorcycle” vehicle	343 (80.7%)	82 (19.3%)		
	“Non-motorcycle” vehicle hit motorcycle	211 (74.3%)	73 (25.7%)		
5	*Angle crash*			0.94	3.8
	Motorcycle moved straight, and “non-motorcycle” vehicle turned left	431 (75.5%)	140 (24.5%)		
	Other situation	62 (76.1%)	15 (23.9%)		

Differences in the proportion of two-vehicle crashes under daylight and dark conditions by crash location were also investigated, as shown in Table 2 (Test 2). This analysis showed that similar proportions of daylight two-vehicle crashes occurred on urban and rural roads ($\chi^2 = 3.81, df = 1, p = 0.05$). This suggests that low motorcycle conspicuity in daylight might not be the reason for the higher proportion of two-vehicle motorcycle crashes on urban roads. Nevertheless, increasing driver awareness of motorcycles in urban areas is recommended.

The test results for the relationship between manner of crash (or collision configuration) and light conditions in two-vehicle crashes are shown in Table 2 (Tests 3 to 5). The collision configurations that were considered included those which were frequent in over 10% of two-vehicle crashes, such as: “rear-end”, “angle, oncoming left turn”, “broadside”, and “sideswipe, same direction”. Overall, the distribution of crashes in light and dark conditions did not vary significantly for those different collision configurations ($\chi^2 = 6.8, df = 3, p > 0.05$). It was also of interest to examine the specific crash type and whether it is possible to impute fault to the motorcyclist or the “non-motorcycle” vehicle driver involved in the crash. For example, rear-end crashes occurred when a vehicle was struck from behind by another vehicle; in 60.0% of the crashes the motorcycle hit the “non-motorcycle” vehicle’s rear part (assuming motorcycle’s fault), while in 40% of the crashes the “non-motorcycle” was “at-fault”. However, when comparing the “at-fault” percentage under light and dark conditions, a higher percentage of rear-end crashes were the fault of the “non-motorcycle” vehicle (25.7%) than the fault of motorcyclists (19.3%) during dark conditions ($\chi^2 = 4.1, df = 1, p < 0.05$). This suggests the need to increase drivers’ awareness of motorcycles under dark conditions. Lastly, the authors examined the hypothesis adopted in previous work that there is a conspicuity problem associated with motorcycles as other vehicles in the traffic stream that make a left turn are unable to recognize them in daylight in comparison to other vehicles (Olson et al., 1979; Williams and Hoffmann, 1979). However, the authors found that the distribution of crashes where a vehicle was turning left and a motorcycle was going straight compared to other situations that led to angle crash did not vary significantly by light conditions. As such, this analysis did not provide evidence to support this hypothesis.

The authors also investigated the differences in two-vehicle motorcycle crash severity for the collision configurations discussed above where “non-motorcycle” vehicles were “at-fault”. Collision configurations included rear end crashes where a “non-motorcycle” vehicle hit a motorcycle; angle crashes where “non-motorcycle” vehicle turning left and motorcycle moving straight; and sideswipe crashes (same direction). The results, presented in Table 3, suggest that motorcycle crash severity was related to three crash configurations where “non-motorcycle” drivers were “at-fault”. Note that these results pertain to all two-vehicle crashes that occurred in daylight and dark conditions. The authors performed the contingency table analysis relating crash severity and these collision configurations separately for daylight and dark conditions and statistically significant results were found in both the cases (not presented herein for brevity). Further analysis suggested that angle crashes with “non-motorcycle” vehicle turning left and motorcycle moving straight had higher proportion of fatal crashes (3.6%) and major injury crashes (26.5%) compared to rear end and sideswipe crashes ($\chi^2 = 69.94, df = 8, p < 0.05$). Minor injury crashes were overrepresented in sideswipe (same direction) crashes (38.0%), while PDO crashes were overrepresented in rear end crashes (30.5%).

The contingency table analysis for two-vehicle crash severity and “non-motorcycle” vehicle driver contributing factors showed that there was no significant difference in crash severities for these factors ($\chi^2 = 4.5, df = 4, p > 0.05$). The analysis of crash severity outcomes by light conditions showed that fatal crashes were significantly higher in dark conditions than in daylight. The same however was true for possible/unknown and PDO crashes. Riders not wearing a helmet had significantly higher number of fatal and PDO crashes compared to those not wearing helmets.

Table 3 Contingency table between potential conspicuity-related factors and crash severity

Factor	*Crash Severity*					*Estimated chi-squared value*	*Standard chi-squared value at alpha =0.05*
	fatal	*major*	*minor*	*possible/ unknown*	*PDO*		
Manner of Crash/Collision							
Rear end (Non MC hit MC)	7 (1.4%)	66 (13.4%)	148 (30.1%)	121 (24.6%)	150 (30.5%)		
Angle (Non MC turning left, MC moving straight)	15 (3.6%)	112 (26.5%)	146 (34.5%)	102 (24.1%)	48 (11.4%)	69.94	15.51
Sideswipe (same direction)	8 (3.4%)	36 (15.2%)	90 (38.0%)	55 (23.2%)	48 (20.3%)		
Non-motorcycle (MC) driver contributing factor							
FTYROW: from stop sign	16 (4.7%)	76 (22.2%)	125 (36.6%)	78 (22.8%)	47 (13.5%)	4.5	9.4
FTYROW: making left turn	18 (4.2%)	109 (25.4%)	149 (34.7%)	112 (26.1)	42 (9.8%)		
Light conditions							
Daylight	101 (4.29%)	575 (24.44%)	1004 (42.67%)	467 (19.85%)	206 (8.75%)	669.28	9.49
Dark	68 (5.07%)	119 (8.87%)	270 (20.12%)	346 (25.78%)	539 (40.16%)		
Helmet Use							
Helmet used	24 (2.84%)	197 (23.29%)	379 (44.8%)	190 (22.46%)	56 (6.62%)	152.9	9.49
Helmet not used	145 (5.09%)	497 (17.44%)	895 (31.41%)	623 (21.87%)	689 (24.18%)		

Multinomial Logit Model Estimation Results

The estimation results for the multinomial logit model using data from 2001 to 2008 are presented in the Table 4, with corresponding elasticities in Table 5. Note that all estimated elasticities are pseudo-elasticities as all the variables considered for the modeling purpose were indicator variables.

Estimation results showed that victims were 33.7% more likely to sustain major injury in angle crashes where “non-motorcycle” drivers turned left and motorcyclists moved straight. On the other hand, rear end crashes (where "non- motorcycle" hit motorcycle) were more likely to result in a PDO crash (by 51.7%) and possible injury crashes (by 8%) and less likely to result in minor or major injuries. These results are consistent with the contingency analysis results presented in Table 3. In addition, it was found that when crashes occurred with "non-motorcycle" vehicle drivers failing to yield to motorcycles at stop sign and "non-motorcycle" vehicle drivers failing to yield to motorcycles while turning left, crashes were less likely to result in PDO (by 32.9% and 41.3%, respectively).

Crashes that occurred in daylight were less likely to result in a fatal or major injury outcome. The probability of fatal and major injury crashes decreases by 44.3% and 14.2%, respectively, if the crashes occurred in daylight. Interestingly, helmet use would reduce the likelihood of a PDO crash by 44.6%. Additional information on whether the helmets that were reported being used were in compliance with the federal safety standards could help evaluating this finding.

Other significant variables than the motorcycle conspicuity-related variables were surface condition and crash location. Results show that crashes occurring on dry road surface were more likely to be severe than PDO. Note that the effect of dry surface on fatal crash outcome is elastic (elasticity of 113%). Furthermore, major injury crashes were 48.4% less likely to occur on urban roadways, while crashes involving possible injury were 63.1% more likely to occur on urban roadways.

It was of interest to examine whether the estimated coefficients presented in Table 4 were different for motorcycle crash severities in daylight and dark conditions. A likelihood ratio test was conducted to determine whether the hypothesis that the two models (one corresponding to motorcycle crashes that occurred during daylight and one corresponding to motorcycle crashes that occurred during dark conditions) are the same or not. The likelihood ratio test statistic is as follows

$$X^2 = -2[LL(\beta_{all}) - LL(\beta_{daylight}) - LL(\beta_{dark})] \quad (6)$$

where $LL(\beta_{all})$ is the log-likelihood at convergence of the model estimated on all data, $LL(\beta_{daylight})$ is the log-likelihood at the convergence of the model estimated on the "daylight" crash data, and $LL(\beta_{dark})$ is the log-likelihood at convergence of the model estimated on "dark condition" crash data. The statistic is χ^2 distributed with degrees of freedom equal to the summation of coefficients estimated in the two models minus the number of coefficients estimated in the total-data model. The estimated χ^2 of this test was less than the critical χ^2 value at the 90% confidence level with 17 degrees of freedom. So, the hypothesis that "daylight" motorcycle crash severity model and "dark condition" motorcycle crash severity model are not different could not be rejected.

Table 4 Multinomial logit model estimation results for motorcycle crash injury outcomes. (Variables are defined for injury outcomes: [F] fatal, [MJ] major, [MN] minor, [PS] possible or unknown, [PD] property damage only)

Variable	**Estimated coefficient**
Constant [MJ]	1.527***
Constant [MN]	1.895***
Constant [PS]	1.043*
Constant [PD]	2.504***
Motorcycle Conspicuity-related Variables	
Angle crash (1 if non-MC turned left and MC moved straight, 0 otherwise) [MJ]	0.428***
Rear end crash (1if non-MC hit MC, 0 otherwise) [MJ]	-1.037*
Rear end crash (1if non-MC hit MC, 0 otherwise) [MN]	-1.193**
Rear end crash (1if non-MC hit MC, 0 otherwise) [PS]	1.348**
Rear end crash (1if non-MC hit MC, 0 otherwise) [PD]	1.689***
FTYROW: from stop sign (1 if non-MC driver FTYROW to motorcycle at stop sign, 0 otherwise) [PD]	-0.475***
FTYROW: making left turn (if non-MC driver FTYROW to motorcycle while turning left, 0 otherwise) [PD]	-0.628***
Light condition (1 if daylight, 0 otherwise) [F]	-0.667***
Light condition (1 if daylight, 0 otherwise) [MJ]	-0.240***
Helmet use (1 if helmet used, 0 otherwise) [PD]	-0.699***
Other Variables	
Surface condition (1 if dry surface, 0 otherwise) [F]	1.648***
Surface condition (1 if dry surface, 0 otherwise) [MJ]	1.563***
Surface condition (1 if dry surface, 0 otherwise) [MN]	1.159***
Surface condition (1 if dry surface, 0 otherwise) [PS]	1.025***
Crash location (1 if urban, 0 otherwise) [MJ]	-0.548***
Crash location (1 if urban, 0 otherwise) [PS]	0.602***
Number of observations	3,693
Initial log likelihood	-3,288.76
Log likelihood at convergence	-3,203.65

(Note: ***, **, and * indicate statistical significance at 99%, 95% and 90% confidence level, respectively)

Table 5 Estimated elasticity values of the multinomial logit model

Variable	Elasticity
Motorcycle Conspicuity-related Variables	
Angle crash (1 if non-MC turned left and MC moved straight, 0 otherwise) [MJ]	33.71
Rear end crash (1if non-MC hit MC, 0 otherwise) [MJ]	-20.97
Rear end crash (1if non-MC hit MC, 0 otherwise) [MN]	-7.63
Rear end crash (1if non-MC hit MC, 0 otherwise) [PS]	7.96
Rear end crash (1if non-MC hit MC, 0 otherwise) [PD]	51.68
FTYROW: from stop sign (1 if non-MC driver FTYROW to motorcycle at stop sign, 0 otherwise) [PD]	-32.95
FTYROW: making left turn (if non-MC driver FTYROW to motorcycle while turning left, 0 otherwise) [PD]	-41.30
Light condition (1 if day light, 0 otherwise) [F]	-44.26
Light condition (1 if day light, 0 otherwise) [MJ]	-14.22
Helmet use (1 if helmet used, 0 otherwise)	-44.63
Other Variables	
Surface condition (1 if dry surface, 0 otherwise) [F]	113.61
Surface condition (1 if dry surface, 0 otherwise) [MJ]	96.01
Surface condition (1 if dry surface, 0 otherwise) [MN]	29.82
Surface condition (1 if dry surface, 0 otherwise) [PS]	14.68
Crash location (1 if urban, 0 otherwise) [MJ]	-48.35
Crash location (1 if urban, 0 otherwise) [PS]	63.11

CONCLUSIONS

Using motorcycle crash data for Iowa from 2001 to 2008, this paper identified those motorcycle-conspicuity factors that could potentially relate to a collision between a motorcycle and another vehicle. Motorcycle conspicuity-related factors that were examined included: light conditions, helmet use, manner of crash, and motorcycle and "non-motorcycle" driver actions.

The contingency table analysis of potential conspicuity-related factors by light conditions revealed that daylight helmet use was higher than helmet use during dark conditions. In addition, a higher percentage of rear-end crashes were caused by the "non-motorcycle" vehicle's driver than motorcycle drivers during dark conditions rather than in daylight. However, the distribution of crashes where a vehicle was turning left and a motorcycle was going straight compared to other situations that led to an angle crash did not vary significantly by light conditions. As such, this paper could not establish that there are statistical significant differences in motorcycle conspicuity-related factors by light conditions. However, motorcycle crash severity outcomes differ significantly by light conditions; fatal crashes were significantly higher in dark conditions than in daylight. Riders not wearing a helmet had also significantly higher number of fatal and PDO crashes compared to those wearing helmets.

A multinomial logit model was also estimated to gain a better understanding for motorcycle conspicuity-related factors affecting motorcycle crash injury severities in Iowa. Estimation results showed a higher likelihood of a major injury outcome in an angle crash with the "non-motorcycle" vehicle turning left and the motorcycle moving straight. Rear end crashes caused by a "non-motorcycle" vehicle hitting a motorcycle were less likely to result in severe injury outcomes. Furthermore, crashes that occurred with "non-motorcycle" vehicle drivers failing to yield to motorcycles at stop sign and "non-motorcycle" vehicle drivers failing to yield to motorcycles while turning left were less likely to result in PDO. Crashes occurring on dry surface condition had higher likelihood of having severe outcomes, possibly because of higher speeds. Turning to the differences in motorcycle crash severity outcomes by light conditions, it was found that two-vehicle motorcycle crashes that occurred in dark conditions were more likely to result in fatal or major injury. However, there was no evidence to estimate separate motorcycle crash severity models for daylight and dark conditions and assess the difference in the corresponding variable elasticities across the two models.

Some recommendations related to improving motorcycle conspicuity and driver awareness in Iowa, and conspicuity-related campaigns and interventions, can be mentioned from the study. Iowa is one of the 39 states that include conspicuity in its motorcycle manual, listing eight important ways to increase conspicuity: clothing, headlight, signals, brake lights, mirrors, head checks, horns, and riding at night. The Iowa DOT could also consider specifying the color of the helmet in the manual, such as yellow or lime yellow, since the bright color of the helmet can improve motorcycle conspicuity. Moreover, the manual could emphasize the reflectivity of the frontal area of the motorcycle/rider, and the brightness contrast between the motorcyclist and their surroundings, which have been shown to be more significant factors to enhancing motorcycle conspicuity than bright clothing and headlight use alone. Finally, the Iowa DOT could consider improving motorcycle training and education to enhance rider skills.

Safety campaigns are also considered an effective way to improve safety on the roadways. In view of the analysis results, some important key findings are important considerations in implementing motorcycle conspicuity-related campaigns such as

- A higher number of motorcycle crashes occur in June and July, on weekends, and between 5 a.m. and 4 p.m.
- 81% of two-vehicle crashes occur on urban roads and more than half of two-vehicle crashes occur at intersections.
- The major driver-contributing factors to two-vehicle crashes are as follows:
    - *Non-motorcycle vehicle drivers*
        - "Failed to yield right of way when making left turn" and "failed to yield right of way from stop sign "
- Less severe crashes during day light

- Since helmet use could improve motorcycle conspicuity, safety campaigns could encourage drivers to wear helmets, especially when traveling in high motorcycle crash locations.

However, there are some limitations to examining motorcycle conspicuity by analysis of crash data. In specific, potential conspicuity-related factors such as rider clothing, color of motorcycle, helmet color, and motorcycle type could not be collected from the crash database. In addition, while there is information on the speed limit on the roads where the motorcycle and the other vehicle involved in a collision with a motorcycle were traveling, this information is likely to be imprecise as a surrogate of the motorcycle and the "non-motorcycle" vehicle's speeds. Obtaining speed information would be useful in understanding the dynamics of the motorcycle-vehicle interaction. For example, Brenac et al. (2006) stated that a motorcyclist's speed is significantly higher for motorcycle-related crashes in urban areas than others. This could be a reason for the high number of two-vehicle crashes in urban areas in our sample rather than low motorcycle conspicuity. Lastly, accurate information on vehicle-miles traveled by motorcycles that would be essential in a comparison of exposure during day and night is missing or, when available, is of poor quality (Bigham et al., 2009). Unless the crash data collection can be expanded to include information on the aforementioned potential conspicuity-related factors, naturalistic driving and driving simulator studies that would allow for such information to be collected are a promising avenue for future research on motorcycle conspicuity.

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