# U.S. MOTORCYCLE USE:
# CRASH EXPERIENCES, SAFETY PERSPECTIVES, AND COUNTERMEASURES

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## ABSTRACT

Motorcycles are an important form of personal transportation pursued by many Americans. They provide an enjoyable recreational opportunity for many and a convenient, functional mode of transportation for others. However, U.S. motorcycle crash rates are 90% higher (per vehicle-mile traveled [VMT]) than those for other vehicles, their fatal crash rates are 2400% higher (NHTSA 2011).

This investigation examines the riding and crash experiences and safety perceptions and recommendations of 238 U.S. motorcyclists. Top rider recommendations to other motorcyclists are to wear a helmet, to avoid riding under the influence (of alcohol or drugs), and to obtain motorcycle training. Negative binomial model results for crash count experiences suggest that inexperienced riders on long-distance trips, students and those with criminal convictions are at greater risk of crashing (on their motorcycle) than others (per year of riding), while those who have not received motorcycle training and have more adults in their household are less likely to have been involved in a crash at some point in their riding history. Ordered probit model results for helmet use prediction suggest that those who ride on a daily or weekly basis and have received formal motorcycle training are more likely to wear a helmet, while those who have been licensed longer, own motorcycles with larger engines, or have children are less likely to use one.

A second ordered probit model indicates that those who wear a helmet, ride for mandatory purposes (like work and school), and/or ride their once a month or more frequently (though not nearly every day) are more likely to receive formal motorcycle training. These findings may be used to enhance motorcycle training for and outreach efforts to motorcyclists, other system users, and transportation professionals by targeting riders most receptive to and in need of training, and highlighting key safety issues while addressing misperceptions among all stakeholders.

## INTRODUCTION

Motorcycles are a fast and seemingly efficient form of personal transportation. They differ from other motor vehicles in their physical operation, much smaller size (and lower weight), two-wheel (rather than four-wheel) base, and driver exposure (with seating on top of the vehicle rather than inside it). Their design renders them highly unstable for many potential users while providing little protection in the event of a crash (Daniello et al. 2010). While all motorists are at risk of injury and death due to collisions, the prevalence of crashes and severity is far higher for motorcycles. For example, NHTSA (2011) crash facts and exposure estimates show how motorcycles ridden in the U.S. have a 90% higher crash rate per vehicle mile traveled (VMT) than passenger cars and light trucks. Even more worrisome, 4462 motorcyclists were killed while riding on U.S. highways in 2009, representing 14% of all US motor vehicle fatalities, even though motorcycle travel comprised only 0.7% of total VMT, resulting in a startling 2400 percent higher fatality rate per person-mile traveled.

Past research has examined which factors cause and increase the severity of motorcycle crashes. These factors include rider intoxication or drug impairment (NHTSA 2007), aggressive riding (Savolainen and Mannering [2007], Preusser et al. [1995], Haque et al. [2010]), other drivers' failure to see motorcyclists (Clarke et al. 2004), wet surfaces and higher speed roadways (Haque et al. 2010), use of helmets and protective gear (Liu et al. 2008), and riding motorcycles with larger engines (Haque et al. 2010 and Langley et al. 2000).

Roadway design details can also cause more frequent and more severe crashes. Schneider et al. (2010) concluded that riders have greater single-vehicle crash frequencies on longer and tighter horizontal curves, and Kweon and Kockelman (2005) and others estimate that outcome severity in all vehicle crashes increases with degree of curvature. While training can help riders better navigate curves, basic licensing remains an issue: NHTSA (2011) notes that 22 percent of US riders involved in 2009 fatal crashes did not have a valid motorcycle license, compared with passenger vehicle drivers, 12 percent of whom were improperly licensed. Furthermore, guardrails and other longitudinal barriers pose special risks and may be more hazardous to motorcyclists than what they are shielding (Daniello et al. 2010, Hurt et al. 1981, and Savolainen and Mannering 2007). Other roadway design components can also represent issues for motorcyclists, including pavement surfaces during reconstruction and unresponsive loop detectors at traffic signals (Kanhere et al. 2010).

## MOTORCYCLE CRASHES: THE U.S. PERSPECTIVE

This work interprets U.S. survey results for safety perceptions of current and former riders. The survey results also help identify those at greatest risk of crashing, and those most likely to wear a helmet. An initial examination of US motorcycle crash records provides useful background. Using NHTSA's 2010 Fatal Accident Reporting System (FARS) data, one can determine *who* is being killed on motorcycles, *what* types of crashes are responsible for most deaths, and *when, where* and *why* such crashes are occurring.

In 2010 there were 4,187 fatal crashes involving a motorcycle, resulting in a total of 4,462 persons killed. 86% of all fatally injured U.S. motorcyclists were male, though roughly 90 percent of licensed U.S. motorcyclists are men (State of Michigan 2007), and 93% of U.S. motorcycle trips are driven by men (based on the 2009 National Household Travel Survey [FHWA 2011]), with motorcyclists riding 20.8 billion miles in 2009 (NHTSA 2011). The data exhibits a bi-modal age distribution, with fatal crash counts spiking in the 21 to 25 age range, and at the 46 to 50 years age range, as shown in Figure 1:

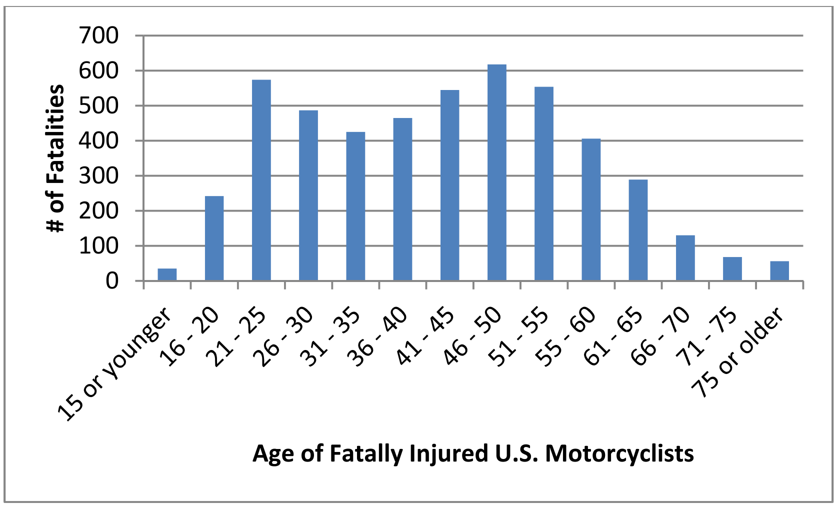


Figure 1: Age Distribution of Fatally Injured Motorcyclists (Source: 2010 FARS)

Single-vehicle and multi-vehicle crashes are categories of special interest. In 2010 there were 1,972 single-vehicle crashes: 25.6% were rollover or overturns, 13.3% involved hitting a guardrail or barrier, 23.2% involved hitting a curb, ditch or embankment, 8.6% involved a utility pole, culvert or sign, 18.7% involved hitting another fixed object, and the remaining 10.3% comprising other crash types. Thus, more than a quarter were due to riders losing motorcycle stability and rolling over while most others involved riders running off the road. Almost 41% involved roadside structure designs that are commonly crash tested for cars and trucks (AASHTO 2011), but not motorcyclists.

Of the 2,215 mutli-vehicle crashes, 51.8% were angle collisions. 15.4% involved head-on collisions, and 17.3% were rear-end collisions, with the remainder sideswipes and other crash types. 47% of multi-vehicle fatal motorcycle crashes occurred at intersections (vs. 38% of all U.S.-reported fatal multi-vehicle crashes), suggesting that motorcycles are particularly vulnerable at intersections. 21.7% involved a stopped vehicle or a vehicle traveling in the same direction, 21.8% involved a vehicle from an opposite direction, 16.9% involved a crossing vehicle, 11.6% with the motorcycle crossing through the intersection (versus 1.7% where the motorcyclist was turning) and 3.0% involving another vehicle coming out of a driveway.

There were more fatal motorcycle crashes on Saturday and on Sunday (24.1% and 18.6%, respectively) than any single weekday, though 16% occurred on Fridays. 67% of fatal motorcycle crashes occurred between 1 PM and 11 PM, with peak times between 3 PM and 8 PM. 82% of all crashes occurred over the 7 months of April through October, suggesting that motorcyclists tend to avoid seasons with cold, icy and/or wet riding weather.

In terms of other environmental conditions, the rural-urban (as defined by U.S. Census data) crash split was almost identical (2056 vs. 2096 fatal crashes), though rural crashes may be over-represented since 67% of all U.S. VMT occurred in urban areas. Approximately 21% of fatal motorcycle crashes occurred on local roads in both rural and urban areas, however, crashes in urban areas were much more likely to be on arterials and higher functional classification roads (70%), and less likely to be in rural areas (43%). Most rural area motorcycle crashes take place on collectors. For single-vehicle crashes, roadway curvature and grade appear to be major factors, with less than a third of crashes occurring on straight-level segments. Horizontal curves were a factor in 57% of single-vehicle crashes, grade changes in 39%, and both were present in 30% of fatal single-vehicle motorcycle crashes. Also, 17% of the nation's fatal multi-vehicle motorcycle crashes occurred at traffic signals in 2010, and 1.7% (69 total) took place in work zones.

Of course, other factors can play important roles too. For example, 32% of FARS 2010 motorcycle collisions involved alcohol (by the rider, a passenger, or other crash-involved parties). Police reported drug involvement in 5% of cases, and toxicology screenings showed drug presence in 16% of fatally injured individuals (which may be car occupants & pedestrians too), the most common being THC (marijuana). Speeding was a factor in 48% of the single-vehicle crashes and 32% of the multi-vehicle crashes. Poor roadway conditions (such as a puddle, pothole or ice) were cited as the critical event in just 28 crashes, and the majority of motorcycle crashes (96.5%) occurred on dry pavement, as compared to 2.9% on wet pavement and just 25 crashes on other road surface conditions. Finally, just 115 (2.6%) involved animals on or approaching the roadway, 30 (0.68%) involved motorcycle vehicle-failures, and only 12 motorcycles were reported to be hidden from view behind other vehicles.

In summary, young (21-25 years old) and middle-aged (45-50 years old) men are involved in the greatest number of fatal motorcycle crashes. Single-vehicle overturns and run-off-the-road motorcycle crashes are often deadly (particularly if the rider hits a fixed object, which is likely not designed with motorcyclists in mind), while angle collisions and intersections are common in fatal multi-vehicle motorcycle collisions. Fatal motorcycle crashes are more common during good weather, and between late spring through early autumn, with high shares occurring on weekends and in the afternoons and evenings, and relatively high shares occurring in rural locations. Other contributing factors appear to be alcohol, drugs, and speeding -- in all crashes, as along with curvature and grade in single-vehicle crashes.

## MOTORCYCLIST SAFETY PERCEPTIONS

To further existing research into the nature of motorcycling and riders' crash histories, a survey of 1257 American adults was conducted in March 2012 on a panel of individuals maintained by Survey Sampling International. Online questions asked about individuals' and their household members' crash histories, vehicle purchases, attitudes and demographic characteristics. 58 such individuals reported *current* motorcycle ownership, and 238 (total) reported owning a motorcycle at some point in their life. Table 1 illuminates general rider demographic information and rider characteristics among the surveyed riding population:

Table 1: Respondent Characteristics (Sample Summary Statistics)

| Demographics | | | Rider Characteristics | | |
|---|---|---|---|---|---|
| Gender | Male | 61% | Years Riding | Min | < 1 year |
| | Female | 39% | | Max | 54 |
| Gender (wtd.) | Male | 80% | | Average | 14 |
| | Female | 20% | Annual Mileage | Min | 8 |
| Age | Min | 19 | | Max | 30,000 |
| | Max | 81 | | Average | 3200 |
| | Average | 48 | MC Trip Length (mi) | Min | 1 |
| Marital Status | Married | 65% | | Max | 10,000 |
| | Single | 14% | | Average | 106 |
| | Divorced | 14% | Riding Frequency | Daily | 22% |
| | Other | 6% | | Weekly | 33% |
| HH Income | < $50k | 44% | | Monthly | 26% |
| | $50k - 100k | 40% | | < Monthly | 19% |
| | > $100k | 17% | Primarily Ride… | In Groups | 13% |
| | Average (est.) | $65,000 | | Alone | 36% |
| Education | HS or lower | 22% | | Both | 50% |
| | Some College | 41% | Riding Purpose | Recreational | 47% |
| | Bachelors | 28% | | Functional | 8% |
| | Graduate | 10% | | Both | 46% |
| Employment | Full Time | 47% | Helmet Use | Always | 75% |
| | Part Time | 14% | | Sometimes | 20% |
| | Retired | 21% | | Never | 5% |
| | Unemployed | 12% | MC Training | 1+ Course | 32% |
| | Student | 2% | | Avg. # Courses | 0.45 |
| | Other | 3% | MC Engine (cc) | Min | 70 |
| Children in HH | At least 1 | 36% | | Max | 2200 |
| | Average | 0.79 | | Average | 800 |
| Adults in HH | Average | 2.1 | | Unknown | 4% |
| Felony or Misdemeanor Convict. | | 11% | Suspend / Revoked License | | 20% |

Key highlights from this data shows that the surveyed rider population was mostly male (80% after weightings were applied), married, not living with children, with pluralities having attended some college and employed in full time work. Most motorcyclist respondents reported often riding with others and for recreational purposes, always wearing a helmet, and not receiving formal motorcycle training. Riders exhibited wide variations in years riding, annual mileage, average trip length, riding frequency, and motorcycle engine size. One rider reported an average trip length of 10,000 miles which is possible (for an around-the-nation entire US ride) though unlikely, while the next four highest average trip lengths varied between 1,000 and 2,000 miles.

Several questions of the survey investigated motorcyclists' perceptions of factors influencing their own safety: "What safety precautions/advice would you give to other motorcyclists?"; "What is your greatest motorcycle-related safety concern regarding other road users?"; and "What is your greatest motorcycle-related safety concern that transportation professionals (designers, planners, construction engineers, and maintenance personnel) should be aware of?" The survey allowed respondents to provide other safety precautions or advice (though these were not ranked), with common responses recommending motorcyclists to exercise caution or ride defensively, and other drivers to be aware of motorcycles and avoid tailgating. Each involved a list of options that respondents ranked in order of importance, with 1 being the most important with the option of ranking concerns "not important". Weightings were applied to account for over-representations of women (originally 65% of all survey respondents) and motorcycle ownership (which was 1 out of 18 respondents' vehicles, instead of the national average: 1 out of 30 [NHTSA 2010]) in the original (n= 1,257) data set, before focusing on current and former motorcycle riders only (n=213). These results are shown in Table 2, with factors sorted in order of importance based on average respondent rankings.

Table 2: Motorcyclist Safety Perceptions

| **Safety Advice for other Motorcyclists** | | | | | |
|---|---|---|---|---|---|
| Concern | Avg. Ranking | # 1 Concern | Top-3 Concern | Bottom-2 Concern | Not Important |
| Use helmet | 3.32 | 53.7% | 69.7% | 6.7% | 3.2% |
| Avoid alcohol | 4.29 | 19.4% | 47.2% | 2.3% | 5.6% |
| Avoid drugs | 4.82 | 2.2% | 31.4% | 4.4% | 5.2% |
| Avoid wet & icy roads | 7.55 | 1.7% | 3.5% | 5.0% | 3.6% |
| Get training | 7.65 | 9.8% | 20.0% | 17.2% | 10.8% |
| Other vehicle awareness | 7.73 | 7.9% | 10.5% | 9.9% | 5.0% |
| Follow rules of the road | 7.99 | 1.5% | 4.6% | 6.4% | 6.2% |
| Use responsible speed | 8.12 | 0.0% | 0.3% | 10.0% | 5.3% |
| Care on horiz. curves | 8.77 | 1.6% | 5.8% | 9.7% | 8.4% |
| Avoid excess. weaving | 9.15 | 0.0% | 0.8% | 15.0% | 5.0% |
| Use proper leaning | 9.16 | 0.0% | 0.9% | 11.7% | 7.2% |
| Use turn signals | 9.39 | 0.6% | 0.6% | 12.6% | 5.6% |
| Care on downhill grades | 10.79 | 0.0% | 1.2% | 29.8% | 12.2% |
| Avoid constrxn & uneven pvmt | 11.07 | 1.2% | 1.2% | 31.2% | 10.2% |
| **Motorcycle Safety Concerns Regarding other Road Users** | | | | | |
| Concern | Avg. Ranking | # 1 Concern | Top-3 Concern | Bottom-2 Concern | Not Important |
| See MCs at intersections | 2.78 | 43.1% | 71.3% | 8.8% | 5.6% |
| MCs hidden behind vehicle | 3.64 | 16.2% | 55.0% | 17.2% | 6.8% |
| Realize MC vulnerable | 4.41 | 13.0% | 37.0% | 30.2% | 6.4% |
| Misjudge MC dist./speed | 4.41 | 8.7% | 36.0% | 21.9% | 8.6% |
| Careless merging | 4.55 | 8.2% | 35.5% | 30.8% | 8.1% |
| Realize MC slowing | 4.71 | 5.1% | 33.4% | 29.3% | 9.2% |
| Misinterpret MC intentions | 5.17 | 3.6% | 20.2% | 36.3% | 10.7% |
| **Motorcycle Safety Concerns for Transportation Professionals** | | | | | |
| Concern | Avg. Ranking | # 1 Concern | Top-3 Concern | Bottom-2 Concern | Not Important |
| Pavement condition | 2.95 | 48.3% | 70.4% | 4.5% | 2.7% |
| Debris | 4.52 | 8.1% | 51.7% | 11.8% | 5.0% |
| Road surface (Construction) | 5.37 | 5.0% | 34.5% | 11.6% | 7.2% |
| Drop-offs (Construction) | 5.72 | 4.1% | 25.5% | 10.3% | 8.4% |
| Roadway design | 5.89 | 16.0% | 28.2% | 19.7% | 8.9% |
| Traffic signals | 6.07 | 8.0% | 25.3% | 23.9% | 6.3% |
| Shoulder drop-offs | 6.19 | 3.4% | 18.9% | 13.2% | 8.1% |
| Roadway cross-slope | 6.78 | 2.9% | 15.4% | 21.1% | 8.4% |
| Vertical grade | 7.39 | 1.1% | 9.5% | 31.3% | 9.8% |
| Horizontal curves | 7.44 | 1.7% | 9.7% | 29.9% | 10.7% |

Responding motorcyclists perceive helmet use to be the best precaution for rider safety. Over half noted this as their top recommendation (among 14 options), with 75% listing it in their top three. NHTSA (2011) estimates that helmets reduce the probability of fatality by 37% for motorcycle operators and by 41% for passengers, in the event of a crash, and Liu et al. (2008) estimated 42% fatality reductions among all riders, and a 69% reduction in probability of head injury.

Alcohol and drug use were also top concerns, with over 69% and 60% (respectively) placing these two factors among their top three concerns. Receiving motorcycle training, awareness of other vehicles, and demonstrating care on wet or icy roads also rated above average, though these were perceived less important than helmet, alcohol and drug use. Other environmental factors (i.e. avoiding construction, uneven pavement gravel and debris, downhill grades, and presence of horizontal curvature) as well as riding behaviors (turn signal use, proper leaning, weaving frequency, following rules of the road, and excessive speeding) rated below average concern among the 14 options. This suggests that riders under-value the importance of speeding, a factor in nearly 40% of all fatal U.S. motorcycle crashes, as previously noted.

Top safety concerns relating to "other road users" focused on motorcyclist visibility, both at intersections and when motorcycles lie behind other larger vehicles. Intersection visibility issues were noted as a top-three concern by 71% of respondents, and non-visibility behind other vehicles was listed as a top-three concern by 55% of respondents. One respondent nicely summarized the issue, writing, "In less than a city block a bike looks like a pinky held at arm's length." Motorcycles are small, travel fast, and can come upon intersections unnoticed by inattentive drivers and other travelers. Several respondents went further to address this issue, suggesting in the "other concerns" question that motorcyclists should always ride with their lights on, wear conspicuous clothing, and rely on noisy motorcycles, opining that, "Loud pipes save lives". Likewise, several noted that such issues could be addressed by installing signs to promote motorcycle awareness on roadways with heavy motorcycle traffic volumes and/or in high-crash locations.

Respondents tended to attribute other motorists' lack of respect for motorcyclists as less crucial than visibility issues, but more important than motorcyclist interpretation issues. Realizing that motorcyclists are vulnerable users, misjudging motorcyclist distance and speed, and expecting motorcycles to get out of the way when merging demonstrate a carelessness on the part of car and truck drivers. Much less important were issues like others' failure to realize a slowing motorcycle (during downshifting) and misinterpreting rider intentions (like those resulting in internal lane shifts, to avoid potholes and debris, or other maneuvers).

Interestingly, the most important issues cited for transportation professionals were the least cited as safety advice for other riders. Most respondents noted that pavement condition was the top-rated concern, with 48% choosing it is their foremost safety priority and 70% as a top-three concern. Debris was a top-three concern for 52% of respondents, and construction-related issues (road surface and lane drop-offs) were also strong concerns. In contrast, design-related considerations like horizontal curves, vertical grades, roadway cross-slopes, shoulder drop-offs, motorcycle detection at signals, and rider consideration in roadway design (such as larger roadside-barrier offsets) were all evaluated as below-average importance.

These perceptions should also be viewed in light of the overall crash data noted in the previous section. Poor road conditions were noted as the critical event in only 28 fatal crashes, or less than 1% of the total. While road surface could have been a contributing factor in other crashes (in particular the 504 fatal motorcycle single-vehicle rollover and overturn crashes), it appears that horizontal- and vertical-curvature (1319 crashes) and roadside design (1265) may have greater roles to play in improving motorcycle safety from transportation professionals' perspectives.

## MOTORCYCLIST CRASH PROPENSITY

While it is valuable to appreciate the safety *perceptions* of motorcyclists, it is very important to characterize actual crash risk and ascertain who is most at risk of crashing. To this end, the survey data were analyzed to identify factors that make a motorcyclist more or less crash-involved. A total of 19 motorcycle crashes were reported among the 214 riders, with four having experienced two motorcycle crashes each. Six other motorcycle crashes were reported: one was unusable because the respondent didn't provide enough information and the others were non-motorcycle riders (likely passengers at the time of the crash). Furthermore, with a motorcycle fatality rate at 5% of the injury rate, it is likely that a fatal crash would have been reported, if examining crash reports, rather than surveying living riders. In total, if 26 crashes are included, this brings the crash rate to 1 crash per 125 years of riding experience, somewhat lower than the national result of 88 injuries per riding year (NHTSA 2007).

Two negative binomial models were used in this exploration: one to estimate a rate of crashes per year of riding/having ridden, and a second to estimate general motorcyclist crash involvement (with no direct exposure variable). These models take the following form, as noted by Greene (2011):

$Y \sim Poisson(\lambda + \varepsilon)$, where $E[y|x,\varepsilon] = T * \exp(\alpha + \beta x + \varepsilon) = Th\lambda$,
$h = \exp(\varepsilon) \sim Gamma(\theta, \theta)$, and $\lambda = E * \exp(\alpha + \beta x + \varepsilon)$, so
$Prob(y_i = j|x_i, T_i) = \frac{\exp(-T_i\emptyset_i)(-T_i\emptyset_i)^j}{j!}, \emptyset_i = \exp(x_i'\beta), j = 0,1, \dots$ .

Here, $T$ is the exposure variable (*Years of Riding* in the crash rate model, and 1 in the involvement model) and the error term (ε) is assumed to follow a Gamma distribution (across the sample population) with a unit mean and variance 1/θ, where θ is called the dispersion parameter.

This interaction of a Poisson and gamma results in a negative binomial for crash count, conditioned on an individual's explanatory factors $x$. The vector of parameters $\beta$ is estimated, via weighted maximum-likelihood regression (with weights reflecting sample corrections, as described earlier). The model's final specification was arrived at using stepwise elimination of statistically insignificant covariates until all coefficients were statically significant at the 5% level, with the exception of motorcycle engine size, which was statistically significant at the 10% level. The overdispersion parameter was not statistically significantly different from the expected mean, so the model collapsed to a Poisson specification, with results shown in Table 3. Parameters were estimated using maximum likelihood estimation in Stata software, with person-level weights, as previously noted. Non-statistically significant variables that were controlled for included age, income, motorcycle annual mileage and other variables noted in Table 1, but not included in Table 3.

Table 3 also provides a column elasticity estimates for each covariate, which is a valuable indicator of practical significance. Elasticities were generated by increasing each covariate value, including indicator variables, for each respondent by 1% and averaging the cumulative predicted percentage change in annual crash rates across the sample population. No elasticities are reported for those with less than a monthly riding frequency, since none of these riders reported a collision and a 1% increase in the coefficient magnitude would result in negligible change.

Table 3: Motorcycling Crash Rate and Involvement Poisson Model Results

| | Crash Rate Model | | | Crash Involvement Model | | |
|---|---|---|---|---|---|---|
| Explanatory Variable | Coef. | P-Val | Elasticity (# Crashes/Yr) | Coef. | P-Val | Elasticity (# Crashes) |
| Constant | -6.684 | 0.000 | - | 2.299 | 0.037 | - |
| Motorcycle Owner | 1.639 | 0.019 | 0.33 | 2.615 | 0.000 | 1.24 |
| Primary Veh. Motorcycle | 2.062 | 0.000 | 0.63 | 1.299 | 0.022 | 0.45 |
| Motorcycle Engine (100 CCs) | -0.100 | 0.064 | -0.43 | - | - | - |
| Unknown MC Engine CCs | 4.365 | 0.005 | 0.63 | - | - | - |
| All Vehicles Insured | - | - | - | -1.422 | 0.004 | -1.03 |
| Years Riding a Motorcycle | (exposure) | - | - | -0.100 | 0.000 | -1.47 |
| Years Licensed (Driving) | - | - | - | 0.045 | 0.010 | 1.44 |
| Average Trip Length | 0.002 | 0.021 | 0.67 | 0.003 | 0.015 | 0.42 |
| Frequency Daily (Base) | - | - | - | - | - | - |
| Frequency Weekly / Monthly | - | - | - | -1.494 | 0.030 | -0.86 |
| Frequency < Monthly | -29.27 | 0.000 | - | -52.52 | 0.000 | - |
| # MC Trainings | 0.932 | 0.000 | 0.84 | 0.980 | 0.000 | 1.11 |
| Helmet Frequency | - | - | - | -2.776 | 0.000 | -2.18 |
| High School Ed. Or Less | - | - | - | -2.053 | 0.008 | -0.12 |
| Bachelor's Degree | -1.812 | 0.004 | -0.50 | -2.768 | 0.012 | -0.50 |
| Student | 3.874 | 0.000 | 1.19 | - | - | - |
| Employed Part Time | 2.041 | 0.011 | 0.65 | - | - | - |
| Retired | - | - | - | -3.314 | 0.008 | -0.23 |
| # Adults in HH | - | - | - | -0.689 | 0.006 | -1.51 |
| Criminal Conviction | 1.923 | 0.001 | 0.75 | 1.343 | 0.023 | 0.37 |
| $n_{obs} = 214$ | Log-Lik: -43.238 | | | Log-Lik: -32.441 | | |

Several meaningful observations come from comparing the two models. First, all coefficient estimates in both models have identical signs. This consistency is encouraging: if a given variable indicates a rider to be more likely to get in a crash, his expected crash *rate* should increase as well. Additionally, variables included in both models lend themselves to a higher degree of confidence regarding their actual impact. Since the total number of crashes available is relatively small (19), this is particularly useful in identifying the most consistently influential variables. Variables included in both models are current motorcycle ownership, riders whose motorcycle was their primary vehicle, average trip length, riding frequency less than monthly, number of formal motorcycle trainings and those with bachelor's degrees and criminal convictions.

A second important conclusion that can be drawn is that the crash rate model's exposure variable (years riding a motorcycle) is estimated to have a *negative* impact on total MC crash involvement levels. This may suggest that riders who are prone to crashing are more likely to crash in their first few years riding, and a number of those who do crash stop riding as a result, which is specifically noted in the survey by at least six of the 15 crash-involved riders. This hypothesis is further supported by Sexton et al. (2004) who estimated that crash rates fall as rider experience increases.

It is also interesting to note the difference in top (most influential) covariates across the two models: The specifications share seven covariates, but none of the top-three practically significant variables in the crash rate model (i.e., student status, past motorcycle trainings, and criminal conviction) are among the top-five in the crash involvement model. Similarly, the top-three variables[1] in the crash involvement model (helmet use, adults in household, and years licensed) were not statistically significant (and so are not even present) in the crash rate model. Only the number of trainings has clearly important elasticity impacts in both – and not in the direction one would normally expect (for reasons discussed below).

It is also worth examining potential reasons behind other coefficients. Some relate directly to exposure. For example, current MC owners are probably more likely to ride their motorcycles longer distances (or more frequently within a daily-weekly-monthly-yearly bin) than those who borrow or rent motorcycles. Riders with motorcycles as their primary vehicle likely ride much more than other motorcyclists. Longer motorcycle trips are associated with higher crash rates (per year) and counts (total to date), which relates to frequency of use as well as, potentially, less familiarity with the locations traveled. Those who ride only a few times a year reported very low crash experiences (none observed in the sample), while those who rode daily had the highest involvement. The number of household adults may also have a negative impact on exposure (resulting in fewer crashes), since MCs have less utility for two or more persons traveling together.

Engine size, helmet use, and convictions also appear to play a role. Larger engines are associated with lower crash rates, in contrast to other findings by Haque et al. (2010) and Langely et al. (2000), who reported more injurious and fatal crashes for those with larger engines. In addition, those reporting no real sense of their engine size(s) are estimated to experience much higher crash rates. Such persons may be less knowledgeable about motorcycling because they less concerned about proper use. Similarly, persons who have been convicted of a misdemeanor or a felony are more crash prone. In contrast, those who insure all their vehicles and those who wear a helmet more frequently are estimated to be less crash involved on a MC. Such behaviors are consistent with greater caution and more risk-averse behaviors, and they do not support some

[1] Excluding years riding a motorcycle, since this variable is the exposure variable in the crash rate model.

riders' perceptions that helmets lead to higher crash rates (due to comfort and visibility issues -- see, for example, reader comments to Schmitt [2012]).

Individuals with formal motorcycle training are estimated to have higher underlying crash rates than others without training. While one may expect crash rates to fall with formal training, ceteris paribus, those who seek out training may have fewer skills to begin with or past crash involvement experiences. Of the riders who reported having received training and being involved in at least one motorcycle crash, four reported having received their last training at least one year before the crash, three reported receiving training the same year as the crash (though in one individual's case it was his first year riding), and the final rider did not report the training year. This suggests that at least two (and possibly three) of the riders likely received training just after their motorcycle crash. Daniello et al.'s (2010) literature review on training courses also shows mixed results for crash-rate reductions.

Interestingly, those a bachelor's degrees, just a high school diploma or less education, are estimated to experience lower crash involvement rates than those with either some college or graduate education – everything else constant. Meanwhile, students and part-time-employed riders are associated with higher rates than full-time workers, while retired individuals appear to enjoy lower crash involvement.

## HELMET USE PROPENSITY

The second model developed here uses an ordered probit (OP) specification to estimate riders' helmet use frequency, across five categories, with $T$=1 for those who report never wearing a helmet ($n_1$=26, or 12% of the $n$=214 sample), $T$=2 for those who occasionally wear/wore a helmet (5 or 2%), $T$=3 for those who sometimes wear/wore a helmet (14 or 7%), $T$=4 for those who usually wear/wore a helmet (22 or 10%), and $T$=5 for those who always wear/wore a helmet (149 or 69%). The main equation for this specification is as follows:

$$y_i^* = x_i'\beta + \varepsilon_i$$

where $T_i^*$ represents the latent and continuous propensity to wear a helmet when riding a motorcycle; $x_i$ represents a vector of explanatory variables regarding the rider, his or her motorcycle and riding habits; $\beta$ represents a vector of parameters to be estimated; and $\varepsilon_i$ represents a random error term, assumed to follow a standard normal distribution.

Four thresholds ($\mu_1$ through $\mu_4$) were estimated to distinguish the five categories. For example, $\mu_1$ represents the threshold between never wearing a helmet to occasionally wearing a helmet. The probability that a rider would exhibit a certain propensity for helmet use is specified as follows (Greene 2011):

$$Pr(Never) = Pr(y_i = 1) = \Pr(y_i \leq \mu_1) = \Phi(\mu_1 - y_i)$$
$$Pr(Occasional) = Pr(y_i = 2) = \Pr(\mu_1 < y_i \leq \mu_2) = \Phi(\mu_2 - y_i) - \Pr(Never)$$
$$Pr(Sometimes) = Pr(y_i = 3) = \Pr(\mu_2 < y_i \leq \mu_3)$$
$$= \Phi(\mu_3 - y_i) - \Pr(Never \ldots Occasional)$$
$$Pr(Usual) = Pr(y_i = 4) = \Pr(\mu_3 < y_i \leq \mu_4) = \Phi(\mu_3 - y_i) - \Pr(Never \ldots Sometimes)$$
$$Pr(Always) = Pr(y_i = 5) = \Pr(y_i > \mu_4) = 1 - \Pr(Never \ldots Usual)$$

Variables were removed from an extensive initial set (all variables in Table 1, plus a few more) using stepwise elimination to arrive at a set of statistically significant covariates. Initial estimates of thresholds $\mu_1$ and $\mu_2$ were statistically quite close (-2.762 and -2.602, with errors of 0.361 and 0.353), so these first two helmet-use categories were combined. Parameters were then re-estimated using stepwise elimination of parameters with p-values over 0.05, resulting in Table 4's estimates and elasticity measures computed by estimating the relative impact that a 1% change in coefficient value (for each respondent) has on estimated helmet use across the entire sample:

Table 4: Helmet Use Model Results (Ordered Probit)

| Explanatory Variable | Coef. | Elasticity (Never/Occ.) | Elasticity (Always) |
|---|---|---|---|
| Years Licensed | -0.021 | 0.720 | -0.256 |
| Criminal Conviction | -0.815 | 0.149 | -0.036 |
| Formal Training* | 0.395 | -0.072 | 0.037 |
| Commercial Drivers' License* | 0.470 | -0.063 | 0.028 |
| Motorcycle Engine CCs (100s) | -0.066 | 0.486 | -0.196 |
| Unknown MC Eng. CCs | -2.162 | 0.397 | -0.053 |
| Current Motorcycle Owner | 0.543 | -0.071 | 0.035 |
| Frequency Weekly or Daily | 0.524 | -0.260 | 0.110 |
| Frequency Monthly (Base) | 1.462 | -0.088 | 0.055 |
| Frequency Less than Monthly | -0.063 | 0.085 | -0.026 |
| Number of Children | -0.021 | 0.720 | -0.256 |
| **Threshold** | **Coef.** | | |
| Never or Occasional / Sometimes | -2.12 | | |
| Sometimes / Usually | -1.68 | | |
| Usually / Always | -1.26 | | |

$\rho^2_{adj}$: 0.22229 Log-Lik: -191.19 $n_{obs} = 216$

* These variables are statistically significant at the 0.10 level. All other variables are statistically significant a level of 5% or lower.

The number of years one has been licensed (to operate a motor vehicle) is associated with lower helmet use, everything else constant in this model. It may be that older people feel more expert and confident in their driving and riding abilities, and/or that they have not grown up in (and been as influenced by) as safety-conscious a society as younger riders.

The model indicates that those with misdemeanor or felony criminal convictions are less likely to wear a helmet while riding. It can be argued that such persons have demonstrated a greater acceptance of risk and a failure to appreciate the potential consequences of their actions, and so may be willing to take risks or engage in behavior that others would find less acceptable, including helmet non-use.

Motorcycle training was also found to increase the helmet use levels, consistent with findings by Daniello et al. (2010). The exact reason behind this correlation remains unclear: Motorcycle training likely includes information on and encouragement of helmet use, and persons who obtain training are presumably more safety-conscious to begin with. It is unclear which factor plays a bigger role. Either way, higher helmet use is associated with lower crash rates (as shown in Table 3, and discussed earlier), while training is not (after controlling for helmet use levels, as though the five response options are uniformly distributed). Moreover, Table 4's low elasticity values suggest only a small training effect, which is unfortunate.

It is interesting to find that commercially licensed riders are more likely to wear helmets while riding, ceteris paribus. Such persons have special training, much of which focuses on safe driving techniques. Additionally, these individuals typically drive more than others and so may have seen more bad crashes (and bad drivers). It is possible that some of these safety-conscious attitudes translate to motorcycle riding as well, leading to a higher level of helmet use.

Persons using larger MC engines are associated with lower helmet use. This is worrisome, since Haque et al. (2010) and Langley et al. (2000) both estimate that those on larger engines are more likely to be in crashes, presumably since such high-power bikes are more difficult to control. From a public safety perspective, it is unfortunate that those who are more likely to get in a crash are also less likely to wear a helmet. In addition, those reporting no real sense of their engine size(s) are associated with much less helmet use. Such persons may be less concerned with their motorcycles, less concerned with using them, and possibly less concerned when using them.

Those who currently own a motorcycle are more likely to wear a helmet, perhaps because they have already made the investment in the vehicle and take their repeat exposure more seriously than others. Riding frequency also plays a role: Those who ride only a few times each year are estimated to be more likely to use a helmet, followed by those who ride on a weekly or daily basis, while those who ride about once per month are least likely. Infrequent riders who take their motorcycle out just a few times per year may be less comfortable riding and so take extra safety measures. Regular riders, who take their motorcycle out on a weekly or daily basis, may have experienced a number of "close calls" or "near misses" (narrowly averted crashes), resulting in greater helmet use than monthly riders.

Finally, those with children appear less likely to wear a helmet, perhaps because they hand theirs to their child on joint rides. Education and outreach may be used to encourage such to obtain an extra helmet for their child, rather than letting go of their own.

## MOTORCYCLE TRAINING

A final model was developed to understand which types of riders are more likely to receive formal training. Like the helmet use model, an ordered probit model was applied, with riders divided into three categories: those who have never received training, those who have received one formal motorcycle training, and those who have received two or more trainings. Similar processes were conducted as in the helmet use model until only statistically significant variables remained, with results shown in Table 5:

Table 5: Motorcyclist Training Model Results (Ordered Probit)

| Variable | Estimate | Elasticity (No Training) | Elasticity (1 Training) | Elasticity (2+ Training) |
|---|---|---|---|---|
| Helmet Use Frequency | 1.224 | -0.379 | 0.925 | 1.829 |
| Motorcycle Primary Vehicle* | -0.744 | 0.006 | -0.018 | -0.012 |
| # Years Riding | 0.000301 | -0.003 | 0.003 | 0.0340 |
| Yearly Miles (All Vehicles, 1000s) | 0.0148 | -0.025 | 0.040 | 0.205 |
| Frequency Weekly/Monthly | 0.497 | -0.103 | 0.237 | 0.557 |
| Trip Purpose: Work, School, Errands | 0.544 | -0.104 | 0.239 | 0.582 |
| Ride Alone | 0.680 | -0.038 | 0.0704 | 0.270 |
| Unemployed | -0.417 | 0.011 | -0.028 | -0.050 |
| Bachelor's Degree[2] | -0.959 | 0.059 | -0.188 | -0.118 |
| **Threshold** | **Estimate** | | | |
| No Training / 1 Training | 0.391 | | | |
| 1 Training / 2+ Trainings | 1.504 | | | |

$\rho^2_{adj}$: 0.1520 Log-Lik: -134.43 $n_{obs} = 216$

* This variable is statistically significant at the 0.10 level. All other variables are statistically significant a level of 5% or lower.

Consistent helmet use is the foremost indicator of having received more motorcycle training, as shown by the comparatively high degree of practical significance for the motorcycle helmet use frequency coefficient. This variable (ranging from zero to one, as described in the motorcyclist crash propensity section) was found to be three times more influential in predicting motorcycle training than any other variable. As previously discussed, however, this gives rise to a classic chicken-and-egg conundrum that remains unanswered in this investigation: to what degree are persons who almost always wear their helmet more likely to get training, and to what degree does receiving training cause a person to wear their helmet more often?

The other coefficients with greatest impacts on increasing probability of increased formal motorcycle training were for motorcyclists who ride on a weekly or monthly basis and for those who ride their motorcycle to and from work, school and/or errands (though not necessarily exclusively so). Riders who sometimes or always ride alone similarly had positive impacts on receiving motorcycle training. All three of these variables are indicative of more serious, functional riders; whereas motorcyclists who ride less than monthly, for recreational purposes only or in groups only are all characteristics of less serious, casual riders. As such, functional riders who use their motorcycles more may see a greater use for training than casual riders, since motorcycling is much more part of their lives. In contrast, the high-intensity daily riders may feel that they already have so much practice riding that they have no need for additional training. This is acutely shown in the negative coefficient for the motorcycle primary vehicle indicator variable.

Several other influences also impacted likelihood of having received greater formal motorcycle training, though to a lesser degree. Motorcyclists who had been riding longer had a higher likelihood, possibly because there were more years in which that person may have obtained training. As yearly driving mileage among all vehicles increased, riders were more likely to receive training, potentially due to increased personal and visual roadway crash exposure, in turn increasing perceptions of the value of roadway safety. Finally, both the unemployed and those who received bachelor's degrees were less likely to have received training.

## CONCLUSIONS

This work analyzed an unusual data set on motorcyclists' crash histories, perceptions, opinions, and practices. Regression models were used to predict crash rates and helmet use, as a function of riding frequency, employment status, and other variables. Riders' top safety recommendation for other motorcyclists is to wear a helmet, followed by avoiding drinking and drugs while riding, and obtaining motorcycle training. They recommend that car and truck drivers should watch for motorcycles at intersections and those hidden behind other vehicles. They also recommend that transportation professionals keep road surfaces in good condition and free from debris. While respondents' safety recommendations generally track well with U.S. fatal-crash-data statistics, their responses indicate that they may over-value the safety benefits of debris-free roadways and good pavement condition and under-value speed-related risks.

The models explored in this investigation have significant overlap. This data indicates that riders who are more likely to wear a helmet are also more likely to obtain more motorcycle training (and vice versa). In contrast, riders who are more likely to have been in a crash are less likely to wear a helmet, but more likely to have received training. Riders who take long-distance trips, have been convicted of a criminal offence and students were estimated to exhibit higher MC crash rates, while riders with more adults in their household, riders who have longer riding and shorter driving histories are less likely to have been involved in a crash, everything else constant. Those who ride on a daily or weekly basis are more likely to wear a helmet, while those who have been licensed longer, own motorcycles with larger engines, and/or have children are less likely to use one. Finally, riders who ride on a weekly or monthly basis and for less discretionary purposes (such as work, school and errands) are more likely to have received formal motorcycle training.

These findings may be used to identify and further enhance current motorcycle training and outreach to transportation system users and professionals in order to improve motorcycle safety throughout the US and elsewhere. In particular, transportation agencies and training courses should 1) seek to target riders most at risk of crashing and those most likely to forego a helmet, 2) address safety misperceptions among motorcyclists (like the significance of speeding), 3) draw attention to motorcycle safety issues among all motorists (particularly visibility issues at intersections), and 4) seek to change the culture of transportation agencies in order to better accommodate motorcycle safety in planning, outreach and design. These actions should improve safety among motorcyclists and ultimately save lives, bringing communities one step closer towards the ultimate goal of zero roadway fatalities across all transportation system users.

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