PA Motorcycle Data Study

FINAL REPORT

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COMMONWEALTH OF PENNSYLVANIA
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EXECUTIVE SUMMARY

The purpose of this study is to retrospectively analyze motorcycle crash data to determine what statistical association, if any, state-sponsored motorcycle training has in reducing the severity of motorcycle crashes in Pennsylvania. A comprehensive dataset containing detailed information on motorcycle crashes was compiled using four separate datasets supplied by the Pennsylvania Department of Transportation (PennDOT). The timeframe for this study encompassed data between 2005 and 2017. A retrospective, cross-sectional analysis was performed to assess the statistical association between motorcycle rider training and crash severity. The dependent (outcome) variable is crash severity with possible values that range from not injured, possible injury, minor injury, serious injury, and fatality. As crash severity is rank ordered in its scaling, an ordinal logistic regression model was constructed. Specific independent variables include the rider's training history, whether the rider had a registered motorcycle, whether the rider had a motorcycle license endorsement or permit , the rider's age, the collision type, whether the rider was wearing a motorcycle helmet, and whether the rider was speeding at the time of the crash.

The assembled dataset contained 29,646 observations – each observation represented one motorcycle crash. Of the 29,646 observations in the analysis file, 8,365 (28.2%) have some sort of training history. When examining motorcycle riders involved in crashes, the largest proportion of riders are men (almost 95%). The average age of the motorcycle rider involved in a crash is 41 years. Approximately 10% of motorcycle crashes are associated with alcohol use. Sixty percent of motorcycle riders have a motorcycle endorsement, and the average length of time between the crash and when the rider obtained their motorcycle endorsement is 2.7 years. As Pennsylvania has a partial motorcycle helmet law, almost 55% of all motorcycle crashes between 2005 and 2017, involved a rider wearing a motorcycle helmet. Nearly all motorcycle crashes in Pennsylvania within the study's timeframe were Pennsylvania residents. Just over 20% of all motorcycle crashes in Pennsylvania involved excess speed. When examining the motorcycle crash types, the vast majority of crashes involved non-collisions (almost 29%) angled crashes (almost 25%) and hitting a fixed object (nearly 18%). While half of all motorcycle crashes in Pennsylvania occur within seven miles of the rider's residence, 75% of all crashes occur within 15 miles.

When examining the effect of motorcycle training on crash severity in a fully adjusted statistical model, the effect of motorcycle training has an odds ratio of 0.90. The interpretation of this coefficient in the model suggests that for motorcycle riders that completed training, the odds of being in a more severe motorcycle crash is 10% lower than motorcycle riders that did not complete motorcycle training (the finding in this model is statistically significant). Other findings of interest in this model include the use of motorcycle helmets and motorcycle licensing. For riders wearing a motorcycle helmet at the time of their crash, their odds of being in a more severe motorcycle crash is 26% lower as compared to riders that did not wear a motorcycle helmet. With licensing, for riders that have a motorcycle license or motorcycle permit at the time of their crash, their odds of being in a more severe motorcycle crash is seven percent lower than riders that did not have a license or permit.

Based upon the findings from this work, the following are recommendations for the PennDOT motorcycle data. These data recommendations are a combination of some of the limitations in linking data across multiple datasets, and some inconsistencies in the way data were captured. Amplifying information for each recommendation is contained in the body of the Conclusion section.

- *Revolve the data around the person and not the event.*
- *Implement a unique person identifier that is consistent across all PennDOT datasets.*
- *Capture detailed training data using required / mandatory data entry fields.*

The following are motorcycle rider-related policy recommendations that are based upon findings from this study.

- *Encourage greater adoption of wearing a motorcycle helmet when riding.*
- *Encourage motorcycle safety training prior to obtaining a motorcycle license for all new riders.*
- *Encourage refresher motorcycle safety training every four years to coincide with license renewal timelines.*

It would be remiss to not acknowledge that one motorcycle crash is one too many, and that each motorcycle crash–whether in Pennsylvania or across the country–has a profound impact upon the rider, the rider's family and friends. This reinforces the importance of this work in assessing the effect of motorcycle training on reducing crash severity in Pennsylvania. With continued support and awareness of this topic, additional efforts can be employed to reduce motorcycle crashes to ensure that while risk of a crash cannot be completely eliminated, measures can be taken to reduce the risks so each rider can return home safely following a motorcycle ride.

BACKGROUND

According to the National Highway Traffic Safety Administration's "Evaluation of State Motorcycle Safety Programs*,"* nearly all states in the U.S. provide training for both beginners and experienced motorcyclists.[1] In order to receive a motorcycle license in Pennsylvania, an individual must pass a basic motorcycle knowledge test and apply for a Class M learner's permit. According to the Pennsylvania Department of Transportation, a learner's permit allows the applicant to ride only between sunrise and sunset and, except for a rider licensed to operate another class of vehicle, only while under the instruction and supervision of an individual who holds a Class M license. The motorcycle learner's permit is valid for one year and costs $10.

Once a motorcycle rider in Pennsylvania receives their learner's permit, the rider has the option to either conduct a skills assessment at a Driver License Center or complete motorcycle safety training through the Pennsylvania Motorcycle Safety Program (PAMSP). If the rider elects to undergo the training portion, a skills assessment is administered by a Motorcycle Safety Instructor following the training; if the rider passes the skills assessment the rider is exempt from taking the skills assessment at a Driver License Center.

The PAMSP was created with the intention of "teaching motorcycle riders of all skill levels the fundamentals needed to reduce risks while operating motorcycles."[2] Training is not only offered for new riders, but training is available for three-wheeled riders, semi-experienced, and also advanced riders. This program was signed into law in 1984 and was implemented in 1985; it is free of charge for Pennsylvania residents and is funded through fees associated with licensing and learner's permits. Of note, the appendix contains a timeline of relevant motorcycle legislation in Pennsylvania.

A 2009 study evaluating the PAMSP found that "drivers with higher PAMSP knowledge test scores were slightly less likely to crash."[3] The study also found that people who had passed the Basic Rider Course (BRC) in the PAMSP, had "fewer suspensions, fewer speeding violations, fewer previous accidents, fewer total violations, fewer sanctions and so on compared to those who did not pass the BRC." While specific to Pennsylvania, the study is also somewhat contradictory because the authors find that motorcycle riders with higher PAMSP skills test scores were "slightly more likely to crash, probably because they ride more and may be more likely to crash due to greater exposure." As motorcycle safety training usually encompasses both a skills and knowledge assessment, partitioning findings by individual aspects of the training could haphazardly undermine the integrity of the overall training.

These findings from previous research highlight the difficulty in using retrospective data to conclusively determine whether motorcycle training is effective in reducing crashes or crash severity. This current study looks to overcome this limitation by utilizing large amounts of data over an extended time period and using statistical models that can simultaneously control for a variety of factors.

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[1] National Highway Traffic Safety Administration (2017, March). Traffic Safety Facts: 2015 Data. (Report No. DOT HS 812 353).

[2] Pennsylvania Motorcycle Safety Program Mission. Retrieved from: http://www.pamsp.com/mission.php

[3] Vance et al. (July 2009). Evaluation of Pennsylvania's Motorcycle Safety Program. Retrieved from: http://www.dot7.state.pa.us/BPR_PDF_FILES/Documents/Research/Complete%20Projects/Operations/Motorcycle Safety-Task4-Final%20Report.pdf

INTRODUCTION

The purpose of this study is to retrospectively analyze motorcycle crash data to determine what statistical association, if any, state-sponsored motorcycle training has in reducing the severity of motorcycle crashes in Pennsylvania. By incorporating data compiled in the first phase of this project,[4] this project examines various rider categories, contained below, with crash severity and legal versus illegal riding (e.g., motorcycle rider involved in a crash and did not have a motorcycle license endorsement).

1. Registered motorcycles, licensed motorcyclists, motorcycle training (by level) and crash severity.
2. Registered motorcycles, motorcycle permit holder, motorcycle training and crash severity.
3. Registered motorcycles, licensed motorcyclists, no training and crash severity.
4. Registered motorcycles, motorcycle permit holder, no training and crash severity.
5. Registered motorcycles, not licensed, no training and crash severity.
6. Not registered, not licensed, no training and crash severity.
7. Any other combination of the above factors that show any other correlations.

The above seven categories represent a combination of categories identified in Table 1. The analysis assesses the following combinations of rider categories while also controlling for other potential, non-rider contributing factors to a crash.[5]

Table 1: Category Combinations Assessed in the Study

Licensing	Registration	Training	Crash
No motorcycle license	Not registered	No training	Crash, no injury
Motorcycle permit	Registered	Completed training	Crash, possible injury
Motorcycle license	-	-	Crash, minor injury
-	-	-	Crash, severe injury
-	-	-	Fatality

Source: Stonewall Analytics

[4] Individual datasets were comprised of licensing, registration, training and crash data.

[5] Please refer to the Methodology section for a complete listing of non-rider contributing crash factors.

METHODOLOGY

A comprehensive dataset containing detailed information on motorcycle crashes was compiled using four separate datasets supplied by the Pennsylvania Department of Transportation (PennDOT). In addition to crash information, additional rider-level data was obtained using a record matching function from other datasets that include licensing, registration, and training.

This study also evaluates the following crash components involving the rider, the motorcycle, and the roadway (or crash scene).

Rider

- Age
- Gender
- Alcohol-related
- Drug-related
- When the rider received their motorcycle license
- Helmet use
- State of residence
- Speed
- Passenger present

Motorcycle

- Engine displacement

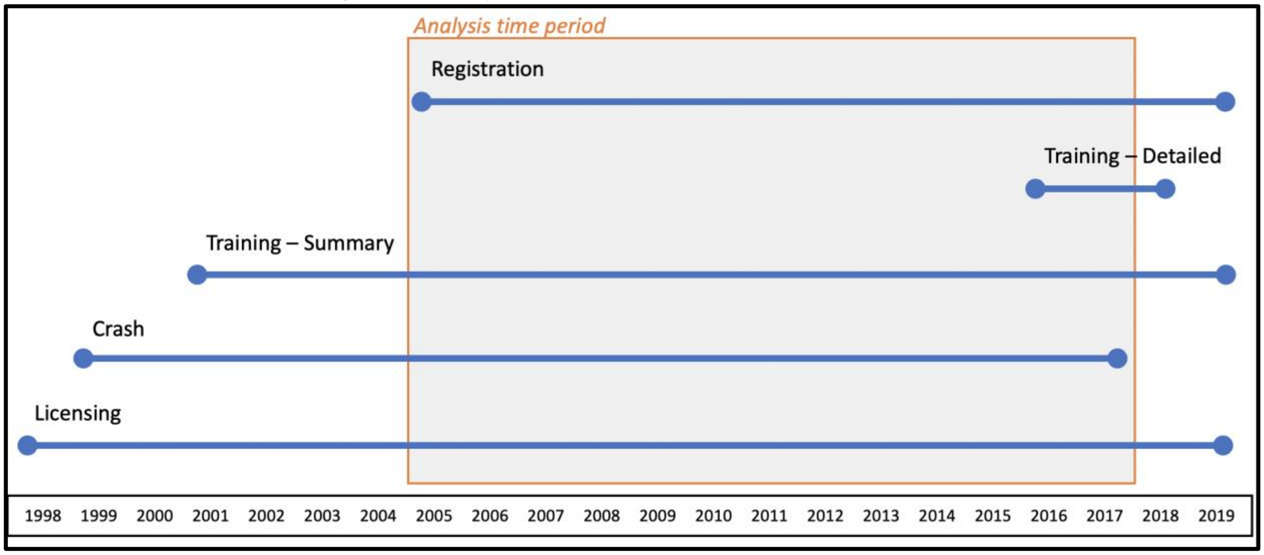
Roadway / Crash Scene

- Single vehicle crashes vs multi-vehicle crashes
- Crash Type (angle versus intersection)
- Distance of crash location from rider's home
- Time of day
- Geography
- Weather / road conditions

Study Timeline

This study involves a subset of the available years of data across multiple datasets. The common time period across all five datasets is 2005-2017. Figure 1 outlines the years of study for each dataset and the timeframe for the primary and secondary analyses.

Figure 1: Study Timeline and Available Data Sources



Source: Stonewall Analytics

Statistical Analysis

A retrospective, cross-sectional analysis was performed to assess the statistical association between motorcycle rider training and crash severity. The study was historical in nature and encompassed a large time span as detailed, existing records were available to examine this topic. In this case, the dependent variable is crash severity. As crash severity is ordinal in its scaling, an ordinal logistic regression model was constructed. One strength of using ordinal logistic regression modeling is its ability to control for other confounding factors at the same time – in this case we can examine the effects of motorcycle training on crash severity but also control for other possible explanations that could be linked to the severity of a motorcycle crash. As the 2016 adoption of the "Suspected Serious Injury" term per the Federal FAST Act significantly increased the count of cases in this category, a variable indicator (dummy variable) is included for crashes occurring in 2016 and later.

The ordinal logistic regression equation is represented by the following equation,

$$logit\big(P(Y \leq j)\big) = \mathrm{B}_{j0} - n_1x_1 - \cdots n_px_p$$

where the cumulative probability of Y (crash), is less than or equal to a specific crash severity category, j. B_{j0} represents the y-intercept for the specific crash category and n_1x_1 through n_px_p represent the parameters of interest included in the study – in this case, rider information to include training history, motorcycle characteristics, and roadway characteristics. The dependent variable, crash severity, is measured on an ordinal scale – the possible values range from not injured, possible injury, minor injury, serious injury, and fatality.[6] Specific independent variables include the rider's training history, whether the rider had a registered motorcycle, whether the rider had a motorcycle license endorsement or

[6] This scale differs from the possible injury severity scores provided by PennDOT. The original categories included not injured; fatal injury; suspected serious injury; suspected minor injury; possible injury; injury, unknown severity; and unknown if injured.

permit , the rider's age, the collision type, whether the rider was wearing a motorcycle helmet, and whether the rider was speeding at the time of the crash.[7]

[7] All statistical analysis was performed using R and all data aggregating, cleaning, and assembly was performed using Python.

RESULTS

This section is made up of two components – descriptive statistics and the statistical model results. The descriptive statistics orient the reader to the nature of the data, while the statistical model results examine and control for all factors and examine training.

Descriptive Statistics

The assembled dataset contained 29,646 observations – each observation represented one motorcycle crash. From 2005-2017, there was a rather consistent trend in reported crashes in the dataset with the exception of 2005 and 2006.

Table 2: Motorcycle Crashes by Year (n = 29,646)

Year	# Crashes	% of Total
2005	995	3.3
2006	1,385	4.6
2007	2,389	8.0
2008	2,749	9.2
2009	2,422	8.1
2010	2,741	9.2
2011	2,450	8.2
2012	2,752	9.3
2013	2,392	8.0
2014	2,263	7.6
2015	2,424	8.1
2016	2,389	8.0
2017	2,295	7.7

Note: % of Total values will not sum to 100 due to rounding. Source: Stonewall Analytics

The following subsections detail the various crash components in this study – training, crash severity, rider characteristics, motorcycle characteristics, and roadway characteristics.

Training

Of the 29,646 observations in the analysis file, 8,365 (28.2%) have some sort of training history. For gathering information on a rider's motorcycle training, data came from either the summary training file or the detailed training file. The vast majority of information came from the summary training file, where 93% of observations indicated passing a motorcycle safety course. While the detailed training file is rich in information such as whether a rider passed the course, did not show up for the training, or rescheduled, the proportion of represented observations in these detailed categories is extremely low– for instance, less than one percent of riders were identified as having any sort of training history.

Table 3: Training History Categories of Motorcycle Riders Involved in Crash (n = 8,365)

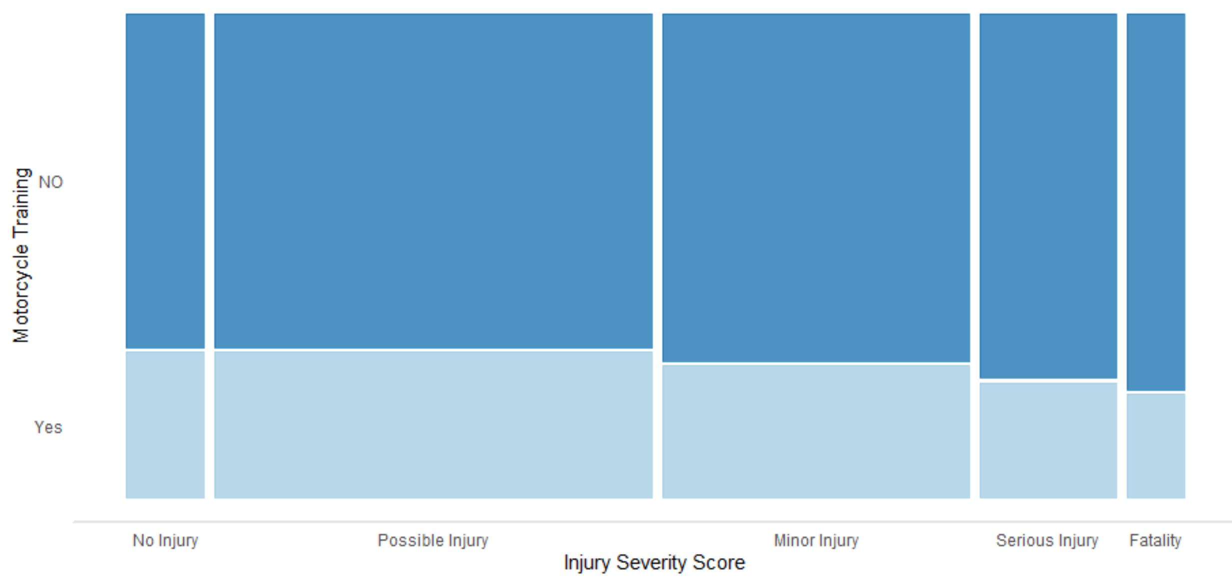
Characteristic	Value
Summary Training File	
Pass, # (%)	7,790 (93.1)
Fail, # (%)	438 (5.2)
Detailed Training File	
Pass, # (%)	81 (0.9)
Cancel, # (%)	20 (0.2)
No Show, # (%)	14 (0.1)
Completed, # (%)	11 (0.1)
Dropped,[8] # (%)	8 (0.09)
Rescheduled, # (%)	2 (0.02)
Failed Skills, # (%)	1 (0.01)

Source: Stonewall Analytics

Crash Severity

As this study examines whether motorcycle training effects the severity of a motorcycle crash, Figure 2 provides a mosaic plot examining these two categorical variables–training and injury severity. While the larger proportion of riders are not associated with motorcycle training, a stepwise appearance begins to emerge as crash severity increases.[9]

Figure 2: Injury Severity Score and Motorcycle Training History (2005-2017)



Source: Stonewall Analytics

[8] Dropped pertains to dropping the course.

[9] The actual effect size of this stepwise appearance is estimated using statistical models later in this report.

Rider Characteristics

When examining motorcycle riders involved in crashes, the large proportion of riders are men (almost 95%). The average age of the motorcycle rider involved in a crash is 41 years. Approximately 10% of motorcycle crashes are associated with alcohol use. Sixty percent of motorcycle riders have a motorcycle endorsement, and the average length of time between the crash and when the rider obtained their motorcycle endorsement is 2.7 years. The study identified approximately 30% of riders had a registered motorcycle at the time of the crash, this low statistic is likely due to the absence of a unique identifier that contains the date of birth for each rider. As Pennsylvania has a partial motorcycle helmet law, almost 55% of all motorcycle crashes between 2005 and 2017, involved a rider wearing a motorcycle helmet. Nearly all motorcycle crashes in Pennsylvania within the study's timeframe were Pennsylvania residents. Just over 20% of all motorcycle crashes in Pennsylvania involved excess speed.

Table 4: Rider-Related Crash Descriptive and Summary Statistics (n = 29,646)

Characteristic	Value
Gender	
Male, # (%)	27,790 (94.7)
Age, mean (SD)	41.4 (14.6)
Alcohol-involved, # (%)	3,199 (10.8)
Drug-involved, # (%)	452 (1.5)
Motorcycle License	
Riders with motorcycle license,[10] # (%)	16,287 (60.0)
For riders with endorsement, length of time in months between endorsement and crash date, mean (SD)	2.7 (2.7)
Motorcycle Registration	
Riders with a registered motorcycle at the time of crash, # (%)	8,986 (30.3)
Helmet Use	
Riders wearing a helmet at the time of crash,[11] # (%)	14,680 (54.9)
State Residence	
Riders with a Pennsylvania residence involved in a crash in Pennsylvania, # (%)	29,276 (99.9)
Motorcycle Speed	
Crashes where motorcycle speed exceeded the posted speed limit, # (%)	6,881 (23.2)
Passenger Present	
Crashes where a motorcycle passenger was present, # (%)	3,021 (10.1)

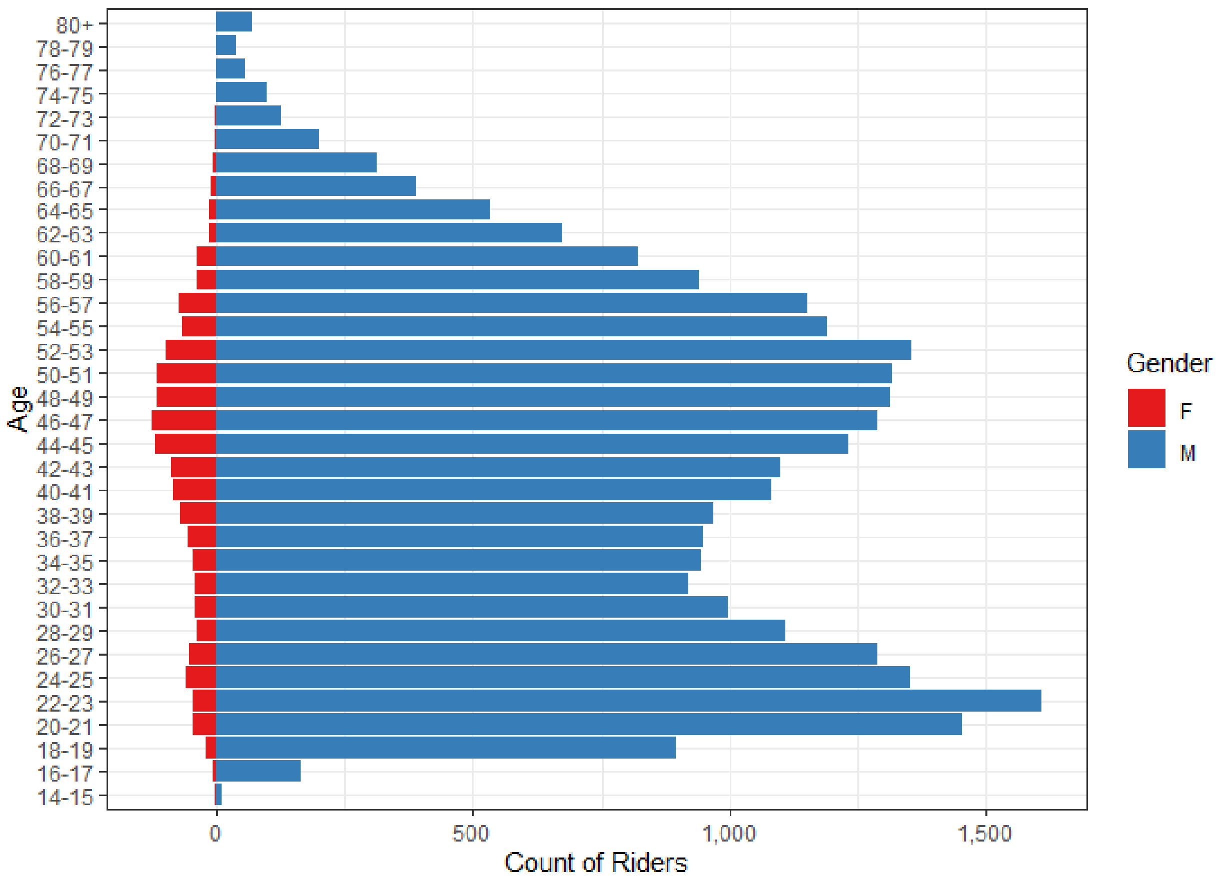
Source: Stonewall Analytics. SD = standard deviation.

While the mean (average) age of motorcycle riders involved in a crash is 41 years, when examining the distribution of age by gender, two aspects are noticeable. First, among men, there is a bimodal distribution among age, with the first mode represented around 22-23 years, and the second mode visible at 52-53 year. Among women, the mode appears at 46-47 years, and is not bimodal as in the case of men.

[10] The remaining 40% either have a motorcycle permit or no motorcycle licensing activity based upon data matching; excludes riders that are deceased.

[11] In 16.4% (4,387) of the riders involved in a crash, the rider's helmet status was unknown.

Figure 3: Age and Gender of Riders Involved in a Motorcycle Crash (2005-2017)



Source: Stonewall Analytics

Motorcycle

Motorcycles are oftentimes classified by their type (e.g., cruiser, sport bike, dual sport) and engine displacement (measured in cubic centimeters, or CCs). Table 5 provides a breakdown of summary statistics for the engine sizes of motorcycles involved in a crash.

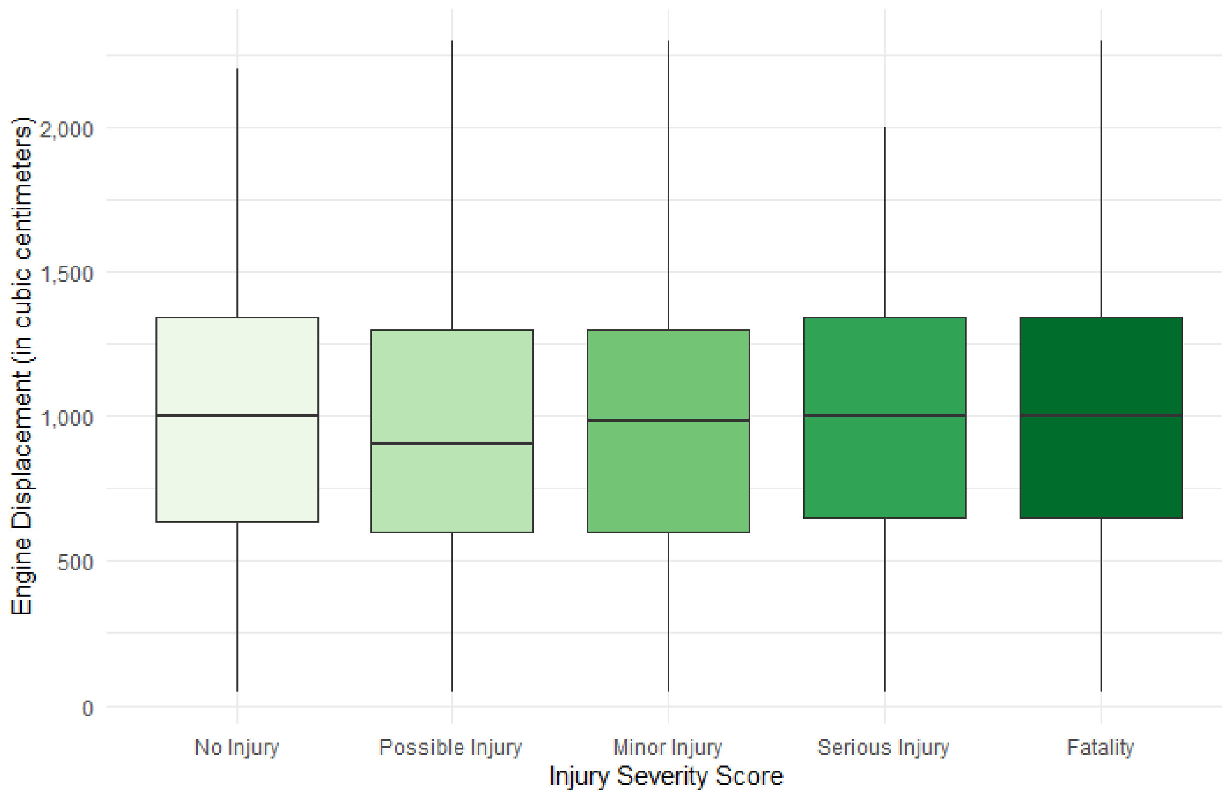
Table 5: Summary Statistics for Engine Displacement of Motorcycle Crashes (n = 29,646)

Measure	**Value (in cubic centimeters)**
Minimum	49
25th Percentile	600
50th Percentile	998
Mean (SD)	973 (429)
75th Percentile	1,340
Maximum	2,000

Source: Stonewall Analytics. SD = standard deviation.

This study identified no relationship between injury severity score and engine displacement. Figure 4 stratifies injury severity score with engine displacement, shown visually as a box plot. The box plot contains a wealth of information – this includes a visual representation within and across categories. For each box, there are three horizontal lines. The bottom-most horizontal line represents the 25th percentile for the engine displacement. The second, or middle, horizontal line represents the 50th percentile (median) for engine displacement. The top of the box represents the 75th percentile for engine displacement. The vertical lines extending from the bottom and top of each box are known as whiskers. The whiskers visually display the data that stretch outside of the 25th and 75th percentiles. A reader can compare the distribution of each box and where the median for all the boxes are located. Large differences in the location of the medians would likely indicate that a strong difference exists in the engine displacement across each category. In this case, the boxes appear nearly identical, which provides strong evidence that engine displacement for a motorcycle involved in a crash does not systematically differ across injury severity scores.

Figure 4: Engine Displacement and Injury Severity Score (2005-2017)

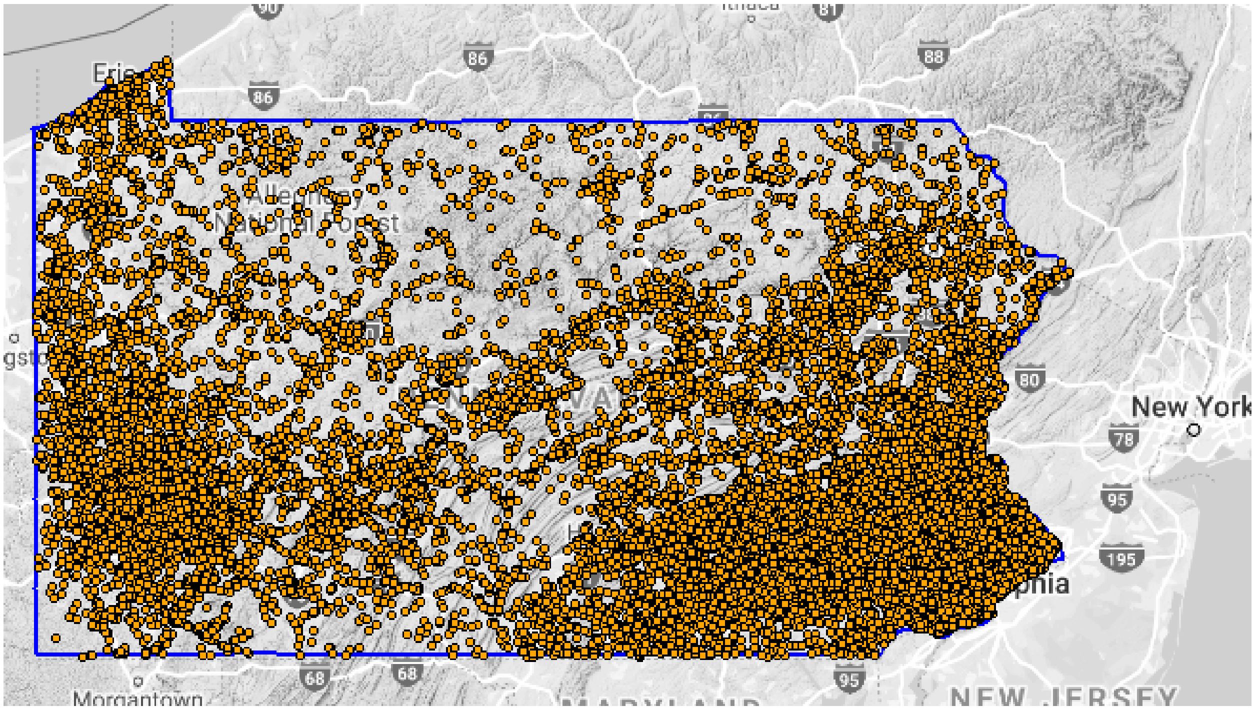


Source: Stonewall Analytics

Roadway

When examining the coordinates (latitude, longitude) of motorcycle crashes across Pennsylvania from 2005 through 2017, it appears that almost no road in Pennsylvania has been spared from a motorcycle crash at some point in time (refer to Figure 5).

Figure 5: Motorcycle Crash Locations in Pennsylvania (2005-2017)

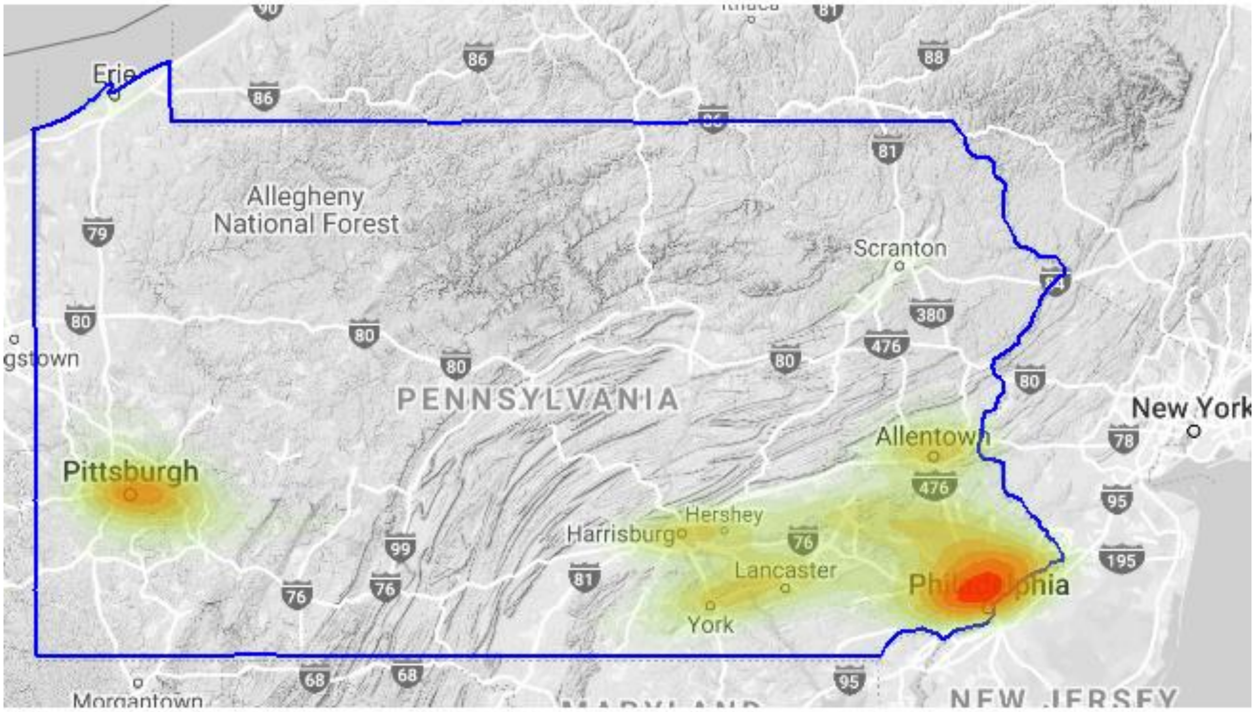


Source: Stonewall Analytics

As the centroids in Figure 5 show the abundance of information, the geographic clusters of crashes become obscured.

Figure 6 calculates the density of the crash area based upon the crash coordinates. The areas in red highlight the densest crash areas, where the yellow indicate a lighter density of crash areas. As expected, the large metropolitan cities within Pennsylvania become the large clusters for motorcycle crashes.

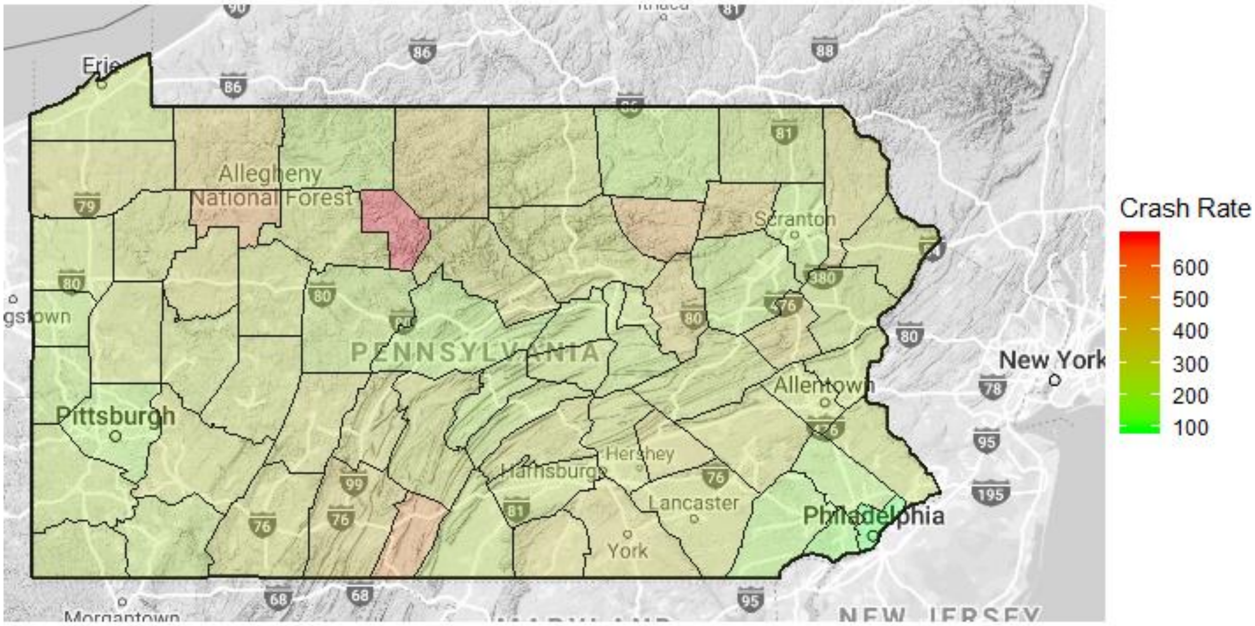
Figure 6: Geometric Density of Motorcycle Crash Locations in Pennsylvania (2005-2017)



Source: Stonewall Analytics

The high concentration of crashes in large cities is likely attributable to the high number of riders residing in the cities as compared to other areas in Pennsylvania. To evaluate whether there are other geographic differences, aside from population-driven factors, in motorcycle crashes, Figure 7 examines the mean (average) annual motorcycle crash rate between 2005 and 2017. The crash rate is constructed by normalizing the county-level crash data using 2017 county population estimates from the Census Bureau. The areas in red highlight the counties with higher crash rates, whereas the green counties indicate a small crash rate. The crash rate denominator is per 100,000 county residents.

Figure 7: Mean Annual County Motorcycle Crash Rate (2005-2017)



Source: Stonewall Analytics. Crash rate is per 100,000 county residents using 2017 Census Bureau population estimates.

Comparing Figure 7 versus Figure 6, when controlling for county-level population the large cities in Pennsylvania have some of the lowest crash rates.

When examining the motorcycle crash types in Table 6, the vast majority of crashes involve non-collisions (almost 29%), angled crashes (almost 25%), and hitting a fixed object (nearly 18%).

Table 6: Motorcycle Crash Type[12] (n = 29,620)

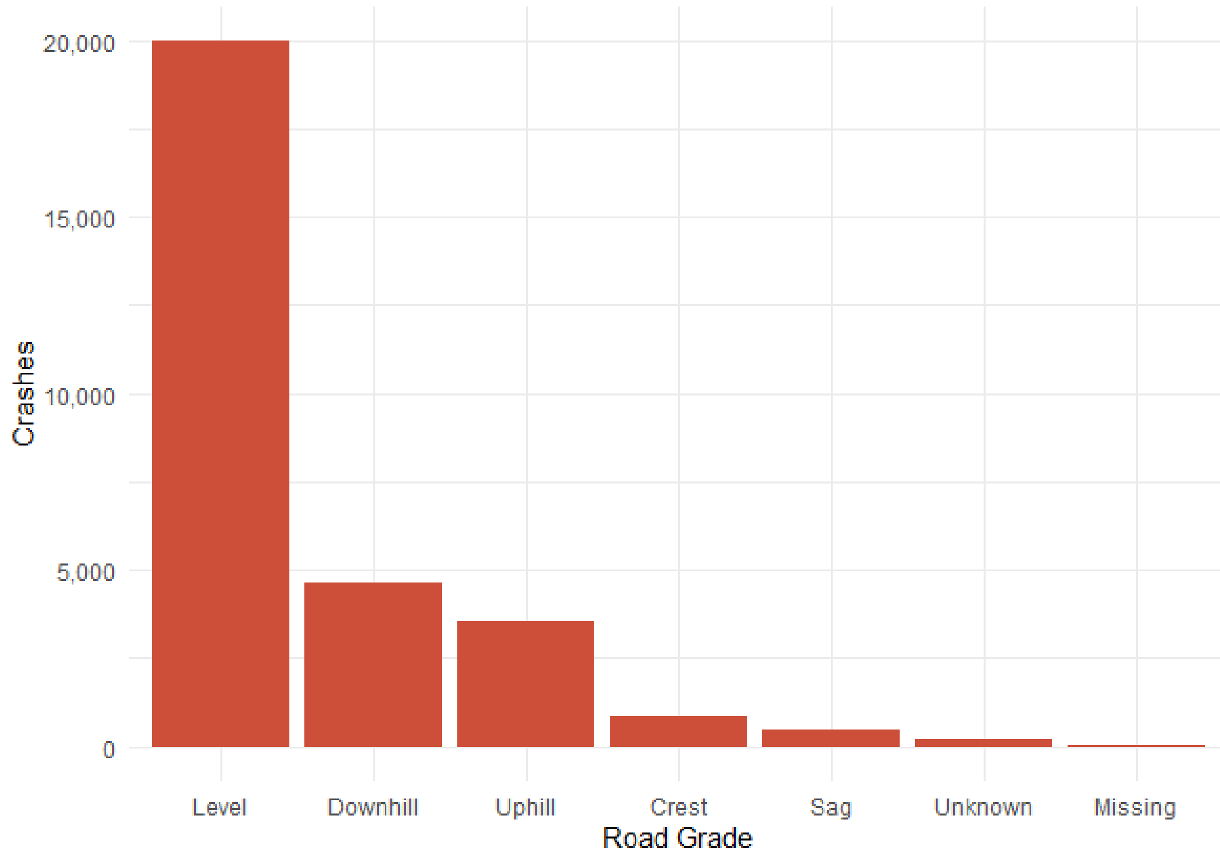
Type	Value
Non-collision, # (%)	8,565 (28.8)
Rear-end, # (%)	3,645 (12.2)
Head-on, # (%)	1,003 (3.3)
Backing, # (%)	37 (0.1)
Angle, # (%)	7,350 (24.7)
Sideswipe (same direction), # (%)	986 (3.3)
Sideswipe (opposite direction), # (%)	539 (1.8)
Hit fixed object, # (%)	5,228 (17.6)
Hit pedestrian, # (%)	134 (0.4)
Other or unknown, # (%)	2,133 (7.1)

Source: Stonewall Analytics

Figure 8 presents a bar plot of the road grade for motorcycle crashes – the number of motorcycle crashes that occur on a level road far surpass any other road grade type.

[12] There were 26 observations where the collision type was not classified.

Figure 8: Motorcycle Crash Road Grade (2005-2017)



Source: Stonewall Analytics

Much like the trend in road grade, the largest proportion of motorcycle crashes occur in mainly one category of road conditions – dry roads (93%).

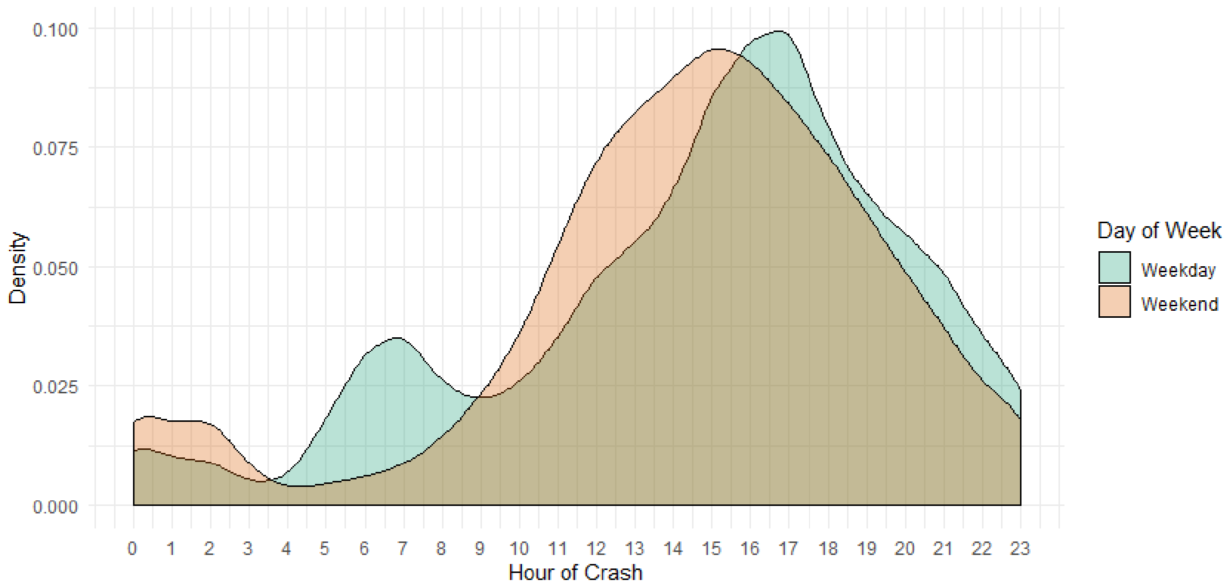
Table 7: Road Conditions in Motorcycle Crashes (n = 29,620)

Condition	Value
Dry	27,665 (93.3)
Wet	1,214 (4.0)
Sand / mud / dirt	441 (1.4)
Snow covered	4 (0.01)
Slush	3 (0.01)
Ice	6 (0.02)
Ice Patches	22 (0.07)
Water	23 (0.07)
Other	242 (0.8)

Source: Stonewall Analytics

As information on the day of the week pertaining to the crash was made available, Figure 8 presents a density plot with two curves – one involves the distribution of crashes that took place during the week and the other curve displays the distribution of crashes to occurred on the weekend. These curves are represented by the time of the day the crash took place (the hour). While the two distributions are similar, a bimodal distribution is present on weekdays, whereas only one mode appears present for crashes involving the weekend. The first (and smaller) hump on weekdays likely involves morning commuters. The second larger hump, evident in both the weekday and weekend curves, represents the late-morning to late-evening riders. Of note, when examining the horizontal axis of Figure 9, 15 would correspond to a crash hour of 3:00 pm.

Figure 9: Day of the Week and Time of Day in Motorcycle Crashes (2005-2017)



Source: Stonewall Analytics

While this study is not specifically focused on single- versus multi-vehicle motorcycle crashes, it is interesting to note that 50% of all motorcycle crashes only involve a single vehicle. Table 8 provides an overview of summary statistics associated with the number of total vehicles involved in a motorcycle crash.

Table 8: Summary Statistics on Number of Vehicles in the Crash (n = 29,646)

Measure	Value
Minimum	1
25th Percentile	1
50th Percentile	1
Mean (SD)	1.5 (0.5)
75th Percentile	2
Maximum	8

Source: Stonewall Analytics. SD = standard deviation.

Utilizing crash coordinates and the address of the rider's residence, the distance of the crash location from the rider's residence was calculated using an application programming interface (API) with Google Maps. Apparent in Table 9 is the relatively short distance between a crash location and the rider's residence. While half of all motorcycle crashes in Pennsylvania occur within seven miles of the rider's residence, 75% of all crash occur within 15 miles.

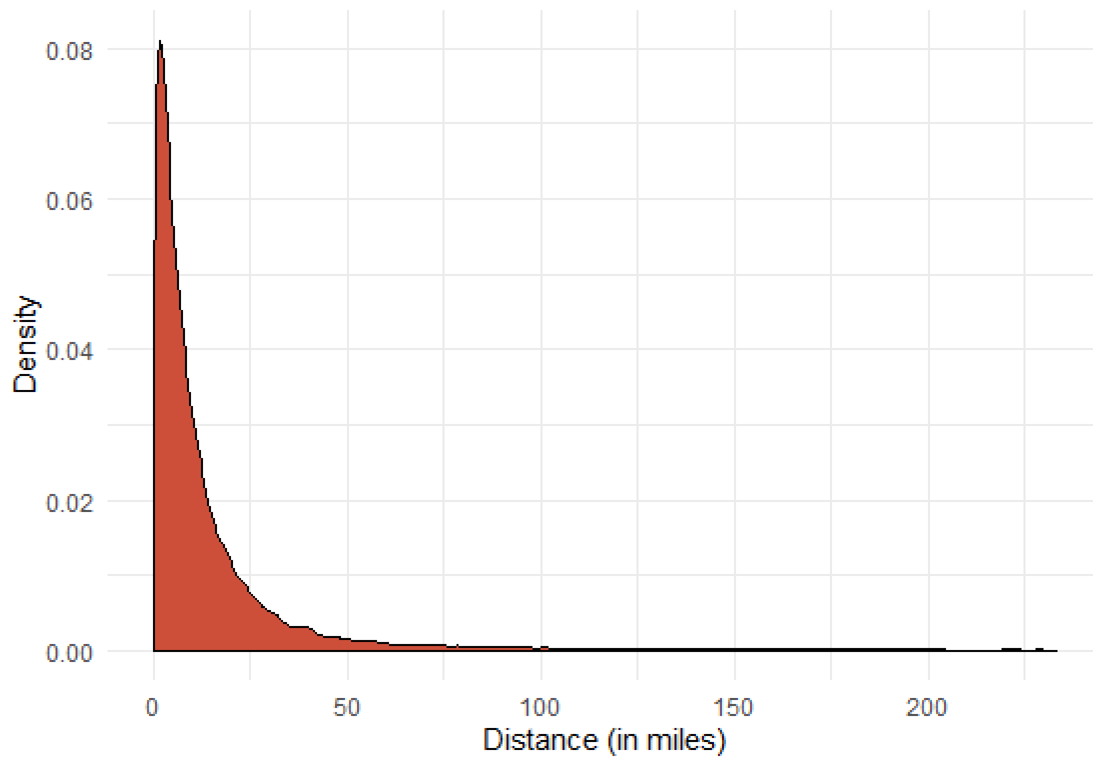
Table 9: Summary Statistics on Crash Location Distance from Residence (n = 29,646)

Measure	Value (in miles)
Minimum	0
25th Percentile	2.7
50th Percentile	6.9
Mean (SD)	14.2 (23.4)
75th Percentile	15.6
Maximum	233.0

Source: Stonewall Analytics

Figure 10 provides a density curve on the distance from the crash location and the motorcycle rider's residence, measured in miles. This figure underscores the information provided in Table 9 – the close proximity to a rider's house from the crash location comprises the vast majority of cases.

Figure 10: Density Curve on Crash Location Distance from Residence (2005-2017)



Source: Stonewall Analytics

Statistical Model Results

For the ordinal logistic regression model, an unadjusted model and an adjusted model was constructed. The unadjusted model only examines the effect of rider training on crash severity. The adjusted model examines the effect of rider training on crash severity, while also controlling for other factors involving the rider, the roadway, and other crash characteristics that could bias the results of rider training on crash severity if not included in the statistical model.

In ordinal logistic regression and other forms of logistic regression, such as binomial or multinomial logistic regression, model results are presented as expected log odds. While the natural logarithm is a transformed scale of a numeric value, the interpretation of a natural logarithm of an odds ratio is difficult to comprehend. To overcome this difficulty, logistic regression models usually transform the model results to discuss the effect size of the model estimates in terms of odd ratios. This transformation is completed by exponentiating the model results. Table 10 provides the unadjusted model results which examine the effect of motorcycle training on crash severity. The unadjusted model only contains one independent variable – in this case, training. The odds ratio is 0.80, which indicates that motorcycle training has a negative effect on crash severity. Stated another way, for riders that have completed motorcycle training, the odds of being involved in a more severe motorcycle crash is 20% lower than riders that did not complete motorcycle training. This finding in the unadjusted model is statistically significant.

Table 10: Unadjusted Ordinal Logistic Regression Model Results

Coefficient	**Odds Ratio**	**Odds Ratio 95% Confidence Interval**
Training		
Completed	0.80 ***	0.76, 0.84
No Training	Ref	-

Source: Stonewall Analytics. Ref = reference. *** = p-value < 0.001, ** = p-value < 0.01, * = p-value < 0.05.

In order to account for other factors that could potentially explain the effect of motorcycle crash severity, Table 11 presents an abbreviated version of the ordinal logistic regression model results. When examining the effect of motorcycle training on crash severity in the adjusted model, the effect of motorcycle training is smaller with an odds ratio of 0.90. While the interpretation of this coefficient in the model would tend to suggest that motorcycle riders that completed training, the odds of being in a more severe motorcycle crash is 10% lower than motorcycle riders that did not complete motorcycle training (holding all other variables constant); the finding in this model is also statistically significant. If the sample were to be repeated 100 times, 95 out of 100 times we would expect the odds ratio to range between 0.85 and 0.96. Any time an odds ratio confidence interval contains the value 1.0, the odds ratio estimate is not statistically significant; an odds ratio of 1.0 is equal to a probability of 50%. In this case, however, the odds ratio confidence interval does not contain 1.0 (which also indicates the model is statistically significant).

Table 11: Adjusted Ordinal Logistic Regression Model Results[13]

Coefficient	**Odds Ratio**	**Odds Ratio 95% Confidence Interval**
Training		
Completed	0.90 ***	0.85, 0.96
No Training	Ref	-

Source: Stonewall Analytics. Ref = reference. *** = p-value < 0.001, ** = p-value < 0.01, * = p-value < 0.05.

Previous research has demonstrated the protective benefits of wearing a motorcycle helmet when a rider is involved in a crash.[14] Reinforcing this previous research, this study finds that when riders are wearing a helmet at the time of their crash, the rider's odds of being in a more severe crash are reduced

[13] Please refer to the appendix for a listing of all model coefficients used to construct the adjusted model.
[14] Peng et al. (2017). Universal motorcycle helmet laws to reduce injuries: A community guide systematic review. *American Journal of Preventive Medicine*, 52(6), 820-832. doi: 10.1016/j.amepre.2016.11.030

by 26% as compared to riders that were not wearing a helmet at the time of their crash. With regard to licensing, for riders that had a motorcycle license or permit at the time of their crash, the rider's odds of being involved in a more severe motorcycle crash are reduced by seven percent, as compared to riders that did not have a motorcycle license of permit.

CONCLUSION

This study has found that when controlling for a multitude of factors, to include rider and crash characteristics, motorcycle training does have a statistically significant effect on reducing crash severity for motorcycle crashes that took place in Pennsylvania from 2005-2017. This study examined many factors associated with motorcycle crashes that revealed several interesting findings. For instance, the close proximity between the rider's residence and the crash location, while not new to motorcycle crash research, does reinforce the notion that motorcycle crashes occur close to one's home. Furthermore, among men, there are two age groups that comprise the majority of motorcycle crash victims – men in their early-20s and men in their mid-50s. Additionally, alcohol-involved motorcycle crashes are relatively high as compared to alcohol-involved car crashes.

This study was aided by the large sample size of available crash data made available for this project – this is certainly one of many strengths in this analysis. It is prudent to highlight the limitations of this study and to point out how the limitations could negatively impact the study's findings and conclusions. One limitation of this study is the dependent variable and how it was recorded. While numerous agencies and personnel report on crash severity, the reliability and accuracy of those scores captured in the crash database have no way to be independently verified. A main assumption for using ordinal logistic regression models is the scale on which the dependent variable changes, in this case injury severity score, is proportional as it moves categories. This assumes that moving from a crash with no injuries has the same proportion effect as moving from a crash with severe injuries to a crash with a fatality. Future studies should examine the factors associated with multi-vehicle collisions and also what factor, if any, motorcycle training has on reducing motorcycle crashes from occurring, not just the crash severity. The data also cannot control for the riding history and frequency of a motorcycle rider. While a motorcycle rider may have a proper motorcycle endorsement and registration, this does not correlate to a rider that rides daily versus a rider that only rides a handful of times in any given year. Another limitation is the ability to retain data and link a higher proportion of riders across multiple datasets for the most recent years of study. This aspect is evident in the linear examination of crashes across the corresponding study years in Table 2, specifically 2005 and 2006.

Based upon the findings from this work, the following subsections provide recommendations for both the PennDOT motorcycle data and motorcycle rider-related policy aspects for Pennsylvania riders.

Data Recommendations

PennDOT possesses robust datasets covering aspects of licensing, registration, motorcycle training, and motorcycle crash data. These data were used extensively in this project and will retain merit in future studies too. The following recommendations are based upon the experiences of the project's authors. These recommendations would not only benefit future studies but could help unify the data sharing within PennDOT.

1. *Revolve the data around the person and not the event.*

   Whether dealing with licensing, vehicle registration, motorcycle training, or motorcycle crashes, all events can be tied back to an individual. If the data for each topic were to revolve around the person (see recommendation # 2 below), then the data can be linked from its onset across all categories involving transportation-related activities. Having separate datasets that are not linked to an individual makes it difficult to identify various categories of interest (e.g., the ability to quickly identify riders that do not have motorcycle license but have a registered motorcycle license).

2. *Implement a unique person identifier that is consistent across all PennDOT datasets.*

   An initial phase of this project entailed linking motorcycle riders across licensing, registration, training, and crash datasets. This was performed by creating a unique identifier for each person which either consisted of (1) the rider's last name, first name, date of birth, or (2) the rider's last name, first name, and the first 25 characters of the rider's home address. Some weaknesses to these unique identifiers consisted of riders with the same first name, last name, and date of birth. Also, very few riders reside at the same residence while they live in Pennsylvania, so using partial characters of a physical address also has drawbacks. Additionally, the project authors recommend the unique identifier not be the driver's license number, as some individuals that have transportation-related activity will not have a valid or current driver's license.

   Several options for an identifier exist. First, the unique person identifier could be known to the individual (i.e., a similar number to a social security number or driver's license number), or it could be applied in PennDOT systems unbeknownst to the individual. Applying a unique identifier in systems-only use is popular in applications where individuals are linked across datasets and over time. For instance, the US Census Bureau used probabilistic matching to be able to track survey respondents across multiple datasets.[15] This unique identifier is based upon a person's name, social security number, gender, and all residence addresses where an individual may have lived. Using an algorithm, a probability is then assigned to where an individual is matched across multiple datasets. The use of a unique identifier, known to the individual, but not tied to a driver's license number or social security number is also possible. While perhaps cumbersome for the individual to remember another identifier, this identifier could be applied across all state-wide systems, not just transportation-related data systems. For example, use of an identifier in this nature would reduce the probability of only having an identifier for those residents that drive (which excludes non-driving residents).

   It is beneficial to outline the intricacies and highlight the caveats associated with a unique identifier. In the case where the identifier is unknown to the individual and is applied only to state-wide data systems, the probability exists that an incorrect record could be matched to the individual. While this threshold could be minimized to a great extent using the algorithm, this probability of misassignment can only be reduced, and not fully eliminated. The cost of having an incorrect assignment to an individual's record could be detrimental to the individual in question. Similar to having incorrect information reported in one's credit report, incorrect records tied to the unique identifier could also negatively impact one's livelihood. In cases where the unique identifier is known to the individual, there are cases where the unique identifier is not applied in cases where it is needed. Specific to this project, an extensive amount of data analysis was performed using PennDOT's crash dataset. This dataset contained a unique identifier that was consistent across all crash-related datasets. In the event where a rider that does not have unique identifier (e.g., the rider is an out-of-state rider involved in a motorcycle

[15] Wagner, D. & Lane, M. (2014). The Person Identification Validation System (PVS): Applying the Center for Administrative Records Research and Applications' (CARRA) Record Linkage Software. CARRA Working Papers 2014-01, Center for Economic Studies, U.S. Census Bureau. Obtained from https://ideas.repec.org/p/cen/cpaper/2014-01.html.

crash), then this data could potentially be lost. To overcome this possibility, a system-generated unique identifier could be applied in cases where the individual does not have a Pennsylvania-issued identifier.

3. *Capture detailed training data using required / mandatory data entry fields.*

   The motorcycle training data provided by PennDOT contained two versions. The first version captured general data over an extended period of time. The second version, which began in 2016 contained detailed training information for the training programs. Unfortunately, not all data fields were used consistently to create unique identifiers of each rider, which resulted in the inability to utilize the detailed dataset in this project. Improving the detailed training dataset where all fields are required / mandatory entries is recommended. While there is a number of available database formats available for use, utilizing any database format that mandates entry for each field is highly recommended (the current format was provided as Microsoft Excel Workbook where fields could be omitted).

Motorcycle Rider-Related Policy Recommendations

The following motorcycle rider-related policy recommendations are made based upon findings from this study. While some states have employed motorcycle rider-related changes through enactment and enforcement of state laws, others have opted for change through non-legislative means. A number of options exist to entice or change behaviors in the absence of enforcing new or more stringent laws. For instance, most motorcycle insurance policies offer a premium discount for riders that have completed formal motorcycle training.[16] Encouraging the pursuit of motorcycle safety training can be achieved through means such as discounts and rebates, as long as the individual perceives this benefit to be equal to or greater than the cost (not just the actuarial cost) of completing the training. Another alternative to legislation is the use of education – targeted public health marketing campaigns. These campaigns could be employed to persuade individuals to change their behaviors or improve their riding skills. The use of educational activities is evident through public health marketing campaigns targeting against the use of tobacco, encouraging the use of seat belts when driving, or not drinking and driving. Of note, these three previous examples were pursued through a combination of federal and state legislation in conjunction with education-related marketing campaigns.

When a change in one's action or behavior occurs, this is oftentimes accompanied by an unintended consequence – outcomes of an action that are not originally intended or foreseen. An example of an unintended consequence includes when individual states have repealed motorcycle helmet laws; there is approximately a 10% increase in the availability of organ donations as a result of helmetless riders dying in motorcycle crashes. Obviously, the intent of repealing a motorcycle helmet law is not to increase the supply of organ donation, but this highlights a beneficial externality to organ donor recipients.[17] For each of the following recommendations presented here, potential unintended consequences are also outlined.

[16] Huang, S., Jeyaraj, V., Emiliano, V., & Lapidus, G. D. (2008). Modeling motorcycle insurance rate reduction due to mandatory safety courses. Society of Actuaries. Retrieved from https://www.soa.org/globalassets/assets/files/static-pages/research/arch/2012/arch-2012-iss1-huang-et-al-paper.pdf.

[17] Dickert-Conlin, S., Edler, T., & Moore, B. (2011). Donorcycles: Motorcycle helmet laws and the supply of organ donors. *The Journal of Law and Economics*, 54(4), 907-935.

1. *Encourage greater adoption of wearing a motorcycle helmet when riding.*

   This study demonstrates that when controlling for a variety of factors, to include a rider's motorcycle training history, their license status, their motorcycle registration status, the type of collision, the rider's age and whether excess speed was involved at the time of the crash, the use of motorcycle helmets are associated with a reduction in the odds of being in a more severe motorcycle crash by 26 percent. At this time, there is no recommendation on the type of motorcycle helmet to wear (i.e., full versus partial) as the type of motorcycle helmet used when the rider crashed was not evaluated.

   Pennsylvania currently has a partial helmet law. In 1968, Pennsylvania passed law that mandated the use of motorcycle helmets – this law was changed in 2003. Riders 21 years or older, or riders that have greater than two years of riding experience, or riders that have completed a motorcycle safety course approved by PennDOT are exempt from wearing a motorcycle helmet.

   This study found the use of a motorcycle helmet is associated with reduced odds of being in a more severe motorcycle crash, which was estimated based upon the ordinal ranking of injury severity scores. The following select states have undergone changes in their motorcycle helmet laws over time and the associated effects on rider safety, injuries, and deaths are well documented.[18]

   - **Nebraska**
     Law in 1989 reinstated the use of motorcycle helmets (rescinding a previous 1977 law). The state experienced a 22% reduction in severe head injuries in motorcycle crashes following implementation of the law.

   - **Texas**
     Partial helmet law introduced in 1977, which replaced a previous universal helmet law. The partial helmet law was associated with a 35% increase in motorcycle fatalities. In 1989, the universal mandate was re-established – this coincided with a decrease in serious motorcycle accidents by 11%. A partial helmet law was re-introduced and a year after the law's implementation, motorcycle crash fatalities increased 31%.

   - **Kentucky**
     Universal helmet law was repealed in 1998. Motorcycle-related fatalities increased nearly 50% following the repeal.

   - **Louisiana**
     Universal helmet law was repealed in 1999. Motorcycle-related fatalities increased 100% shortly following the repeal of the law.

[18] Insurance Institute for Highway Safety (IIHS). Motorcycles. Obtained from https://www.iihs.org/topics/motorcycles#helmet-laws.

A potential unintended consequence of this recommendation is the presumption that free will and choice among motorcyclists not to wear a helmet is eroded. One could assume that based upon the educational outreach and public health awareness messaging campaigns on the benefits of wearing a motorcycle helmet, each motorcycle rider should be fully informed on the benefits and risks of wearing a helmet, and the rider's decision to not wear a helmet is based upon their careful calculation of the risks and benefits involved.

Re-examining the counter to the previous example that led to an increase in supply for organ donations when states repeal motorcycle helmet laws, states could potentially experience a slight decrease in the supply of available organ donors if more riders opted for wearing motorcycle helmets. Previous research noted that a large proportion of deceased motorcyclists were younger in age, which increased the probability for viable organ donation.[19] In the findings from this report, we found that a bimodal representation of motorcyclist crashes were present among men in their mid 20s and also men in their mid 50s.

2. *Encourage motorcycle safety training prior to obtaining a motorcycle license for all new riders.*

This study demonstrated a statistically significant reduction in the odds of being in a more severe motorcycle crash by almost 10 percent when the rider has completed motorcycle safety training. Encouraging all new motorcycle riders to undergo motorcycle safety training would assist in reducing a rider's odds of being involved in a more serious motorcycle crash across the State. An advantageous to implement training is when a rider first learns or begins to ride a motorcycle. Of note, this recommendation coincides with the subsequent recommendation of mandating refresher motorcycle training.

While seemingly benevolent in principle, encouraging more riders undergo state-sponsored motorcycle safety training prior to a new rider receiving a license could also pose unintended consequences. For instance, if the burden to undergo and complete motorcycle safety training is perceived as too high for riders, new motorcyclists could forgo the entire motorcycle licensing process and ride without a motorcycle permit or license. As demonstrated in the statistical models of this study, a seven percent reduction in the odds of being involved in a more severe motorcycle crash was associated with riders that had a motorcycle license or permit, as compared to those riders that did not have a motorcycle license or permit. Some states, such as Rhode Island and Connecticut, require the completion of state-sponsored motorcycle training in order to receive a motorcycle license.[20,21] Specific to Rhode Island, however, not all riders learned to ride using state-sponsored motorcycle training courses,[22] which highlights the potential for some riders to forgo this training and ultimately forgo obtaining a motorcycle license.

[19] Ibid.
[20] State of Rhode Island, Department of Revenue, Division of Motor Vehicles. Motorcycles: Forms and Fees. Obtained from http://www.dmv.ri.gov/licenses/motorcycles/.
[21] State of Connecticut, Department of Motor Vehicles. Obtaining a Motorcycle Endorsement. Obtained from https://portal.ct.gov/DMV/Licenses/Licenses/Motorcycle-License/Motorcycle---Endorsement---Obtaining.
[22] Ranney, M., Mello, M. J., Baird, J. B., Chai, P. R., & Clark, M. A. (2010). Correlates of motorcycle helmet use among recent graduates of a motorcycle training course. *Accident Analysis & Prevention*, 42(6), 2057-2062. doi: 10.1016/j.aap.2010.06.017

3. *Encourage refresher motorcycle safety training every four years to coincide with license renewal timelines.*

   As Pennsylvania motorcycle safety training is associated with a reduction in the odds of being involved in a more serious motorcycle crash, encouraging refresher training to coincide with the expiration of a Pennsylvania driver's license is highly recommended.

   Similar to the previous recommendation, a potential unintended consequence from this recommendation is riders could also forgo the training (after receiving their motorcycle license) and not complete the refresher training.

Closing Remarks

It would be remiss to not acknowledge that one motorcycle crash is one too many, and that each motorcycle crash–whether in Pennsylvania or across the country–has a profound impact upon the rider, and the rider's family and friends. It is these reasons that reinforce the importance of this work in assessing the effect of motorcycle training on reducing crash severity in Pennsylvania. With continued support and awareness of this topic, additional efforts can be employed to reduce motorcycle crashes to ensure that while risk of a crash cannot be completely eliminated, measures can be taken to reduce that risk such that each rider can return home safely following a motorcycle ride.

APPENDIX

Table 12 contains the complete, adjusted ordinal logistic regression model results as a snapshot of this table was displayed in the results section (please refer to Table 11). The results below are displayed as expected log odds – the values are not converted to odds.

Table 12: Adjusted Ordinal Logistic Regression Model Results – Complete Model Output

Coefficient	Value	Standard Error	Z value	95% Confidence Interval
Training				
Completed	-0.09 ***	0.03	-3.4	-0.15, -0.04
No Training	Ref	-	-	-
Licensing				
Motorcycle license or permit	-.07 *	0.03	-2.4	-0.13, -0.01
No license activity	Ref	-	-	-
Registration				
Registered motorcycle	-.08 **	0.02	-3.4	-0.13, -0.03
Unregistered motorcycle	Ref	-	-	-
Collision Type				
Rear-end	-0.40 ***	0.03	-10.7	-0.47, -0.32
Head-on	0.74 ***	0.06	11.8	0.62, 0.87
Backing	-1.27 ***	0.33	-3.8	-1.92, -0.61
Angle	0.22 ***	0.03	7.5	0.16, 0.28
Sideswipe, same direction	-0.19 **	0.06	-3.0	-0.31, -0.07
Sideswipe, opposite direction	0.24 **	0.08	2.9	0.08, 0.40
Hit fixed object	0.53 ***	0.03	16.4	0.46, 0.59
Hit pedestrian	-2.24 ***	0.17	-12.5	-2.59, -1.89
Other or unknown	0.21 ***	0.04	5.0	0.13, 0.30
Non-collision	Ref	-	-	-
Rider Age	0.01 ***	0.001	9.6	0.006, 0.009
Federal FAST Act Indicator	0.22 ***	0.03	7.6	0.16, 0.28
Motorcycle Helmet				
Worn	-0.30 ***	0.02	-14.0	-0.34, -0.26
Not worn	Ref	-	-	-
Excess Speed				
Yes	1.15 ***	0.04	24.1	1.05, 1.24
No	Ref	-	-	-

Source: Stonewall Analytics. Ref = reference. *** = p-value < 0.001, ** = p-value < 0.01, * = p-value < 0.05.

Select Legislative and Program History for Motorcycle Riding in Pennsylvania[23]

The following bulleted years and subsequent descriptions provide a highlight into select, relevant legislative and program history as it relates to motorcycle riding in Pennsylvania.

- 1984
  Pennsylvania Motorcycle Safety Program (PAMSP) was created. A $2.00 annual fee was added to motorcycle licensing and registrations to fund the program.

- 1985
  Operation of PAMSP begins.

- 2002
  Increased fee for motorcycle permits and licenses from $2 to $5 annually.

- 2003
  Motorcycle Helmet law was passed. This law allows individuals 21 years or older with more than 2 years of riding experience to ride a motorcycle without a helmet.

- 2012
  HB254 requires all 16 and 17 years old that wish to obtain their motorcycle license to do so through PAMSP.

- 2014
  HB892 limits the number of times an individual can reapply for their motorcycle learners permit.

- 2019
  HB384 stiffens penalties for operating a motorcycle without the proper endorsements.

[23] Stonewall Analytics credits PennDOT for the information provided in this section.