Final Report

Understanding Florida Motorcycle Crashes and Injury Outcomes Using the Motorcycle Crash Causation Study (MCCS) Dataset

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Understanding Florida Motorcycle Crashes and Injury Outcomes Using the Motorcycle Crash Causation Study (MCCS) Dataset

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With the MCCS dataset mapped to the Florida crash database, an effort to obtain a complementary understanding and knowledge of characteristics related to locational, temporal, trip, motorcycle, injury, and contributing crash factors by most harmful event was conducted to lead to informed decision-making by the Florida Department of Transportation (FDOT) on strategies, countermeasures, and policy (e.g., design standards for motorcycles in the Manual on Uniform Traffic Control Devices [MUTCD]).</td></tr>
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EXECUTIVE SUMMARY

Compared to passenger car occupants, motorcyclists are more likely to be seriously or fatally injured in traffic crashes. During the past decade, Florida has observed a continuous increase in registered motorcycles and drivers with motorcycle endorsements. As of July 2019, Florida had 622,347 registered motorcycles, representing about 3.5 percent of registered vehicles in the state, and more than 1.3 million licensed drivers with a motorcycle endorsement. Unfortunately, Florida has also experienced a corresponding increase in motorcycle crashes and fatalities, with about 550 motorcycle fatalities, including passengers, in 2019. In the same year, motorcyclists represented about 17 percent of Florida traffic fatalities, but motorcycles accounted for only 3.5 percent of all registered motor vehicles and less than 1 percent of vehicle miles traveled (VMT) in Florida.

The Florida Strategic Highway Safety Plan (SHSP) recognizes the significance of motorcycle safety and endeavors to prevent motorcyclist injuries and fatalities. A known challenge in improving motorcycle safety is the difficulty associated with identifying primary causes and contributing factors in motorcycle crashes and injury outcomes.

The Federal Highway Administration (FHWA) conducted the Motorcycle Crash Causation Study (MCCS) in Orange County, California, over a five-year period (2010–2015), with the final dataset including 351 on-scene crash investigations and 702 control cases. FHWA recently completed basic tabulation of the collected data, including a data dictionary, and made the dataset available to the public. This detailed crash database can be helpful to understand confounding factors for motorcycle crashes, allowing for increased insight. By utilizing MCCS data in conjunction with Florida motorcycle crash data (2011–2019), this study aimed to expand the knowledge and understanding of Florida motorcycle crash causation and provide helpful information to mitigate common motorcycle crash types in Florida.

Seven completed studies were identified that used MCCS data to explore contributing factors to MCCS crash frequency and injury outcomes. The crash type "left-turn approach across the path of a motorcycle" was identified as a common motorcycle crash type in those studies. A Web-based survey on research efforts with MCCS data was completed by members of AASHTO's Committee on Safety (COS) and the TRB Motorcycle and Moped Safety (ANF30) Committee. About 43 percent of respondents indicated that they were very familiar or moderately familiar with the FHWA MCCS, and most respondents (86%) said that they were not aware of any ongoing or foreseeable research projects or programs using the MCCS dataset.

Motorcycle crashes in Florida between 2011 and 2019 were analyzed. The three primary types of motorcycle crashes were left-turn approach across the path of a motorcycle (LTAP), motorcycle following too closely (FTC), and single motorcycle run-off-road crashes (ROR). Motorcycle rider age, gender, helmet use, and alcohol or drug involvement were tabulated to explore their distributions and potential associations with crash injury severities for the top three motorcycle crash types. In single motorcycle crashes, running off the roadway was the most common circumstance, especially on horizontal curves. In multiple vehicle crashes, careless riding was a high-risk contributing factor. The most dangerous and common crash scenarios involving a motorcycle were LTAP crashes, which resulted in 893 fatalities in Florida over the 9-year period from 2011–2019. Several limitations were observed while examining Florida crash data, making it difficult to pinpoint specific crash types and scenarios; for instance, "careless riding" was frequently cited by law enforcement in motorcycle crash cases, appearing in over 20 percent of crash reports.

The CUTR research team conducted a comprehensive MCCS data analysis that included filtering MCCS data for primary crash scenarios, analyzing the filtered data, and comparing the data with Florida motorcycle crash data. Additionally, an effort was made to tabulate unique variables that are available only in the MCCS dataset, which granted insight into contributing factors for motorcycle crashes that cannot be assessed using traditional crash databases. The results provided an overall understanding of cause and effect in motorcycle crashes from innovative aspects. It should be noted that the percentage of riders ages 20–29 in MCCS crash cases is about twice the percentage observed for controls. This discrepancy is likely attributable to the MCCS pairing scheme, which matched crash and control cases only by location and temporal factors. As a result, crash-control pairings often involve different age groups and motorcycle types. This means that some comparisons in the initial study design of the MCCS should be treated with caution, as rider age is widely known to be causally associated with motorcycle type and activity.

Distributions of roadway features, environmental features, crash types (single- vs. multiple-vehicle crashes), helmet wearing, riding behaviors, and demographics were compared for Florida motorcycle crashes for 2011–2019 and MCCS crashes. Overall, it appears that the pattern of motorcycle crashes in the two datasets is somewhat different. It is not clear whether this is due to divergent crash reporting practices or the result of sampling error. However, it does mean that it is necessary to evaluate the characteristics of local motorcycle populations and crashes to apply MCCS findings to each state's motorcycle program.

High-risk LTAP motorcycle crashes in Florida were further analyzed to identify associated contributing factors. A binary logistic regression model was developed to estimate the relative crash risk of LTAP crashes at signalized intersections compared to non-LTAP crashes. Results indicate that, compared to non-LTAP crashes, LTAP crashes are more likely to occur between 6:00 PM and 12:00 AM, on roadways with narrow shoulders (<2 ft), in lower Annual Average Daily Traffic (AADT) conditions (<20,000 vph), and among young (age <30) and male riders. For motorcycle crashes occurring at unsignalized intersections, the relationship between relative crash risk and contributing factors is slightly different—e.g., they are more likely to occur between 12:00 PM and 12:00 AM and during early morning (3:00–9:00 AM) on roadways with high speed limits and two-way left-turn lanes (TWLTLs).

Ordered probit injury severity models were built to further predict motorcyclist injury outcomes (possible injury, non-incapacitating injury, incapacitating injury, and fatality). For motorcycle crashes occurring at signalized intersections, severe injury was found to be significantly associated with poor lighting conditions, low-friction roadway surfaces, rural areas, adult and older adult riders, and impaired drivers (alcohol or drugs involved). Similarly, at unsignalized intersections, poor lighting conditions, low-friction roadway surfaces, rural areas, cloudy weather and dry surface conditions, older adult riders, and impaired drivers tend to increase injury outcomes for motorcyclists.

Based on the findings in this report, it is strongly recommended that motorcyclist conspicuity be increased. Other suggested countermeasures include using protected left-turn signal phases to replace TWLTLs with a raised median to separate two-direction traffic, replacing pavement with high-friction aggregates to reduce stopping sight distance, controlling travel speeds at intersections, and improving education programs.

Future efforts to improve motorcycle safety require that multiple parties be involved, and a good foundation to aid in the improvement process relies heavily on the acquisition of good-quality crash data. MCCS data offer an innovative way to collect detailed crash data and identify key contributing or causal factors of motorcycle crashes and their injury outcomes. Using limited crash data for motorcycle safety analysis, this report documents extensive contributing factors and their relationships with Florida motorcycle crashes. Potential countermeasures are also provided, which are expected to be adopted by policymakers, safety engineers, and others to help improve overall motorcycle safety in the community.

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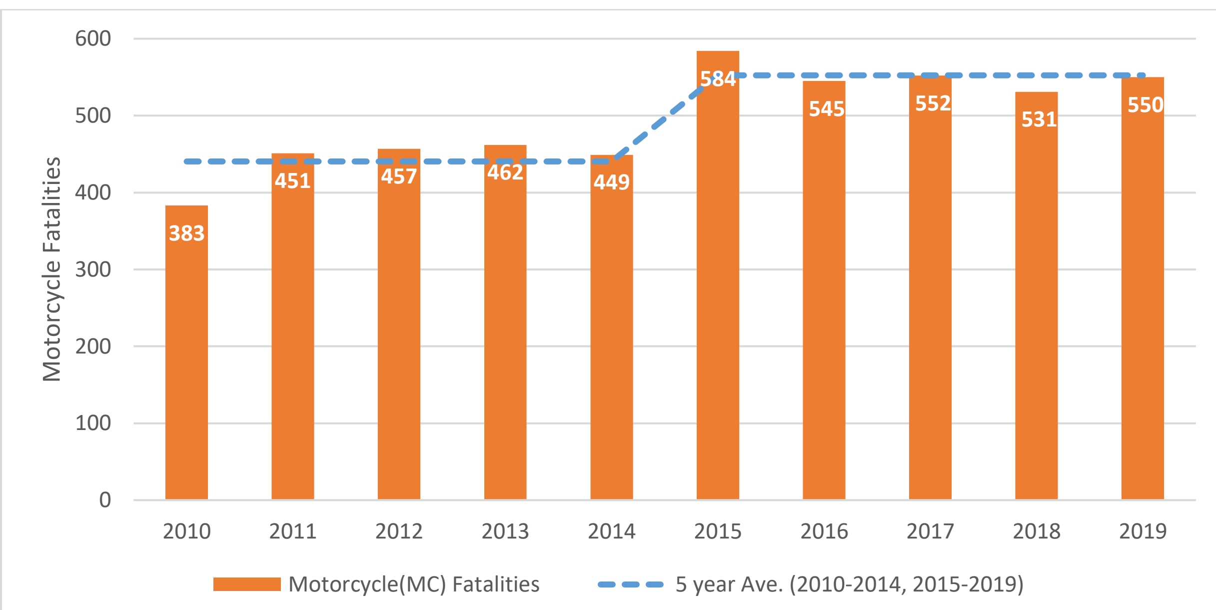
1. Introduction

1.1 Background

Motorcycles as a means of transportation are particularly vulnerable to serious or fatal injuries in traffic crashes. According to a report from the National Highway Traffic Safety Administration (NHTSA), motorcyclists are over 26 times more likely than passenger car occupants to be fatally injured in a traffic crash per vehicle mile traveled (VMT).

Florida's sunny weather, beautiful beaches, and scenic highways make it a popular place for motorcycle enthusiasts, and the state is host to popular motorcycle rallies such as Biketoberfest and Daytona Bike Week. In addition, year-round accommodating weather enables the motoring public to use a motorcycle as their primary mode of transportation. During the past decade, Florida has observed a continuous increase in registered motorcycles and drivers with motorcycle endorsements. As of July 2019, Florida had 622,347 registered motorcycles, representing about 3.5 percent of registered vehicles in the state, and more than 1.3 million licensed drivers with a motorcycle endorsement. Unfortunately, Florida has also experienced a corresponding increase in motorcycle crashes and fatalities, with about 550 motorcycle fatalities, including passengers, in 2019.

In 2019, motorcycles were involved in about 17 percent of Florida traffic fatalities but accounted for only 3.5 percent of all registered motor vehicles and less than 1 percent of VMT in Florida. **Figure 1** shows the trend of motorcycle fatalities in Florida for 2010–2019. Notably, Florida observed a higher number of annual motorcycle fatalities from 2015–2019 compared to the preceding five-year period (2010–2014).



Source: https://www.flhsmv.gov/resources/crash-citation-reports/

Figure 1 Annual motorcycle fatalities, Florida, 2010–2019

The Florida Strategic Highway Safety Plan (SHSP) recognizes the significance of motorcycle safety and endeavors to prevent motorcyclist injuries and fatalities. A known challenge in improving motorcycle safety is the difficulty with identifying primary causes and contributing factors in motorcycle crashes and injury outcomes. Given that traffic crash data are based on Florida police crash reports, they often are limited with regard to the inclusion of specific details unique to motorcycles and motorcyclists; motorcycle crash studies are often constrained by the limited motorcycle-specific information in police crash reports (*1–3*). Therefore, well-designed, comprehensive motorcycle crash data collection and analysis are expected to unlock valuable information, which is needed to develop more focused and robust countermeasures. For example, augmented data collection and analysis will improve our understanding of various safety-enhanced riding behaviors, such as proper Personal Protective Equipment (PPE) and critical maneuvering skills with individual roadway alignments. However, such efforts require significant resources, including dedicated funding and expertise.

In the 30+ years since the in-depth motorcycle study known as the Hurt Study (1981), the Motorcycle Crash Causation Study (MCCS) is the most comprehensive study on data collection and documentation for investigating the causes of motorcycle crashes, rider demographics, and opportunities for countermeasure development. Conducted in Orange County, California, over a five-year period (2010–2015), the final dataset included 351 on-scene crash investigations and 702 control cases. The Federal Highway Administration (FHWA) recently completed basic tabulation of the collected data, including a data dictionary, and made the dataset available to the public. This detailed crash database reveals confounding factors for motorcycle crashes, allowing for a better understanding and increased insight about crash types, vehicle maneuvers, rider demographics, ambient conditions, and injury outcomes from a more in-depth and data-driven perspective. Whereas traditional crash data are unable to shed light on contributing factors related to crash scenes (e.g., tire marks, debris, roadside objects), traffic conditions (e.g., high, medium, or low volume), helmet and motorcycle type, and rider riding characteristics (e.g., riding history, training, license status, emotional state, origin-destination, injury details), MCCS data open up opportunities to understand and enhance motorcycle crash countermeasures (https://highways.dot.gov/safety/motorcycle-crash-causation-study/motorcycle-crash-causation-study). As such, MCCS data are expected to be helpful for expanding our understanding of motorcycle crash causation and are a highly valuable resource given the details available.

To bridge the gap between traditional crash data and the MCCS, this study attempted to use MCCS data to address and complement the limitations of traditional crash data for Florida. Mapping MCCS data elements (1,600+) to the Florida crash database provides increased insight into the types of crashes resulting in particular injury levels for different age groups of riders (under age 30, ages 30–49, age 50+) and for riders of different types of motorcycles (e.g., cruiser, sport, touring, scooter, other); it also brings to light the potential benefits of implementing infrastructure-based countermeasures in Florida.

1.2 Research Objectives

This study aimed to improve understanding about motorcycle crash patterns and causes in Florida by connecting the MCCS dataset to Florida crash data. Efforts are expected to produce tangible outcomes that can be used by traffic safety agencies and stakeholders to improve their strategies, countermeasures, and policy (e.g., design standards for motorcycles in the *Manual on Uniform Traffic Control Devices* [MUTCD]). Given that the MCCS investigated contributing factors leading to crashes, the knowledge gained from this new research effort will identify and quantify the relationships between crash risks and characteristics of motorcyclists.

The major objectives of this research project are the following:

- Review and document motorcycle research literature that used the MCCS dataset.
- Analyze motorcycle crashes in Florida during the past nine years (2011–2019) and identify primary crash types by age group, roadway type, and bike type.
- Analyze the MCCS dataset and document findings.
- Identify extensive contributing factors to Florida primary motorcycle crash and serious injury types based on reconstructed Florida motorcycle crash samples and develop recommendations for potential countermeasures.

1.3 Organization of Report

The organization of this report is as follows: Chapter 2 presents a systematic review of existing literature, including papers and reports using MCCS datasets. Statistical analyses of Florida motorcycle crashes and the MCCS crash dataset are summarized in Chapters 3 and 4, respectively. Chapter 5 presents statistical models to quantify and qualitatively describe left turning across path (LTAP) crash risks, with LTAP crashes representing the primary motorcycle crash type in Florida. Based on the statistical analyses, conclusions and recommendations are provided to improve Florida motorcycle safety in Chapter 6.

2. Literature Review

A comprehensive literature search for completed research projects, academic papers, and other research attempts regarding this topic has been performed. The literature search on the use of the MCCS database was conducted through various transportation and motorcycle research resources such as Google Scholar, Transport Research International Documentation (TRID), the Civil Engineering Database, etc. In addition, to ensure the inclusion of all related projects, an online survey of the motorcycle safety community was also conducted via Qualtrics. A summary and findings from the questionnaire are provided in this report.

2.1 Background

Although studying motorcycle crashes has become increasingly common, few studies have considered causal factors or attempted to build an in-depth understanding of those crashes. MCCS data could help to fill this research gap, as more than 2,000 motorcycle crash features are included. Different from other studies, the MCCS gathered comprehensive data with the pre-crash, crash, and post-crash features of motorcycle riders, drivers, and crash sites, as well as information on similar non-crash-involved motorcyclists and their vehicles. Additionally, MCCS built detailed data-collection forms for case-control studies and training materials for future large-scale studies. Currently, the MCCS dataset is being used by over 20 studies focused on motorcycles, with each exploring the causal factors and/or schemes underlying motorcycle crashes.

2.2 Papers and Reports Using MCCS Dataset

In total, seven completed studies using the MCCS dataset were identified: (1) Motorcycle Crash Causation Study: Final Report, (2) Select Risk Factors Associated with Causes of Motorcycle Crashes, (3) A Heterogeneity Based Case-Control Analysis of Motorcyclist's Injury Crashes: Evidence from Motorcycle Crash Causation Study, (4) Examining Correlations between Motorcyclist's Conspicuity, Apparel Related Factors and Injury Severity Score: Evidence from New Motorcycle Crash Causation Study, (5) Contrasting Crash- and Non-Crash-Involved Riders: Analysis of Data from the Motorcycle Crash Causation Study, (6) Topic Models from Crash Narrative Reports of Motorcycle Crash Causation Study, and (7) A Motorcycle-Injury Severity Analysis: A Comparison of Single-, Two-, and Multi-Vehicle Crashes Using Latent Class Ordered Probit Model. These studies are summarized in the following sections based on their objectives, data processing procedure, methodology, and major findings and recommendations.

2.2.1 Study Objectives

The seven studies reviewed in this report analyzed MCCS data for different objectives. However, all studies, including the MCCS final report, aimed to identify causal factors and factors contributing to MCCS crash risks and injury severities. The findings can be summarized as follows:

- Two of the seven studies employed MCCS data to determine contributing factors for motorcycle crash risks.
- Three of the seven studies identified causal factors for motorcycle injuries.
- One of the seven studies used natural language processing tools to analyze the crash narratives and provide in-depth discussion of crash causation.

2.2.2 Data Processing Procedure

To achieve different research goals, the seven studies used distinctive approaches to extract, organize, and analyze MCCS data:

- In addition to the MCCS final report, two of the studies (*1*, *2*) used both 351 crash cases and 702 non-crash controls. Comparison of crash cases and controls can provide insights on crash injury prevention strategies.
- One report (*3*) employed partial MCCS data (177 MC crashes, 354 paired controls) to provide descriptive statistics and modeling results that quantified the effects of risk factors.
- Two reports (*4, 5*) used only crash data, including 351 motorcycle crashes that were analyzed.
- One study (*6*) developed three models for partial crash data (322 injury crashes), including a single-motorcycle crash model, a two-vehicle crash model, and a multi-vehicle crash model.

2.2.3 Methodologies

The seven included studies used different datasets and methodologies to capture the unique features of MCCS data. The following were observed:

- Most of the studies (4 of 7) employed a case-control experiment design to explore and quantify the effects of different characteristics on motorcycle crash risks or crash injury severity.
- Two studies used a medical scoring system to identify factors contributing to motorcycle crash injury outcomes. Specifically, one study used the Injury Scoring System (ISS), which provides an overall tally of injury scores for each of the rider's three most severely injured body parts, and the other study used the New Injury Severity Score (NISS).
- Two of the seven studies considered novel machine learning models to identify the causal factors of motorcycle injury crashes.
- Four of the seven studies employed logistic regression models to identify the effects of risk factors on crash injuries.
- All of the studies provided descriptive statistics to visualize the study data and compare crashes and controls in different configurations.

2.2.4 Major Findings

With the MCCS dataset, these studies obtained multiple findings that had not been addressed in previous studies, including the impact of motorcycle clothing on motorcyclist conspicuity and risk of injury, the difference between partial-coverage and full-coverage helmets, and the potential causes of motorcycle crashes. A summary of objectives, data processing procedures, methodologies, and major findings for the seven studies is presented in **Table 1**.

Table 1 Literature Review and Comparison

Title	Year	Authors	Objectives	Data	Methodology	Major Findings
Motorcycle Crash Causation Study: Final Report fhwa.gov/publications/safety/18064.pdf	2019	Nazemetz, J. W., F. D. Bents, J. G. Perry, C. Thor, Y. M. Mohamedshah, Oklahoma State University	• Provide comprehensive MC crash data inventory for further analysis	• 351 motorcycle (MC)-involved injury crashes as cases • 702 controls	• Descriptive statistics to compare crashes in different configurations	• In fatal crashes, single-vehicle crashes were overrepresented. • Left-turning crashes and motorcyclists failing to avoid had most shares. • Most MC crashes (62%) occurred without any traffic control at crash scene.
Select Risk Factors Associated with Causes of Motorcycle Crashes http://www.ddot-hso.com/assets/docs/general/SR1801.pdf	2018	National Transportation Safety Board (NTSB)	• Identify causal factors contributing to crash risks • Quantify relationships between factors and crash risks • Provide suggestions on countermeasures	• 177 MC-involved injury crashes • 354 non-crash exposure as controls	• Descriptive statistics of different crash configurations • Logit regression model to quantify effects of risk factors on motorcycle crashes	• More than half (54%) of motorcycles were touring, cruiser, or chopper types. • Half of fatal motorcycle crashes occurred on Fridays, Saturdays, and Sundays. • Over half of fatal crashes were single-vehicle crashes.
A Heterogeneity Based Case-Control Analysis of Motorcyclist's Injury Crashes: Evidence from Motorcycle Crash Causation Study https://doi.org/10.1016/j.aap.2018.07.024	2018	Behram Wali, Asad J. Khattak, Aemal J. Khattak, University of Tennessee	• Compare different effects of rider behavior, clothing, and exposure-related factors on crash propensity	• 351 crash-involved MC riders • 702 non-crash involved riders	• Logit model with random parameters • Logit model with heterogeneity-in-means random parameters	• Riders with partial helmet coverage have lower risk of injury crash involvement. • Drowsy riding and riding under the influence of alcohol or drugs lead to higher risks of crash involvement.

Table 1 Literature Review and Comparison (Continued)

Title	Year	Authors	Objectives	Data	Methodology	Major Findings
Examining Correlation between Motorcyclist's Conspicuity, Apparel Related Factors and Injury Severity Score: Evidence from New Motorcycle Crash Causation Study https://doi.org/10.1016/j.aap.2019.04.009	2019	Behram Wali, Asad J. Khattak, Numan Ahmad, University of Tennessee	• Explore factors contributing to crash injury • Assess effects of these factors on motorcycle injuries	• 351 MC-involved injury crashes	• Fixed and random parameter Tobit models to account for effects of conspicuity-related factors on Injury Severity Score (ISS)	• Bright color of rider gear could decrease Injury Severity Scores (ISS). • If rider had taken an experienced rider course, injury severity score decreased. • Positive Blood Alcohol Concentration (BAC) found to be associated with significant increase of 15.61 units in injury severity.
Contrasting Crash- and Non-Crash-Involved Riders: Analysis of Data from the Motorcycle Crash Causation Study https://doi.org/10.1177/0361198119851722	2019	Hitesh Chawla, Ilker Karaca, Peter T. Savolainen, Michigan State University	• Explore leading risk factors extensively and rider risk-taking strategy while riding	• 351 MC-involved injury crashes • 702 controls	• Logistic regression models to identify rider and vehicle attributes associated with motorcycle crashes	• Younger riders associated with increased crash risk. • Ownership of motorcycle found to be negatively associated with crash risk.

Table 1 Literature Review and Comparison (Continued)

Title	Year	Authors	Objectives	Data	Methodology	Major Findings
Topic Models from Crash Narrative Reports of Motorcycle Crash Causation Study https://doi.org/10.1177/03611981211002523	2021	Subasish Das, Anandi Dutta, Ioannis Tsapakis, Texas A&M Transportation Institute and University of Texas at San Antonio	• Examine the unstructured textual contents of MCCS data	• 351 MC-involved injury crashes	• Natural language processing tools (text mining and topic modeling) to identify the hidden trends in motorcycle crashes from unstructured textual contents	• The high-risk clusters in motorcycle crashes are identified as crashes on curves on the right, inflated tire, crossing using dedicated left lane, brake failure, passing solid yellow line, and speeding over the posted speed limit. • “Unsafe speed,” “male,” “intersection,” “bilateral contusion,” and “fracture” are highly representative keywords in fatal crash reports.
A Motorcyclist-Injury Severity Analysis: A Comparison of Single-, Two-, and Multi-Vehicle Crashes Using Latent Class Ordered Probit Model https://doi.org/10.1016/j.aap.2020.105953	2020	Jing Li, Shouen Fang, Jingqiu Guo, Ting Fu, Min Qiu, Tongji University	• Compare the injury severity of single-, two-, and multi-vehicle crashes involving a motorcycle	• 322 MC-involved injury crashes	• Latent class clustering to identify the different clusters in each class • Ordered probit models to determine the contributing factors to the crash severity of motorcyclists	• The contributing factors to motorcyclist injury severity differ by number of involved vehicles. • Pre-speed of the motorcycle is a significant factor contributing to serious and critical injury in most types of crashes. • Optical speed limit of road and traffic law enforcement can help to reduce the injury severity of motorcyclists.

2.3 Survey of States on Previous or Ongoing Efforts with MCCS Data

A Web-based questionnaire about research efforts with MCCS data was developed, and an invitation to the survey was sent to AASHTO's Committee on Safety (COS) and the TRB Motorcycle and Moped Safety Committee (ANF30). The questionnaire was used to obtain information about participant familiarity with MCCS projects, knowledge of any ongoing projects related to MCCS (including those in a participant's own state), and other feedback related to the MCCS database.

Over a period of two weeks, 21 responses were received. Respondents were identified as engineers, program managers, traffic safety analysts, a program coordinator, and a motorcycle riding education program manager. About 43 percent of the respondents indicated that they were very familiar or moderately familiar with the MCCS. Additionally, most respondents (86%) said they were not aware of any ongoing or foreseeable research projects/applications/programs using the MCCS dataset.

Among the respondents, an engineer from Arizona stated that the Arizona DOT Safety Office sponsored a similar investigative project about motorcycle crashes that showed how traffic crashes are investigated differently across different agencies, and a unique crash investigation system for each state was recommended. Over half of respondents were interested in studies that could implement a detailed investigation of specific motorcycle crash configurations.

Although over half of all respondents were not familiar with the MCCS, several experts provided suggestions that can shed light on conducting motorcycle safety studies in Florida; future studies may adopt some investigation techniques, training, and risk factors from the MCCS:

- The Arizona traffic safety engineer noticed significant differences in crash investigations across agencies in Arizona and suggested that crashes be investigated by state training curricula.
- The Michigan traffic analyst expected to learn the evolved risk factors in each crash and possible mitigation for these risks.
- The Virginia program director pointed out the insufficiency of alcohol data in crash data reports and expected to use MCCS data in the future.

2.4 Summary

The research team found only a few completed studies that had used MCCS data. These studies demonstrated the use of MCCS data on various topics through descriptive analysis or statistical modeling; however, they did not attempt to connect the MCCS dataset to local data. The small sample size of MCCS data and local characteristics (roadway, environment, riding behavior, etc.) that vary from those in Orange County, California, could impact the value of study findings with MCCS data when addressing local motorcycle safety issues in a state.

Overall**,** most of the studies (4 out of 7) (*1*–*3*, *5*) employed a case-control experiment design to explore and quantify the effects of different characteristics on motorcycle crash risks or crash injury severity. By mining the MCCS dataset, these studies obtained multiple findings that had not been addressed in previous research, including the impact of motorcycle clothing on motorcyclist conspicuity and risk of injury, the difference between partial-coverage and full-coverage helmets, and the potential causes of motorcycle crashes.

3. Florida Motorcycle Crash Data Analysis

Around 8,000 motorcycle injury crashes were observed annually in Florida over the past 9 years (2011–2019), resulting in an average of over 500 annual motorcycle fatalities. As of July 2019, Florida had more than 1.3 million licensed drivers with a motorcycle endorsement and 622,347 motorcycles registered. Florida adopted a new police crash report form in 2011, and this study analyzed nine years of Florida motorcycle crash information; no injury (property damage only) crashes were included so as to maintain the same crash definition as the MCCS dataset.

3.1 Overview of Florida Motorcycle Crash Trends

A summary of Florida motorcycle injury crash statistics from the past nine years is as follows:

- 75,049 police-reported motorcycle injury crashes, of which:
  - 17,263 were "possible injury" crashes
  - 33,213 were "non-incapacitating injury" crashes
  - 19,914 were "incapacitating injury" crashes
  - 4,659 were "fatal" crashes

As shown in **Table 2**, the percentage of Florida motorcycle crashes involving severe or fatal injuries has remained relatively steady over the past nine years, with around one-third of all crashes in that period resulting in fatality or incapacitating injury.

Table 2 Motorcycle Injury Crash Trends in Florida, 2011–2019

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019
Fatal crashes	1454	1771	1892	2013	2148	2107	2058	1938	1882
Incapacitating injury crashes	3644	3863	3876	3811	3866	3891	3537	3397	3328
Non-incapacitating injury crashes	2240	2303	2244	2282	2302	2365	2202	2017	1959
Possible injury crashes	460	471	467	452	577	556	568	548	560
All injury crashes	7798	8408	8479	8558	8893	8919	8365	7900	7729

*Preliminary data
Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

Table 3 breaks down Florida motorcycle crashes by the number of vehicles involved, with additional focus on fatal and incapacitating injury crashes. The respective proportions attributed to crashes involving one, two, and more than two vehicles have remained relatively stable over time for all crash types. More specifically, between 2011 and 2019, motorcycle crashes were approximately half as likely to involve a single vehicle (around 30% of motorcycle crashes) as they were to involve two (around 60%), with some deviation depending on the specific crash type being considered.

Table 3 Motorcycle Injury Crashes by Number of Vehicles Involved

Number of Vehicles in Crash	2011 (%)	2012 (%)	2013 (%)	2014 (%)	2015 (%)	2016 (%)	2017 (%)	2018 (%)	2019 (%)
Fatal Crashes									
One	33.48	35.67	33.40	32.08	30.50	32.73	28.87	28.83	27.68
Two	58.26	54.99	55.25	58.63	60.14	58.09	61.97	62.96	61.96
More than two	8.26	9.34	11.35	9.29	9.36	9.18	9.16	8.21	10.36
Total (N)	100.0 (7,798)	100.0 (8,408)	100.0 (8,479)	100.0 (8,558)	100.0 (8,893)	100.0 (8,919)	100.0 (8,365)	100.0 (7,900)	100.0 (7,729)
Incapacitating Injury Crashes									
One	40.94	38.56	40.82	38.91	37.36	36.70	36.60	33.22	35.43
Two	53.79	56.32	54.90	56.49	57.47	57.67	58.22	60.49	59.16
More than two	5.27	5.12	4.28	4.6	5.17	5.63	5.18	6.29	5.45
Total (N)	100.0 (2,240)	100.0 (2,303)	100.0 (2,244)	100.0 (2,282)	100.0 (2,302)	100.0 (2,365)	100.0 (2,202)	100.0 (2,017)	100.0 (1,959)
All Crashes									
One	37.41	37.17	37.14	36.64	35.77	34.02	33.64	32.72	33.94
Two	57.57	58.08	58.11	58.42	59.47	60.77	60.60	61.53	60.71
More than two	5.02	4.76	4.65	4.93	4.75	5.21	5.76	5.70	5.34
Total (N)	100.0 (7,798)	100.0 (8,408)	100.0 (8,479)	100.0 (8,558)	100.0 (8,893)	100.0 (8,919)	100.0 (8,365)	100.0 (7,900)	100.0 (7,729)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

The number of drivers with a motorcycle endorsement in Florida rose steadily each year between 2011 and 2019, increasing by 289,770 overall. Motorcycle registrations also increased by 49,774 over the same time period. Despite these increases, motorcycle fatalities declined from a 9-year-high of 584 in 2015 to a total of 537 in 2019, an 8% decrease. More detailed information is shown in **Table 4**.

Table 4 Motorcycle Registrations and Licensed Drivers with MC Endorsement in Florida

Year	Motorcycle Registrations	Drivers with Motorcycle Endorsements	Fatalities	Fatalities per 100,000 Registered Motorcycles
2019	622,347	1,332,581	537	86.3
2018	615,931	1,307,266	531	86.2
2017	622,941	1,271,350	552	88.6
2016	621,744	1,232,780	545	87.7
2015	610,191	1,185,787	584	95.7
2014	601,253	1,143,549	449	74.7
2013	585,067	1,111,813	462	79
2012	579,191	1,080,655	457	78.9
2011	572,573	1,042,811	451	78.8

Sources: Injuries and fatalities, FDOT Crash Analysis Reporting System (CARS), as of August 17, 2021, Registrations, Florida Department of Highway Safety and Motor Vehicles

Table 5 breaks down Florida motorcycle crashes occurring between 2011 and 2019 by gender. Supplementing this information, which pertains to Florida motorcycle crashes in general, data regarding fatal and incapacitating injury crashes were also reported. Notably, males were found to be involved in motorcycle crashes at a higher rate than females, accounting for 91.1% of the incidents reported, regardless of the year or the crash type being considered.

Table 5 Gender of Operators in Motorcycle Crashes by Crash Severity, Florida, 2011–2019

	2011 (%)	2012 (%)	2013 (%)	2014 (%)	2015 (%)	2016 (%)	2017 (%)	2018 (%)	2019 (%)
Fatal Crashes									
Male	95.61	93.98	95.86	96.57	96.82	95.26	96.32	95.93	93.99
Female	3.35	4.42	3.52	3.43	3.18	4.39	3.68	3.72	5.15
Unknown	1.04	1.60	0.62	0.00	0.00	0.35	0.00	0.35	0.86
Total (N)	100.0 (478)	100.0 (498)	100.0 (483)	100.0 (466)	100.0 (598)	100.0 (570)	100.0 (598)	100.0 (565)	100.0 (582)
Incapacitating Injury Crashes									
Male	91.98	91.74	92.57	91.34	92.63	93.02	93.34	93.27	93.34
Female	7.37	7.59	7.17	8.36	7.20	6.82	5.57	6.73	6.41
Unknown	0.65	0.68	0.26	0.30	0.16	0.16	0.08	0.00	0.25
Total (N)	100.0 (2,293)	100.0 (2,373)	100.0 (2,302)	100.0 (2,357)	100.0 (2,361)	100.0 (2,449)	100.0 (2,262)	100.0 (2,065)	100.0 (2,013)
All Crashes									
Male	91.13	91.07	91.61	91.16	91.77	92.54	92.70	93.22	92.24
Female	8.13	8.17	7.85	8.45	7.87	7.01	6.83	6.45	7.13
Unknown	0.64	0.75	0.53	0.39	0.36	0.45	0.47	0.33	0.64
Total (N)	100.0 (7,971)	100.0 (8,589)	100.0 (8,645)	100.0 (8,742)	100.0 (9,076)	100.0 (9,083)	100.0 (8,576)	100.0 (8,066)	100.0 (7,911)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

As shown in **Table 6**, individuals ages 20–29 had the largest proportion of Florida motorcycle crashes from 2011–2019, accounting for 26.4% of all such crashes, regardless of the year. In contrast, riders who were age 70 or older had a lower percentage of Florida motorcycle crashes than any other individual age group.

Table 6 Age of Operators in Motorcycle Crashes, Florida, 2011–2019

Age	2011 (%)	2012 (%)	2013 (%)	2014 (%)	2015 (%)	2016 (%)	2017 (%)	2018 (%)	2019 (%)
15-19	8.76	9.18	8.95	9.00	9.67	8.66	8.74	8.26	7.68
20-29	26.42	27.95	28.32	29.46	30.91	30.97	30.12	29.94	29.11
30-39	15.87	14.73	15.32	15.70	15.82	15.99	16.47	17.73	17.89
40-49	19.39	18.55	18.62	16.67	15.96	15.66	15.87	14.40	14.77
50-59	17.98	18.17	17.23	17.67	16.24	16.31	17.10	16.68	17.10
60-69	9.29	9.29	9.31	9.14	8.79	9.22	8.87	10.18	10.24
70-79	2.04	1.90	1.99	2.19	2.31	2.37	2.50	2.49	2.89
80 or more	0.27	0.22	0.26	0.17	0.30	0.82	0.33	0.33	0.33
Total (N)	100.0 (7,903)	100.0 (8,514)	100.0 (8,549)	100.0 (8,676)	100.0 (8,999)	100.0 (9,019)	100.0 (8,505)	100.0 (7,993)	100.0 (7,826)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

In summary, the number of registered motorcycles and drivers with motorcycle endorsements in Florida has increased substantially over the past nine years. These increases have been accompanied by a decline in overall motorcycle crash and fatality numbers, but it is important to note that the proportion of motorcycle crashes that involved a fatality actually increased between 2014 (5.3%) and 2019 (7.2%).

Notably, from 2011 to 2019, the proportion of motorcycle crashes involving a single vehicle (37.4% vs. 33.9%) and the proportion of fatal motorcycle crashes involving a single vehicle (33.5% vs. 27.7%) also declined. It is possible that this finding is related to an increased rate of distracted driving, a prospect that warrants further investigation. With regard to gender, females accounted for a lower percentage of fatal crashes than incapacitating injury crashes throughout the study period; this may be related to the relatively high rates of risk-taking behavior commonly observed among male riders. Finally, the age distribution of motorcyclists involved in a crash is slowly changing, with the proportion of riders in older age groups (age 60+) increasing between 2011 and 2019.

3.2 Common Motorcycle Crash Types in Florida

To identify the most common types of motorcycle crashes, the research team analyzed several aspects of Florida motorcycle crashes, including collision types and roadway alignments, using features extracted from police crash reports.

3.2.1 Overview

When filling out a police crash report, the investigating officer at the scene can select from and designate a number of contributing factors. **Table 7** presents a summary of the harmful events and contributing factors for motorcycle crashes occurring in Florida for 2011–2019; data are further broken down by injury severity. As shown, around 63% of all recorded motorcycle crashes during this timeframe involved collisions with other motor vehicles.

Table 7 Motorcycle Crashes by Injury Severity and Harmful Events, Florida, 2011–2019

Harmful Event \ Crash Severity		Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
Non-collision	Overturn/ rollover	8.29	13.76	15.77	9.91	12.81 (9,894)
	Fell/jumped from motor vehicle	3.50	5.22	4.08	2.27	4.34 (3,351)
	Subtotal (N)	11.79 (2,078)	12.8 (6,479)	12.2 (4,088)	12.18 (600)	17.15 (13,245)

Table 7 Motorcycle Crashes by Injury Severity and Harmful Events, Florida, 2011–2019 (Continued)

Harmful Event \ Crash Severity		Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
Collision with non-fixed object	Pedestrian	0.35	0.49	0.72	1.18	0.56 (436)
	Pedal cycle	0.29	0.37	0.31	0.21	0.33 (251)
	Animal	0.56	0.78	0.77	0.42	0.70 (544)
	Motor vehicle in transport	71.13	59.56	59.55	64.03	62.45 (48,226)
	Parked motor vehicle	1.04	0.78	0.78	0.76	0.84 (651)
	Subtotal (N)	80.7 (12,934)	61.24 (21,170)	61.41 (12,794)	65.42 (3,215)	64.89 (50,113)
Collision with fixed object	Curb	2.09	2.94	3.31	3.11	3.1 (2,207)
	Ditch	0.56	0.74	0.76	0.56	0.30 (538)
	Guardrail face	0.11	0.11	0.15	0.15	0.40 (596)
	Concrete traffic barrier	0.27	0.54	1.06	3.04	0.18 (421)
	Traffic barrier except concrete/cable	0.27	0.46	0.62	1.47	0.35 (557)
	Tree (standing)	0.37	0.52	0.90	2.58	0.10 (261)
	Utility pole/light support	0.12	0.21	0.43	1.64	0.09 (230)
	Traffic sign support	0.16	0.27	0.42	0.50	0.11 (288)
	Fence	0.27	0.32	0.48	0.63	0.09 (110)
	Fixed object (wall, building, tunnel, etc.)	1.54	1.95	1.97	1.49	1.2 (592)
	Subtotal (N)	5.76 (1,108)	8.06 (2,949)	10.10 (2,209)	15.17 (796)	7.4 (7,062)

Table 7 Motorcycle Crashes by Injury Severity and Harmful Events, Florida, 2011–2019 (Continued)

Harmful Event \ Crash Severity		Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
Sequence of events	Equipment failure (blown tire, brake failure, etc.)	0.3	0.4	0.3	0.2	0.3 (150)
	Ran off roadway, right	2.1	3.4	4.5	6.8	3.1 (1,508)
	Ran off roadway, left	1.2	1.7	2.5	3.3	1.7 (827)
	Cross centerline	0.2	0.3	0.3	1.0	0.3 (172)
	Subtotal (N)	3.7 (370)	5.4 (972)	7.4 (798)	11.2 (297)	5.4 (2,657)
Total (N)		100.0% (17,628)	100.0 (34,146)	100.0 (20,593)	100.0 (4,765)	100.0 (77,224)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

Previous studies have found a high level of risk associated with a single motorcyclist riding on horizontal curves (*6–8*), and Florida crash report data support that finding. As shown in **Table 8**, around 20 percent of Florida motorcycle crash fatalities occurred on horizontal curves. Looking deeper, for single motorcycle crashes (**Table 9**), the relative percentage of fatalities occurring on horizontal curves more than doubled, with over 750 such deaths recorded during the same timeframe.

Table 8 Motorcycle Crashes by Injury Severity and Roadway Horizontal Curves

Roadway Alignment \ Injury Severity	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%)
Straight	90.08	86.93	84.36	78.95	78.26 (66,770)
Curve right	4.81	6.15	7.33	9.23	7.61 (4,905)
Curve left	4.97	6.85	8.23	11.82	14.13 (5,485)
Total (N)	100.0 (17,628)	100.0 (34,146)	100.0 (20,593)	100.0 (4,857)	100.0 (77,224)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

Table 9 Single Motorcycle Crashes by Injury Severity and Roadway Horizontal Curves

Injury Severity / Roadway Alignment	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%)
Straight	77.90	75.69	69.27	48.96	73.68 (21,476)
Curve right	10.31	11.02	14.11	20.58	5.26 (3,594)
Curve left	11.58	13.20	16.47	30.46	21.05 (4,321)
Total (N)	100.0 (5,674)	100.0 (14,045)	100.0 (8,164)	100.0 (1,487)	100.0 (29,427)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

As shown in **Table 10**, "following too closely" and "failure to yield right-of-way" were two of the most frequent actions in Florida motorcycle crashes. This is consistent with what has been found in previous research (*8–11*).

Table 10 Motorcycle Crashes by Injury Severity and Motorcyclist Riding Actions

Injury Severity / Riding Action	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%)
Not coded	0.1	0.2	0.2	0.61	0.6 (281)
No improper riding action	54.3	49.6	49.8	37.0	49.7 (24,660)
Careless riding	18.8	21.5	26.2	22.1	21.3 (10,537)
Failed to yield right-of-way	2.7	1.9	2.2	2.0	2.3 (1,147)
Improper backing	0.0	0.0	0.0	0.0	0.1 (42)
Improper lane change	0.6	0.5	0.5	0.3	0.5 (260)
Followed too closely	3.5	3.0	1.5	0.4	2.8 (1,399)
Disregarded traffic signal	0.7	0.7	1.4	1.8	0.9 (441)
Exceeded safe speed limit	1.8	2.3	2.8	3.0	2.1 (1,053)
Disregarded stop sign	0.5	0.5	0.5	1.0	0.5 (261)
Improper passing	1.8	1.6	1.8	1.3	1.8 (866)
Exceeded stated speed limit	0.7	1.0	1.9	9.1	1.4 (699)

Table 10 Motorcycle Crashes by Injury Severity and Motorcyclist Riding Actions (Continued)

Riding Action \ Injury Severity	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%)
Driving wrong side/way	0.2	0.2	0.2	0.6	0.2 (90)
Failed to keep in proper lane	1.8	1.8	2.9	3.1	2.1 (1,028)
Ran off roadway	1.6	2.3	2.9	5.0	2.2 (1,077)
Disregarded other traffic sign	0.1	0.1	0.1	0.0	0.1 (35)
Disregarded other road markings	0.1	0.1	0.1	0.2	0.1 (32)
Over-correcting/over-steering	1.0	1.3	0.8	0.1	0.9 (454)
Swerved or avoided, due to wind, slippery surface, MV, object, non-motorist in roadway, etc.	1.5	2.0	0.8	0.7	1.6 (778)
Operated MV in erratic, reckless or aggressive manner	0.7	1.0	1.6	2.9	1.1 (557)
Other contributing action	7.4	8.4	1.6	8.6	7.8 (3,886)
Total (N)	100.0 (17,430)	100.0 (33,908)	100.0 (20,475)	100.0 (4,838)	100.0 (76,651)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

Several studies have identified the most common types of motorcycle crashes based on specific contributing factors and rider or driver actions (*8–11*), with the most common types of crashes being identified as (1) crashes with vehicles turning left across the path of a motorcycle, or "left-turning across path" crashes (LTAP), (2) crashes with motorcyclists following too closely (FTC), and (3) crashes with motorcyclists running off the road (ROR). As shown in **Table 11**, in Florida, LTAP are the most dangerous motorcycle crashes based on preliminary data. FTC are defined as two-vehicle motorcycle crashes with a motorcyclist following too closely as the contributing factor, or as rear-end crashes with the involved vehicle presenting with a rear-side damage point. ROR are identified as single-motorcycle crashes with a motorcycle running off the roadway or colliding with some fixed object(s) along the roadway including a curb, ditch, embankment, guardrail face, guardrail end, cable barrier, traffic barrier, tree, utility pole, and/or fence.

Table 11 Most Common Types of Motorcycle Crashes in Florida, 2011–2019

Injury Severity / Crash Configuration	Possible Injury	Minor Injury	Severe Injury	Fatality	Total
LTAP	1401	2773	2551	893	7618
FTC	992	1404	420	42	2858
ROR	446	1101	866	379	2792
Other	14424	27935	16077	3345	61781
Total (N)	17263	33213	19914	4659	75049

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

3.3 LTAP Motorcycle Crashes

Previous studies have identified LTAP as the primary type of motorcycle crash (*8*, *9*, *11*, *12*); it is important to consider the characteristics associated with this designation in further detail. LTAP crashes are broken down by injury severity and rider age group in **Table 12**.

Table 12 LTAP Crashes by Injury Severity and Rider Age

Injury Severity / Age	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
15-19	5.36	6.02	5.69	6.76	5.89 (449)
20-29	33.53	34.99	32.92	36.37	34.19 (2,605)
30-39	17.02	16.83	16.40	16.22	16.63 (1,267)
40-49	15.86	15.82	16.17	13.51	15.66 (1,193)
50-59	16.87	15.21	17.37	15.65	16.29 (1,241)
60-69	8.91	8.68	9.12	2.82	8.86 (675)
70-79	2.24	2.5	2.06	2.82	2.27 (173)
80 or more	0.22	0.14	0.27	0.23	0.21 (16)
Total (N)	100.0 (1,381)	100.0 (2,927)	100.0 (2,404)	100.0 (807)	100.0 (7,619)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

LTAP crashes by rider gender and injury severity are shown in **Table 13**; each of the five injury categories mirrors the distribution of Florida motorcycle riders in general (i.e., riders in all categories are predominantly male).

Table 13 LTAP Crashes by Rider Gender and Injury Severity

Rider Gender \ Injury Severity	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
Male	94.09	95.08	95.68	97.41	95.36 (7,301)
Female	5.13	4.63	4.16	2.03	4.27 (327)
Not coded	0.79	0.29	0.16	0.56	0.36 (28)
Total (N)	100.0 (1,404)	100.0 (2,786)	100.0 (2,570)	100.0 (896)	100.0 (7,656)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

LTAP crashes by alcohol or drug involvement and injury severity are shown in **Table 14**. Around 80 percent of Florida's alcohol-involved LTAP crashes from 2011–2019 resulted in severe injuries or fatalities, and around 97% of all drug-involved crashes led to the same outcomes. When considered collectively, it is strikingly clear that alcohol-, drug-, and alcohol- and drug-impaired crashes accounted for a significantly larger proportion of LTAP motorcycle fatalities (29.6%) than for LTAP motorcycle crashes in general (5.6%).

Table 14 LTAP Crashes by Alcohol or Drug Involvement and Injury Severity

Alcohol or Drug Involvement \ Injury Severity	Possible Injury (%)	Non-Incapacitatin g Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
None	98.31	98.39	96.12	70.38	94.38 (7,255)
Alcohol-involved	1.62	1.36	2.79	8.67	2.73 (210)
Drug-involved	0.07	0.14	0.43	12.50	1.65 (127)
Alcohol- and drug-involved	0.00	0.11	0.66	8.45	1.24 (95)
Total (N)	100.0 (1,416)	100.0 (2,797)	100.0 (2,578)	100.0 (896)	100.0 (7,687)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

LTAP crashes by rider helmet use and injury severity are presented in **Table 15**. In the police crash reports, it was found that over one-third of riders involved in LTAP crashes were not wearing a helmet. This large proportion of unhelmet riders reflects Florida motorcycle legislation—there is no universal helmet law in Florida.

Table 15 LTAP Crashes by Helmet Use and Injury Severity

Helmet Use \ Injury Severity	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)

None	7.48	5.31	3.81	2.48	4.90 (375)
DOT-compliant motorcycle helmet	56.27	55.71	53.27	54.84	50.00 (4,202)
Other helmets	1.78	1.7	2.02	3.04	2.12 (162)
No helmets	34.47	36.93	40.89	39.64	39.0 (2,917)
Total (N)	100.0 (1,404)	100.0 (2,786)	100.0 (2,570)	100.0 (896)	100.0 (7,656)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

3.4 Crashes with Motorcyclists Following Too Closely (FTC)

Another important type of motorcycle crash to consider is FTC, a crash in which a motorcyclist was following too closely behind another motor vehicle or a rear-end crash that involved vehicle damage and had a rear-side point of impact. As shown in **Table 16**, most riders involved in FTC crashes were under age 60. Moreover, injury severity varied greatly by age in such crashes, and relatively few resulted in death or severe injury.

Table 16 FTC Crashes by Injury Severity and Rider Age

Injury Severity / Age	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
15-19	7.24	7.44	4.88	10.81	7.07 (197)
20-29	28.75	29.77	25.85	10.81	28.59 (797)
30-39	17.84	18.06	15.61	10.81	17.50 (488)
40-49	14.48	17.70	17.07	24.32	16.57 (462)
50-59	15.84	15.61	17.07	18.92	15.93 (444)
60-69	10.18	7.73	15.61	18.92	9.86 (275)
70-79	3.88	2.75	2.93	5.41	3.23 (90)
80+	1.78	0.94	0.98	0.02	1.26 (35)
Total (N)	100.0 (953)	100.0 (1,384)	100.0 (410)	100.0 (40)	100.0 (2,788)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

FTC motorcycle crashes by injury severity and rider gender are shown in **Table 17**. As was the case for LTAP crashes, the gender distribution of each injury severity category mirrors the distribution of Florida motorcycle riders in general.

Table 17 FTC Motorcycle Crashes by Injury Severity and Rider Gender

Gender \ Injury Severity	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
Male	76.49	83.97	83.81	84.62	81.32 (2,324)
Female	21.80	14.74	13.57	2.56	16.83 (481)
Not coded	0.38	1.29	2.62	12.82	1.05 (72)
Total (N)	100.0 (991)	100.0 (1,404)	100.0 (420)	100.0 (42)	100.0 (2,858)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

FTC crashes by alcohol or drug involvement and injury severity are shown in **Table 18**. Almost one-third (30.8%) of FTC crashes resulting in fatalities involved drug and/or alcohol use, which is a higher proportion than what was observed for LTAP crashes.

Table 18 FTC Crashes by Alcohol or Drug Involvement and Injury Severity

Alcohol or Drug Involvement \ Injury Severity	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
None	97.68	96.65	93.57	69.23	96.15 (2,748)
Alcohol-involved	1.82	2.92	5.71	12.82	3.11 (89)
Drug-involved	0.2	0.21	0.24	2.56	0.24 (7)
Alcohol- and drug-involved	0.3	0.21	0.48	15.38	0.49 (14)
Total (N)	100.0 (991)	100.0 (1,404)	100.0 (420)	100.0 (42)	100.0 (2,858)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

FTC crashes by helmet use and injury severity are presented in **Table 19**. Again, it was found that over one-third of Florida riders involved in such crashes between 2011 and 2019 were not wearing a helmet.

Table 19 FTC Crashes by Helmet Conditions and Injury Severity

Helmet Use \ Injury Severity	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
None	18.77	10.90	10.24	2.56	6.90 (827)
DOT-compliant motorcycle helmet	35.02	42.24	35.95	30.77	53.00 (6,366)
Other helmets	0.81	1.78	1.43	0.01	2.00 (242)
No helmets	45.41	45.09	52.38	66.67	38.10 (4,584)
Total (N)	100.0 (991)	100.0 (1,404)	100.0 (420)	100.0 (42)	100.0 (2,858)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

3.5 Run-Off-Road Motorcycle Crashes (ROR)

The third type of motorcycle crash that is important to consider is ROR, a single-motorcycle crash that involves a motorcycle running off the roadway or colliding with a fixed object along the roadway (e.g., curb, ditch, embankment, guardrail face, guardrail end, cable barrier, traffic barrier, tree, utility pole, or fence). These types of crashes account for a significant proportion of single-motorcycle crashes overall and are associated with relatively high risks. ROR crashes by injury severity and rider age are presented in **Table 20**. As shown, the severity of injury most associated with ROR crashes varied considerably by age group, with those between ages 20 and 29 accounting for the largest percentage of ROR fatalities.

Table 20 ROR Crashes by Injury Severity and Rider Age

Age \ Injury Severity	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
15-19	4.86	5.76	4.39	2.70	4.76 (132)
20-29	25.69	29.89	22.98	26.49	26.60 (737)
30-39	19.44	15.45	16.40	15.95	16.46 (456)
40-49	16.67	15.54	19.05	16.49	17.00 (471)
50-59	18.29	18.01	20.32	21.35	19.20 (532)
60-69	10.88	11.70	13.39	10.81	11.98 (332)
70-79	3.47	3.20	2.89	5.14	3.39 (94)
80+	0.69	0.46	0.58	1.08	0.61 (17)
Total (N)	100.0 (432)	100.0 (1,094)	100.0 (866)	100.0 (378)	100.0 (2,771)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

ROR motorcycle crashes by injury severity and rider gender are shown in **Table 21**. As was the case for LTAP and FTC crashes, males vastly outnumbered females in each injury severity category, largely mirroring the distribution of Florida motorcycle riders in general. However, it should be noted that the percentage of ROR fatalities attributed to males was about 5 percent higher than the percentage of ROR crashes they accounted for (94.9% vs. 89.5%).

Table 21 ROR Motorcycle Crashes by Injury Severity and Rider Gender

Injury Severity / Gender	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
Male	88.57	86.83	90.99	94.88	89.47 (2,499)
Female	10.09	12.53	8.55	4.85	9.88 (276)
Not coded	1.35	0.64	0.12	0.00	0.43 (12)
Total (N)	100.0 (446)	100.0 (1,101)	100.0 (866)	100.0 (378)	100.0 (2,771)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

ROR crashes by alcohol or drug involvement and injury severity are shown in **Table 22**. Drug and/or alcohol use was involved in over half (57.4%) of all fatal ROR crashes (a higher proportion than what was observed for both LTAP and FTC crashes) and in 15 percent of ROR crashes that resulted in severe injury.

Table 22 ROR Crashes by Alcohol or Drug Involvement and Injury Severity

Injury Severity / Alcohol or Drug Involvement	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
None	89.46	88.83	84.87	42.59	81.49 (2,276)
Alcohol-involved	9.87	9.81	12.93	28.84	13.35 (373)
Drug-involved	0.45	0.45	0.35	7.55	1.36 (38)
Alcohol- and drug-involved	0.22	0.91	1.85	21.02	3.80 (106)
Total (N)	100.0 (446)	100.0 (1,101)	100.0 (866)	100.0 (378)	100.0 (2,793)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

ROR crashes by helmet conditions and injury severity are presented in **Table 23**. Although it was found that around half of all riders involved in such crashes were not wearing a helmet, and around 60 percent of all ROR fatalities can be attributed to non-helmet wearers, it should be noted that similar numbers were found for riders wearing DOT-compliant motorcycle helmets (46% and 38%, respectively). This further highlights the risk for those involved in an ROR crash.

Table 23 ROR Crashes by Helmet Conditions and Injury Severity

Helmet Use \ Injury Severity	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury (%)	Fatal (%)	Total (%) (N)
None	6.28	4.18	2.42	1.89	3.69 (103)
DOT-compliant motorcycle helmet	48.88	49.77	42.38	38.01	45.65 (1,275)
Other helmets	1.79	1.91	1.96	1.89	1.90 (53)
No helmets	43.05	44.14	53.23	58.22	48.76 (1,362)
Total (N)	100.0 (446)	100.0 (1,101)	100.0 (866)	100.0 (378)	100.0 (2,793)

Source: FDOT Crash Analysis Reporting System (CARS) as of August 17, 2021

3.6 Summary

Through a detailed review and analysis of crash report data, the CUTR research team built an in-depth understanding of Florida motorcycle crashes occurring between 2011 and 2019. Areas of focus included primary crash types, injury severity levels, and the correlates for severe injuries that occur in motorcycle crashes. Major findings are as follows:

- The three primary types of motorcycle crashes are left turn approaching across path of a motorcycle, motorcycle following too closely, and single motorcycle run-off-road crashes.
- In single motorcycle crashes, running off the roadway is the most common circumstance, especially on horizontal curves.
- In multiple vehicle crashes, careless riding is a high-risk contributing factor. The most dangerous cases involve a motor vehicle turning left across the path of a motorcycle, which caused 893 fatalities in Florida during 2011–2019.
- Alcohol- and drug-impaired riding are highly correlated with severe injuries and fatalities.

Several limitations were observed when examining Florida crash data, making it difficult to pinpoint specific crash types and scenarios. For instance, “careless riding” was frequently cited by law enforcement in motorcycle crash cases, appearing in over 20 percent of crash reports. Also, the harmful event cited most frequently by law enforcement officers was collision with a “motor vehicle in transport” (62.5%). These types of categorizations lack sufficient detail, preventing more comprehensive analysis.

4. MCCS Data Analysis

4.1 Introduction

Sponsored by FHWA, the MCCS is known as the most comprehensive study on experiment design and data collection procedures in the field of motorcycle safety (*2*, *4*). Different from other studies, the MCCS gathered comprehensive data with pre-crash, crash, and post-crash features of riders, drivers, and crash sites for motorcycle crashes, as well as information on similar non-crash-involved motorcyclists and their vehicles. Additionally, the MCCS has built detailed data-collection forms for case-control studies and training materials for future large-scale studies. In the MCCS design, a crash involving at least one motorcycle or scooter and with a reported injury of an operator or passenger of the motorcycle or scooter is defined as a case (*5*). Thus, non-injury collisions and injury crashes involving only an injured driver from another vehicle type are not included in the dataset. For each focal case, concurrent exposure data collected from two non-crash-involved control motorcyclists are matched based on day of week, travel direction, location, and time of day (similarly-at-risk controls). Two methods were used in the MCCS for acquiring the matched controls:

- Voluntary traffic stops at or near the crash scene (same time of day, day of week, and direction of travel)
- Recruiting motorcyclists who may be at nearby gas stations

Data collection was implemented in Orange County, California, the state with the most registered motorcycles for 2010–2015. In total, 351 on-scene motorcycle crashes and 702 control cases, based on the matching conditions, were included in the dataset. As a variety of contributing factors (e.g., tire marks, debris, roadside objects, traffic volume) were creatively investigated and documented, the MCCS database differs greatly from traditional crash data. Inclusion of these variables will enhance the in-depth understanding of motorcycle safety in multiple dimensions. The MCCS includes 14 data collection forms; in addition to crash and rider information consistent with traditional crash long forms, it includes crash scenes, motorcycle mechanics, crash contributing factors, helmet testing, and other forms.

4.2 Methodology

The CUTR research team conducted a comprehensive data analysis that included filtering MCCS data for primary crash scenarios, analyzing the filtered data, comparing the data with Florida data, and providing recommendations for reconstructing Florida crash databases:

- *Identification* – Task 2 identified the three most common types of motorcycle crashes in Florida: (1) crashes with vehicles turning left across the path of the motorcycle, or “left-turning across path” crashes (LTAP), (2) crashes with motorcyclists following too closely (FTC), and (3) crashes with motorcyclists running off the road (ROR).
- *Filtration* – The research team developed and validated filtering criteria for identifying the three primary crash types from the MCCS dataset.

- *Analysis* – The sample size of MCCS data was too small (up to 23 observations for each crash type) to apply regression and hypothesis testing; thus, descriptive statistics were used to analyze the distribution of MCCS crashes by different factors.

The procedure is shown in **Figure 2**.

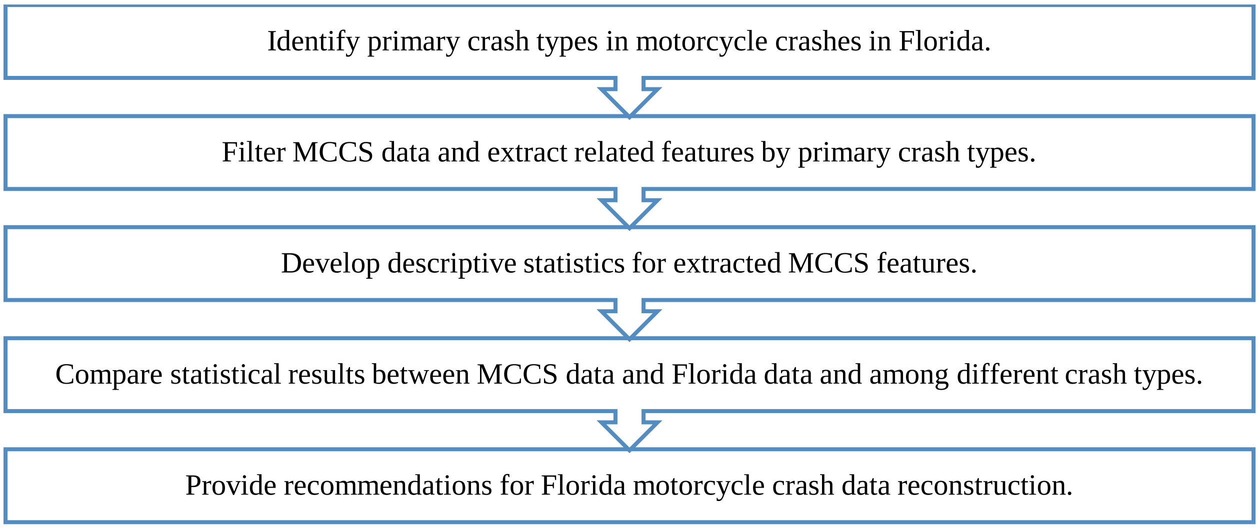


Figure 2 Data analysis procedure

4.3 Overview of MCCS Data

The CUTR research team examined 351 MCCS crashes, with the overall analysis primarily focused on comparing the distribution of MCCS and Florida motorcycle crashes. Additionally, an effort was made to tabulate unique variables available only in the MCCS dataset, which provided insight into contributing factors for motorcycle crashes that cannot be assessed using traditional crash databases. The results provided an overall understanding of cause and effect in motorcycle crashes from innovative aspects.

4.3.1 Roadway and Environment

As shown in **Table 24**, Saturday and Friday were the top two days with MCCS crashes (18.2% and 18.0%, respectively), followed by Sunday (15.1%) and Wednesday (14.3%). Motorcycle exposure and behaviors may vary across different days in a week. In Florida, the distributions are similar, with Saturday and Sunday as the top two days. The shares of crash cases over day of week from MCCS or FDOT CARS data could mirror the diversity of motorcycle exposures and behaviors. Researchers and engineers need to apply more efforts to reduce motorcycle crash risk for these two days.

Table 24 Motorcycle Crashes by Day of Week, MCCS and Florida, 2011–2019

Day of Week	MCCS (%)	Florida (2011–2019) (%)
Monday	11.1	11.9
Tuesday	11.1	12.3
Wednesday	14.3	12.9
Thursday	12.3	13.6
Friday	18.0	15.5
Saturday	18.2	18.1
Sunday	15.1	15.8
Total (N)	100.0 (351)	100.0 (75049)

The distribution of crash cases by roadway type is presented in **Table 25**. Major arterials and minor arterials account for the majority of MCCS crashes (45.6% and 28.9%, respectively). In Florida, arterials are the top roadway type where motorcycle crashes occur. This may be caused by significant motorcycle traffic and more conflicting points on major or minor arterials.

Table 25 Motorcycle Crashes by Roadway Type, MCCS and Florida, 2011–2019

Roadway Type	MCCS (%)	Florida (2011–2019) (%)
Interstate/freeway mainline	1.72	1.16
Freeway exit ramp	0.86	2.10
Freeway transition	0.57	2.78
Principal arterial, non-freeway	45.56	56.77
Minor arterial	28.94	18.86
Collector	3.72	3.28
Local road/street	16.91	8.01
Parking area, off-street	0.29	0.11
Driveway	1.43	1.88
Total (N)	100.0 (351)	100.0 (75049)

Intersections are usually considered high-risk areas because of frequent conflict points between motorcycles and other vehicles. **Figure 3** shows motorcycle crashes by junction type. At-grade intersections account for the majority of MCCS crashes (67%), and non-junction areas comprise a significant percentage (30%), which is somewhat different than what is observed for Florida motorcycle crashes.

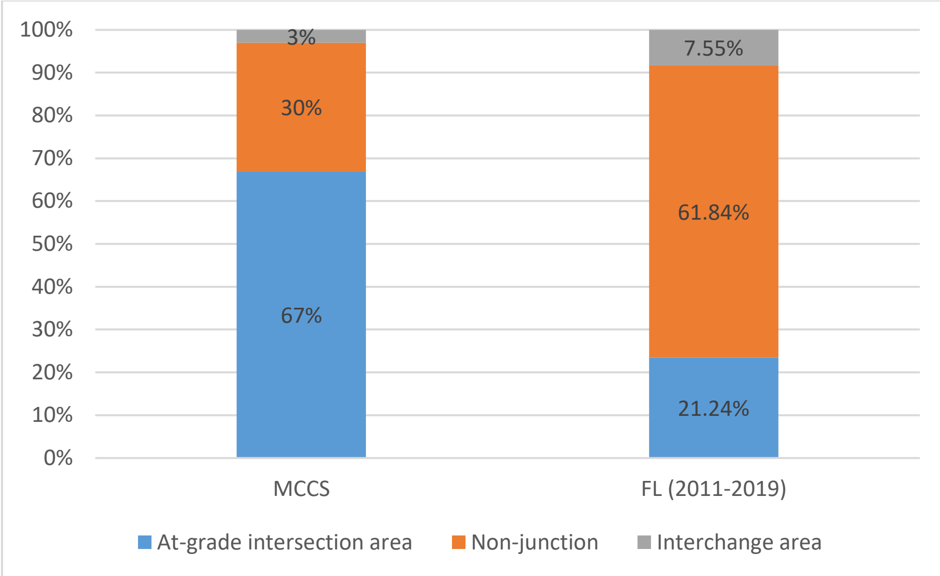


Figure 3 Motorcycle crashes by junction type, MCCS and Florida, 2011–2019

A comparison of the distribution of crash percentages by intersection type for MCCS crashes and Florida crashes is shown in **Table 26**. Consistent with the distribution of crashes by junction type, in Florida, over half of all motorcycle crashes occurred at non-intersections.

Table 26 Motorcycle Crashes by Intersection Type, MCCS and Florida, 2011–2019

Type of Intersection	MCCS (%)	Florida, 2011-2019 (%)
Not at intersection	29.63	61.05
Four-leg intersection, not skewed	25.36	20.85
Four-leg intersection, skewed	3.42	--
T-intersection	19.66	14.32
Y-intersection	1.14	0.74
Alley, driveway	17.95	0.09
Offset intersection	0.85	0.39
Intersection as part of interchange	1.71	0.07
Rail/ light-rail crossing	0.28	--
Total (N)	100.0 (351)	100.0 (75049)

4.3.2 Motorcycle Characteristics and Safety Equipment

In MCCS data, two crash types are defined—(1) single-motorcycle crash, in which only one motorcycle is involved and no other vehicles are engaged, and (2) multi-vehicle crash, involving one motorcycle and at least one other vehicle. The distribution of MCCS and Florida motorcycle crashes by crash type is presented in **Table 27**.

Table 27 Single- and Multi-Vehicle Motorcycle Crashes, MCCS and Florida, 2011–2019

Motorcycle Crash Type	MCCS (%)	Florida 2011–2019 (%)
All Injury Crashes		
Single-vehicle	23	29.99
Multi-vehicle	77	70.01
Fatal Crashes		
Single-vehicle	55	30.09
Multi-vehicle	45	69.91

Based on Organization for Economic Co-operation and Development (OECD) standards, there are 16 types of motorcycles. In the MCCS, 12 motorcycle types, including mopeds, were investigated. **Table 28** shows that most crash-involved motorcycles are sport models (41.9%); cruisers also have a large share (23.4%). Motorcycle types in Florida crashes were obtained by decoding VIN numbers using the NHTSA Product Information Catalog and Vehicle Listing (vPIC). After removing "unknown" cases, which accounted for about 25 percent of the data, it appears that cruiser, touring, and scooter types are much more commonly used in Florida compared to the MCCS.

Table 28 Motorcycle Type, MCCS and Florida, 2011–2019

Motorcycle Type	MCCS (%)	FL (2011-2019) (%)
Conventional street L1 or L3 vehicle (tank between knees)	6.6	-
Conventional street L1 or L3 vehicle (tank between knees)	6.3	-
Dual-purpose, on-road–off-road motorcycle	3.4	1.7
Sport, race replica	41.9	20.5
Cruiser	23.4	29.7
Chopper, modified chopper	3.1	0.3
Touring	5.1	14.9
Scooter	5.4	19.4
Step-through	1.7	8.4
Sport-touring	2.3	0.8
Off-road motorcycle, motocross, enduro, trials	0.6	1.0
Moped	0.3	3.3
Total (N)	100.0 (351)	100 (56424)

Figure 4 presents a comparison of rider age between crash cases and controls included in the MCCS and in Florida motorcycle crashes. The percentage of riders between ages 20–29 in crash cases is about twice the percentage observed for controls. This discrepancy is likely attributable to the MCCS pairing scheme, which matched crash and control cases by location and temporal factors. As a result, crash-control pairings often involved different age groups and motorcycle types. MCCS crashes also included a larger proportion of young riders (ages 20–29) than observed in Florida data. This means that some comparisons should be treated with caution, as rider age is widely known to be causally associated with motorcycle type and activity.

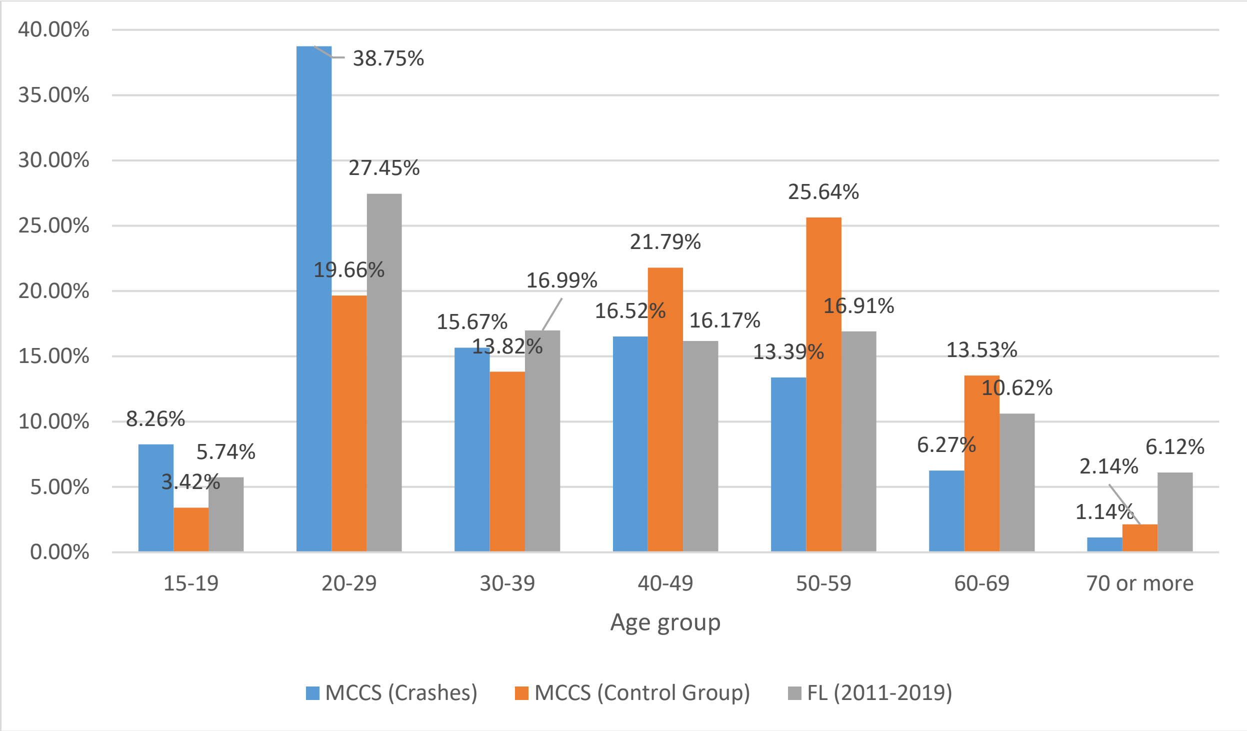


Figure 4 Age of motorcycle operators in crashes, MCCS data

Figure 5 provides information on the gender distribution of riders. Although a slightly larger percentage of female riders was observed in Florida, the distribution in MCCS and Florida crash data are relatively consistent, with male riders predominant across all groups at over 90%.

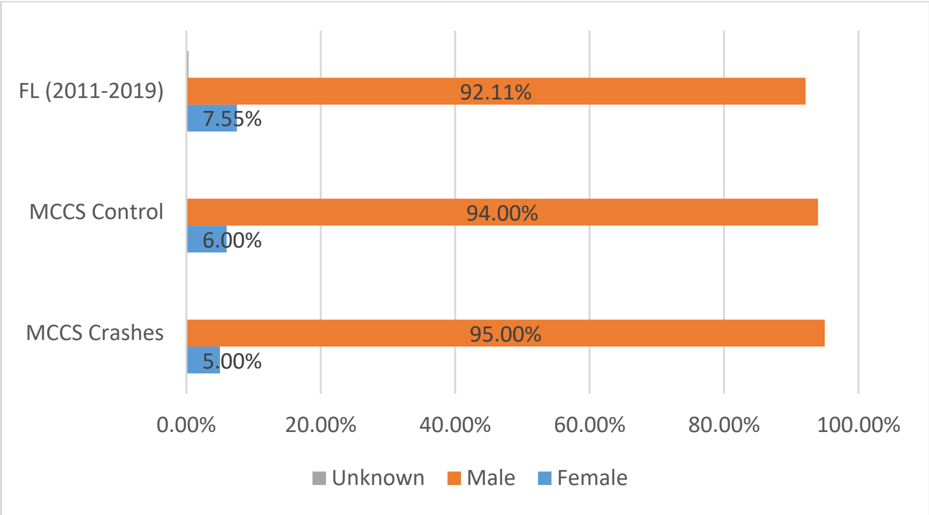


Figure 5 Gender, MCCS and Florida, 2011–2019

Overall, it appears that the pattern of motorcycle crashes in the two datasets is somewhat different. It is not clear whether this is due to divergent crash reporting practices or the result of sampling error. However, it does mean that it is necessary to evaluate the characteristics of local motorcycle populations and crashes to take advantage of MCCS findings. The MCCS dataset includes many unique details about motorcycle crashes, including information about injuries and the use of PPE such as helmets.

Table 29 shows the effects of motorcyclist upper extremity and upper torso coverage (UECE) on injury prevention or reduction. Motorcycle riders were indicated as wearing UECE in 51 percent of MCCS crashes. If upper extremity and upper torso coverage equipment was present, injuries in 57% of crash cases were prevented or reduced. **Table 30** shows the effects of motorcyclist lower extremity and lower torso coverage (LECE) on injury reduction and prevention. In total, 33 percent of motorcyclists wore LECE in MCCS crashes. If LECE equipment was present, the injuries in 9.1 percent of MCCS crashes were prevented or reduced.

Table 29 Effects of Motorcyclist Upper Extremity and Upper Torso Coverage on Injury Prevention and/or Reduction, MCCS Data

	Percent (%)
Equipment present but did not affect injury prevention	18.5
Equipment present and reduced injury	16.2
Equipment present and prevented injury	8.3
No injury-producing contact in the region of equipment	8.0
Equipment, not present, and injury occurred	20.2
Not applicable, no upper torso/extremity coverage	2.3
Other	0.3
Unknown	26.2
Total (N)	100 (351)

Table 30 Effects of Motorcyclist Lower Extremity and Lower Torso Coverage on Injury Prevention and/or Reduction, MCCS Data

	Percent (%)
Equipment present but did not affect injury prevention	16.5
Equipment present and reduced injury	8.0
Equipment present and prevented injury	1.1
No injury-producing contact in the region of equipment	7.4
Equipment, not present, and injury occurred	33.9
Not applicable, no lower torso/extremity coverage	4.0
Unknown	29.1
Total (N)	100 (351)

Footwear was also found to influence motorcycle rider injury prevention and reduction, as shown in **Table 31**. Results indicated that 18.8 percent of MCCS crashes had injury prevention or reduction if footwear was present. The effects of gloves on injury prevention were more significant than those of footwear. **Table 32** shows that injury in 30.8 percent of MCCS crashes tended to be reduced or prevented if gloves were present. Overall, motorcyclists wore footwear and gloves in 64 percent and 51 percent of MCCS crashes, respectively. However, it is important to note the large proportion of “unknown” for both footwear (27.4%) and glove (34.2%) use, which means that these results should be treated with caution.

Table 31 Effects of Motorcyclist Footwear on Injury Prevention and/or Reduction

	Percent (%)
Footwear present but did not affect injury prevention	13.7
Footwear present and reduced injury	10.3
Footwear present and prevented injury	8.5
No injury-producing contact in the region of the footwear	31.9
Footwear, not present, and injury occurred	6.8
Not applicable, no footwear coverage	0.9
Other	0.6
Unknown	27.4
Total (N)	100 (351)

Table 32 Effects of Motorcyclist Gloves on Injury Prevention and/or Reduction

	Percent (%)
Gloves present but did not affect injury prevention	5.7
Gloves present and reduced injury	9.7
Gloves present and prevented injury	21.1
No injury-producing contact in the region of gloves	15.4
Gloves, not present, and injury occurred	4.0
Not applicable, no gloves	9.7
Other	0.3
Unknown	34.2
Total (N)	100 (351)

As shown in **Table 33**, although most riders wore a helmet (84%), 31 percent of MCCS crash cases still experienced an injury to the head. Despite this high rate of use, it is important to note that California has a universal helmet law. More than 30 U.S. states lack universal helmet legislation, which makes state-level comparisons with MCCS data difficult. Still, helmets were attributed with reducing or preventing injury in around 45 percent of MCCS crashes, which confirms previous research about helmet use being an effective countermeasure for preventing or reducing motorcyclist injuries.

Table 33 Effects of Helmet Usage on Injury Reduction and Prevention

	Percent (%)
Helmet worn but injury occurred to head	20.8
Helmet worn but no effect on head injury	0.9
Equipment present and reduced injury	8.8
Equipment present and prevented injury	36.2
No injury-producing contact in the region	17.4
Not applicable, no helmet present	1.4
Other	0.3
Unknown	14.2
Total (N)	Total (N)

4.3.3 Motorcyclist Behaviors

Motorcyclist riding strategy, avoidance behavior, speed choice, evasive actions, and other riding skills can be highly associated with injury outcomes. **Table 34** describes the distribution of MCCS crashes by riding skill factors that reflect rider riding skills and experience. The top behavioral factors are faulty traffic strategies (34.5%), position relative to other traffic (29.9%), distraction (28.8%), low or exceedingly high-speed (28.8%), traffic scanning error (25.4%), skill deficiency (25.4%), and aggressive attitude (24.5%).

Table 34 Distribution of MCCS Crashes by Riding-skill-related Causal Factors

Causal Factor	Percent (%)
Motorcyclist faulty traffic strategy contributed to crash causation	34.5
Motorcyclist position relative to other traffic contributed to crash causation	29.9
Motorcyclist attention failure/distraction/stress contributed to crash causation	28.8
Motorcyclist slow or exceedingly high-speed difference caused or contributed to crash causation	28.8
Motorcyclist traffic scanning error contributed to crash cause	25.4
Motorcyclist skills deficiency presented as a contributing factor	25.4
Motorcyclist aggressive attitude contributed to crash causation	24.5
Motorcyclist lane choice contributed to crash causation	16.8
Motorcyclist view obstructions were present and contributed to crash causation	12.5
Motorcyclist alcohol or drug involvement contributed to crash causation	12.5
Evidence of control unfamiliarity as a contributing factor	8.3
Motorcyclist temporary traffic obstruction present and contributed to crash causation	6.6
Motorcyclist temporary traffic obstruction was a contributing factor	3.7
Gas-tank design affected the rider’s post-crash trajectory	3.1
Motorcyclist attention failure/distraction/stress present but did not contribute to crash causation	2.8
Gas-tank design contributed to the rider's pelvic injuries	2.6
Gross underinflation contributed to the loss of tire traction and caused the loss of control	2.0
Gross error of inflation contributed to stability problem and caused the loss of control	2.0

Table 35 presents the distribution of MCCS data by loss of control factors. Overall, 10 percent of motorcycle crashes ran wide on a turn or ran off-road, which is the top loss of control factor.

This finding is consistent with a previous study (*8*) that identified running-off-roadway crashes (ROR) as the primary type of motorcycle crash. Wheelies are an exclusive motorcycle loss-of-control behavior, accounting for the second-highest percentage (3.4%).

Table 35 Distribution of Motorcycle Crashes by Loss of Control Factors

	Percent (%)
No loss of control	64.7
Ran wide on turn, ran off road, under cornering	10.0
Lost wheelie	3.4
Low-speed wobble	0.9
High-speed wobble	0.6
Pitch weave, low speed	3.1
Pitch weave, high-speed cornering	0.9
End-over, endo, reverse wheelie	0.6
Over-braking/slide out	9.7
Total (N)	100 (351)

Table 36 presents the effects of motorcyclist failure factors on MCCS crashes. The most prevalent factor is failure to detect a potential hazard (28.8%), followed by an incorrect reaction (15.1%). Training programs are necessary to educate motorcyclists about how to detect potential risks and how to adopt correct reactions when responding those risks.

Table 36 Distribution of MCCS Crashes by Motorcyclist Failure Factors

	Percent (%)
No failure by motorcyclist	38.2%
Potential hazard-detection failure	28.8%
Impairment resulted in potential hazard-detection failure	6.3%
Incorrect reaction to potential hazard	15.1%
Incorrect action due to impairment	1.7%
Potential hazard detected, reaction-time failure	5.7%
Potential hazard detected; reaction-time failure due to impairment	1.4%
Total (N)	100% (351)

Figure 6 shows the distribution of MCCS crashes by whether or not an evasive action was taken. It was found that riders in 61 percent of MCCS crashes took an evasion action.

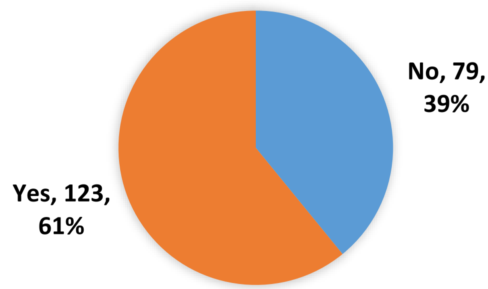


Figure 6 Distribution of MCCS crashes by evasive action

Table 37 presents the distribution of MCCS crashes by license type. Although a valid license is required in California, riders in 5.4 percent of MCCS crashes had no license, and only 0.1 percent of MCCS control cases demonstrated a similar phenomenon. In addition, the percentage of those with a motorcycle license in MCCS crashes was 69.8 percent, which is significantly lower than what was observed in MCCS control cases (93.7%). A valid motorcycle license is important to ensure motorcycle safety.

Table 37 Distribution of MCCS Crashes and Controls by License Type

License Type	Crash Cases		Paired Controls	
	Number	*Percent (%)*	*Number*	*Percent (%)*
No license	19	5.4	1	0.1
Learner's permit only	12	3.4	12	1.7
Motorcycle license	245	69.8	658	93.7
Automobile license	61	17.4	29	4.1
Other	5	1.4	1	0.1
Unknown	9	2.6	1	0.1
Total	351	100.0	702	100.0

Table 38 shows the connection between rider violation records and MCCS crashes. In total, 10.3 percent of riders involved in MCCS crashes had violation records, and 21.1 percent of riders in MCCS crashes had no related violation records.

Table 38 Distribution of MCCS Crashes by Violation Record

Previously-recorded violations related to current-crash contributions?	Count	Percent (%)
Unrelated violations on record	74	21.1
Record of violations for actions similar to those in crash	36	10.3
Not applicable, no violations on record	69	19.7
Unknown	172	49.0

Table 39 provides braking evidence on the front and rear tires; it appears that more riders tended to use rear braking at the time of collision.

Table 39 Braking Evidence on Front and Rear Tires for Crash-involved Motorcycles

Front Tire	Percent (%)	Rear Tire	Percent (%)
None	85.2	None	76.6
Evidence of moderate braking	4.6	Evidence of moderate braking	3.1
Evidence of heavy braking without wheel lock-up	0.3	Evidence of heavy braking without wheel lock-up	2.3
Evidence of heavy locked-wheel braking, one skid patch	3.7	Evidence of heavy locked-wheel braking, one skid patch	9.7
Evidence of heavy locked-wheel braking, multiple skid patches	0.6	Evidence of heavy locked-wheel braking, multiple skid patches	1.7
Unknown	5.7	Unknown	6.6

An antilock braking system (ABS) is used to prevent the wheels from locking up during braking so as to maintain contact with the road's surface. It is believed that ABS can prevent motorcycle injuries. Relatively speaking, crash-involved motorcycles have a lower percentage of ABS usage in the front tire (4.6% vs. 14.5%) and rear tire (4.0% vs. 14.1%), as shown in **Table 40**.

Table 40 ABS Usage in MCCS

ABS	Front		Rear	
	Case (%)	Control (%)	Case (%)	Control (%)
No	91.7	85.2	92.9	85.8
Yes	4.6	14.5	4.0	14.1
Not applicable	3.4	0.3	2.8	0.1
Unknown	0.3	0.0	0.3	0.0

In summary, it is clear that the MCCS collected many unique variables that provide considerable insight regarding contributing and causal factors for motorcycle crashes. However, the limited sample size of MCCS crashes places constraints on the further development of advanced statistical techniques for motorcycle crash analysis.

4.4 Crash Analysis (LTAP, FTC, and ROR)

4.4.1 Left-Turning across Path Crashes (LTAP)

Definition and Data Filtering

LTAP collision events involve a left-turning vehicle hitting a motorcycle and have been identified by previous studies (*13–15*) as the motorcycle crash type with the highest risks. **Figure 7** shows possible trajectories of the motorcycle and other vehicle (OV) in LTAP crashes (69, 83, and 77 represent motorcycle trajectories).

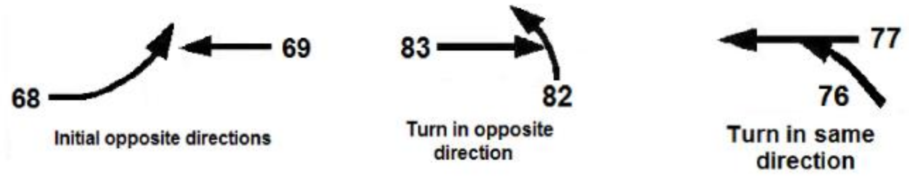


Figure 7 LTAP crash diagram

When crash type is applied, a total of 45 LTAP cases were identified. Their paired controls—non-crash motorcycle driving events—were selected and used for comparison. Consistent with the age distribution of all crashes, younger riders have higher risks in LTAP crashes after eliminating the influence caused by time of day, day of week, and location.

Roadway and Environment

The distribution of LTAP crashes by weather condition for MCCS and Florida crash data are shown in **Table 41**. A higher percentage of cloudy conditions in MCCS crashes may result from the limited sample size of LTAP crashes in MCCS data.

Table 41 Distribution of LTAP Crash Percentages by Weather Condition, MCCS and FDOT CARS

Weather Conditions	MCCS (%)	Florida, 2011-2019 (%)
Clear	55.56	82.48
Cloudy, partly cloudy	35.56	13.65
Overcast	6.67	3.33
Drizzle, light rain	2.22	0.54
Total (N)	100.0 (45)	100.0 (7,618)

The distribution of LTAP crashes by lighting condition for MCCS and Florida data are shown in **Table 42**. In Florida crash reports, continuous illumination and spot illumination are not distinguished from lighted nighttime conditions.

Table 42 Distribution of LTAP Crashes by Lighting Conditions, MCCS and FDOT CARS

Lighting Condition	MCCS (%)	Florida, 2011-2019 (%)
Daylight, bright	48.89	60.62
Daylight, not bright	17.78	4.70
Dusk, sundown	8.89	2.00
Night, lighted	11.11	25.30
Night, continuous illumination	6.67	7.21
Night, spot illumination	6.67	0.20
Total (N)	100.0 (45)	100.0 (7,618)

The distribution of LTAP crashes by roadway classification in MCCS and Florida data are presented in **Table 43**. As shown, the percentage of LTAP crashes that occurred on local roads differs considerably in MCCS and Florida data.

Table 43 LTAP Crashes by Roadway Functional Classification, MCCS and Florida, 2011–2019

Roadway Functional Classification	MCCS (%)	Florida, 2011-2019 (%)
Interstate/freeway mainline	0.0	0.02
Freeway entrance ramp	0.0	1.64
Freeway transition (freeway to freeway)	0.0	2.79
Principal arterial, nonfreeway	46.67	59.53
Minor arterial	35.56	24.74
Collector	4.44	1.94
Local road/street	13.33	3.26
Parking area, off-street	0.0	0.22
Total (N)	100.0 (45)	100.0 (7,618)

Motorcyclist Features and Behaviors

Age distributions of LTAP riders in MCCS and Florida crashes are presented in **Figure 8**. It is not surprising that younger riders have a larger share of LTAP crashes, a fact that might be related to younger rider inexperience, lack of professional training, and careless riding.

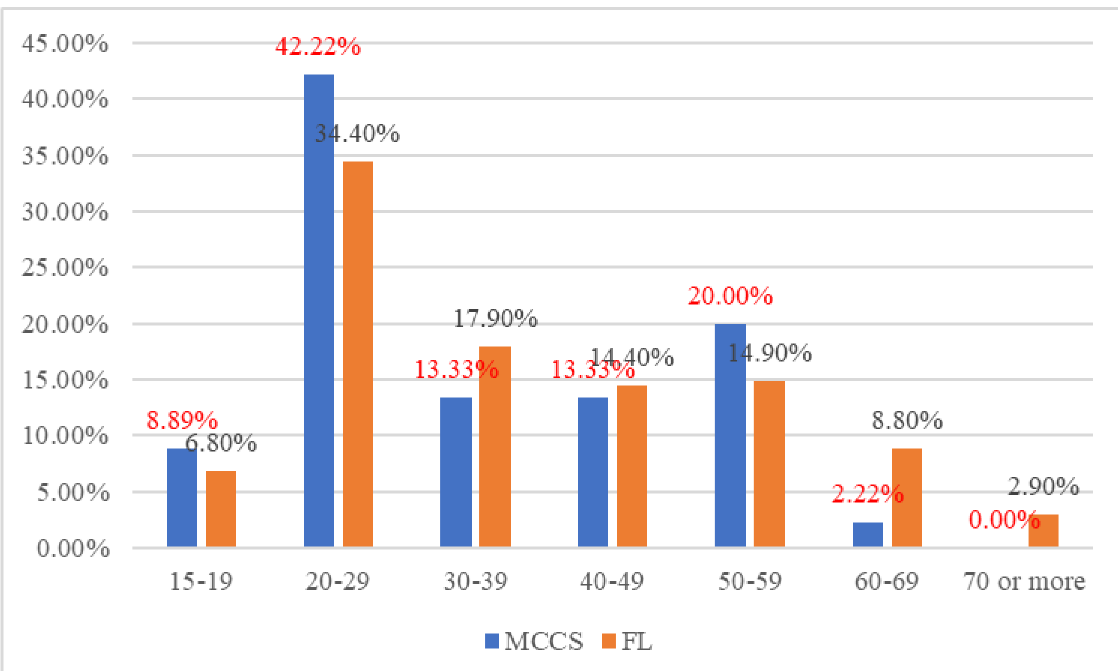


Figure 8 Age of motorcyclists in LTAP crashes, MCCS and Florida, 2011–2019

Table 44 compares the types of helmet coverage between LTAP crash cases and paired controls. There is a higher percentage of partial coverage in controls than in LTAP crashes.

Table 44 Type of Helmet Coverage in LTAP Crashes and Paired Controls

Type of Helmet Coverage	Crash Cases (%)	Controls (%)
Partial coverage	11.1	28.3
Full coverage	2.2	6.5
Full-facial coverage, integral chin bar but no face shield	6.7	2.2
Full-facial coverage, retractable chin bar	2.2	8.7
Full-facial coverage, integral chin bar and face shield	48.9	45.7
Open-face helmet with flat wraparound face shield	0.0	2.2
Open-face helmet with bubble-type face shield	2.2	--
Open-face helmet with visor/face-shield combo	0.0	6.5
Unknown	26.7	0.0
Total	100.00	100.00

Table 45 provides information on factors contributing to motorcycle rider loss of control in LTAP crashes. The majority of riders (71.1%) believe they lost control due to all three factors—weather, roadway, and mechanical problems.

Table 45 Factors Contributing to Motorcyclist Loss of Control in LTAP Crashes

Loss of Control due to	Count	Percent (%)
No control loss due to weather, roadway, or mechanical problems	32	71.1
Yes, control loss due to weather	3	6.7
Yes, control loss due to mechanical problems	7	15.6
Yes, control loss due to both weather and mechanical problems	1	2.2
Yes, control loss due to all three	1	2.2
Other	1	2.2

As shown in **Table 46**, based on the path of the motorcycle and other vehicle, there are generally three LTAP crash scenarios. After mapping the location described onto the diagrams presented in **Figure 7**, it was found that the first scene—a motorcycle and a left-turning vehicle approaching from the left-front side of the motorcycle—has the highest risks among the three cases.

Table 46 Other Vehicle Location Relative to Motorcycle in LTAP Crashes

OV Location Relative to MC	Count	Percent (%)
180 degrees opposed (oncoming)	5	11.1
Left-front	23	51.1
Left	15	33.3
Right-front	1	2.2
Directly in front	1	2.2

Generally, a motorcycle rider can detect hazard conditions, decide on a negotiation strategy, and avoid potential conflicts and collisions. The choice of collision avoidance actions in the procedure is significant under hazardous conditions. **Table 47** presents a distribution of collision avoidance actions taken by riders.

Table 47 Collision Avoidance Actions Taken by Riders in LTAP Crashes

Collision Avoidance Actions Taken	Count	Percent (%)
No action	10	22.2
Braking	27	60.0
Swerving	6	13.3
Counter steering	2	4.4

4.4.2 Following Too Close Crashes (FTC)

Definition and Data Filtering

Following too close (FTC) crashes are another important type of motorcycle crash. FTC is defined as a crash in which the motorcyclist was following too closely behind the other motor vehicle or as a rear-end crash in which the involved vehicle had a rear-side damage point. After filtering, 26 cases were found that meet these criteria.

Roadway and Environment

The distribution of FTC crashes by weather condition in MCCS and Florida crash data are shown in **Table 48**. The relatively higher share of cloudy and overcast conditions in FTC crashes in MCCS data may result from the limited sample size of FTC crashes.

Table 48 FTC Crashes by Weather Condition, MCCS and Florida, 2011–2019

Weather Condition	MCCS (%)	Florida, 2011-2019 (%)
Clear	57.7	85.13
Cloudy, partly cloudy	26.9	10.08
Overcast	11.5	4.65
Other	3.8	0.13
Total (N)	100.0 (26)	100.0 (2,858)

The distribution of FTC crashes by lighting condition in MCCS and Florida data are shown in **Table 49**. In Florida crash reports, continuous illumination and spot illumination are not distinguished from lighted nighttime conditions.

Table 49 FTC Crashes by Lighting Conditions, MCCS and Florida, 2011–2019

Lighting Condition	MCCS (%)	Florida, 2011-2019 (%)
Daylight, bright	69.2	68.70
Daylight, not bright	15.4	20.88
Dusk, sundown	0.0	3.65
Night, lighted	3.8	6.76
Night, continuous illumination	3.8	--
Night, spot illumination	7.7	--
Total (N)	100.0 (26)	100.0 (2,858)

The distribution of roadway functional classifications in FTC crashes from MCCS and Florida crash data are shown in **Table 50**.

Table 50 FTC Crashes by Roadway Functional Classification, MCCS and Florida, 2011-2019

Roadway Functional Classification	MCCS (%)	Florida, 2011-2019 (%)
Interstate/freeway mainline	7.7	5.72
Freeway entrance ramp	3.8	2.41
Freeway transition (freeway to freeway)	3.8	1.74
Principal arterial, non-freeway	57.7	66.05
Minor arterial	26.9	19.53
Collector	0.0	1.07
Local road/street	0.0	0.17
Parking area, off-street	0.0	0.62
Total (N)	100.0 (26)	100.0 (2,858)

Motorcyclist Features and Behaviors

Age distributions of motorcyclists in FTC crashes are shown in **Figure 9**. Younger riders under age 39 have higher crash risks in FTC crashes; this finding is consistent with what is found for all motorcycle crashes included in the MCCS database. As shown in **Figure 10**, while riders were predominantly male in both datasets, females accounted for a larger proportion of riders in Florida than in MCCS (17% vs. 8%).

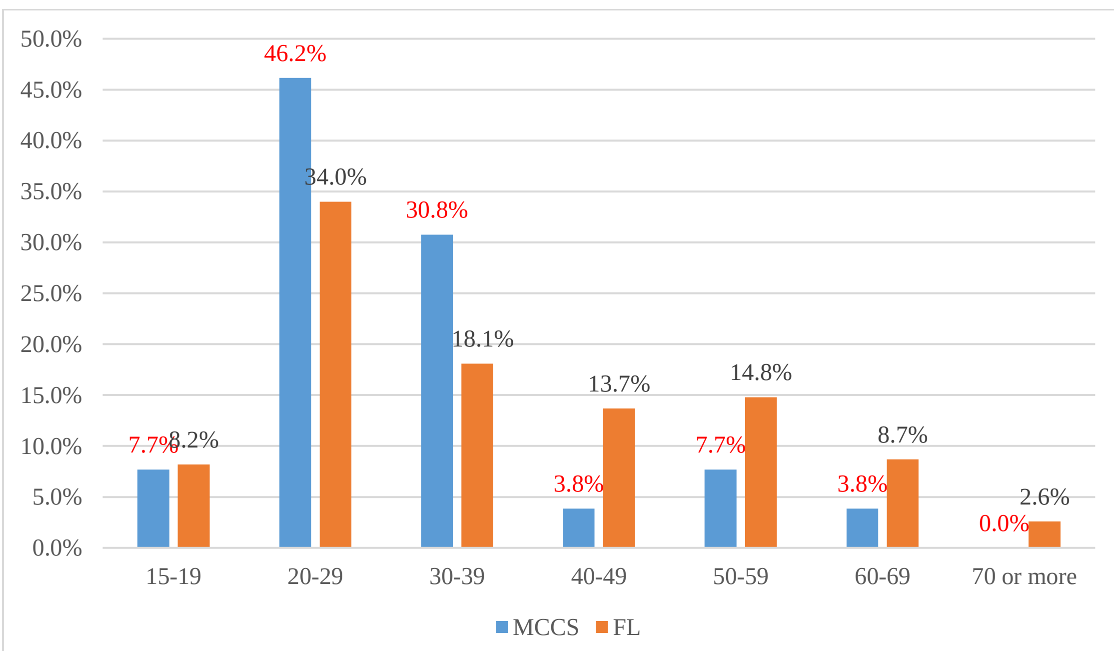


Figure 9 Age of motorcyclists in FTC crashes, MCCS and Florida, 2011–2019

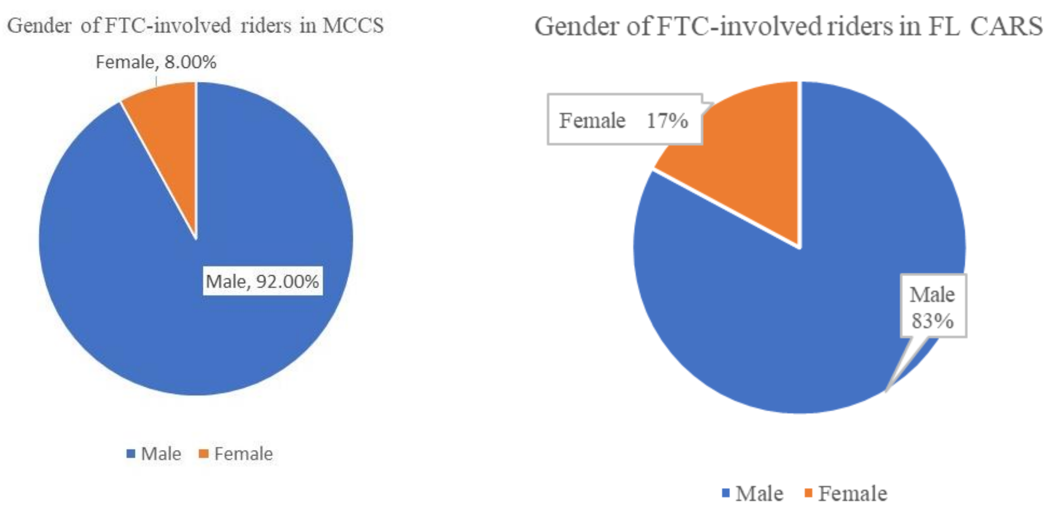


Figure 10 Gender in FTC crashes and paired controls

Compared with control events, fewer riders in FTC crashes used partial-coverage helmets as their protection equipment, as shown in **Table 51**.

Table 51 Types of Helmet Coverage in FTC Crashes and Paired Controls

Type of Helmet Coverage	FTC Crashes		Controls	
	Count	*Percent (%)*	*Count*	*Percent (%)*
Partial coverage	2	8.7	8	17.4
Full coverage	1	4.3	6	13.0
Full-facial coverage, integral chin bar but no face shield	0	0.0	0	0.0
Full-facial coverage, retractable chin bar	4	17.4	3	6.5
Full-facial coverage, integral chin bar and face shield	11	47.8	29	63.0
Open-face helmet with flat wraparound face shield	0	0.0	3	6.5
Open-face helmet with visor/face-shield combo	0	0.0	1	2.2
Unknown	8	34.8	2	4.3
Total	26	100.00	52	100.00

Around 60% of riders lost control in FTC crashes (**Table 52**). The collision avoidance actions taken by motorcyclists often vary, so **Table 53** provides information about the specific avoidance actions taken in FTC crashes. It is not surprising to find that most riders used braking when attempting to avoid the collision in this scenario.

Table 52 Factors Contributing to Motorcyclist Loss of Control in FTC Crashes

Loss of Control due to	Count	Percent (%)
No control loss	8	30.8
Roadway factors	1	3.8
All weather, roadway, and mechanical problems	15	57.7
Unknown	2	7.7

Table 53 Collision Avoidance Actions Taken by Riders in FTC Crashes

Collision Avoidance Actions Taken	Count	Percent (%)
No avoidance actions	1	3.8
Braking	14	53.8
Downshifting	2	7.7
Steering left	6	23.1
Steering right	1	3.8
Laid bike down	2	7.7

4.4.3 Roadway Departure Crashes (ROR)

Definition and Data Filtering

Roadway departure crashes (ROR) are single-motorcycle crashes with a motorcycle crossing an edge line or a centerline or otherwise leaving the travelway. In total, 35 out of the 351 crashes were identified as ROR.

Roadway and Environment

The distribution of ROR crashes by weather condition in MCCS and Florida crash data are shown in **Table 54**.

Table 54 ROR Crashes by Weather Condition, MCCS and Florida, 2011–2019

Weather Condition	MCCS (%)	Florida 2011-–2019 (%)
Clear	51.43	83.64
Cloudy, partly cloudy	34.29	12.71
Overcast	11.43	2.54
Other	1.00	1.11
Total (N)	100.0 (35)	100.0 (2,793)

The distribution of ROR crashes by lighting condition in MCCS and Florida data are shown in **Table 55.**

Table 55 ROR Crashes by Lighting Conditions, MCCS and Florida, 2011–2019

Lighting Condition	MCCS (%)	Florida, 2011-2019 (%)
Daylight, bright	31.43	52.13
Daylight, not bright	8.57	3.54
Dusk, sundown	2.86	23.99
Night, lighted	11.43	18.73
Night, not lighted	5.71	0.39
Night, continuous illumination	8.57	0.07
Night, spot illumination	31.43	0.18
Total (N)	100.0 (35)	100.0 (2,793)

The distribution of roadway functional classifications in ROR crashes from MCCS and Florida crash data are shown in **Table 56**.

Table 56 ROR Crashes by Roadway Functional Classification, MCCS and Florida, 2011–2019

Roadway Functional Classification	MCCS (%)	Florida, 2011–2019 (%)
Interstate/freeway mainline	0.0	3.38
Freeway entrance ramp	0.0	4.48
Freeway transition (freeway to freeway)	2.86	4.57
Principal arterial, non-freeway	37.14	39.12
Minor arterial	31.43	14.26
Collector	5.71	2.74
Local road/street	20.00	7.59
Parking area, off-street	2.86	5.20
Total (N)	100.0 (35)	100.0 (2,793)

Motorcyclist Features and Behaviors

Figure 11 presents a comparison of age group shares between ROR crashes and paired controls. Young riders under age 30 make up a larger share of ROR crashes than controls. This finding might be related to riding distraction, lack of riding experience, or other riding behaviors.

As the shares of male and female riders are the same in cases and controls, comparison between gender percentages in the two groups was omitted for ROR crashes. **Table 57** shows that for ROR crashes, like other types of crashes, half of the involved riders wore helmets with full-facial coverage, and more riders in the control group wore helmets with partial coverage.

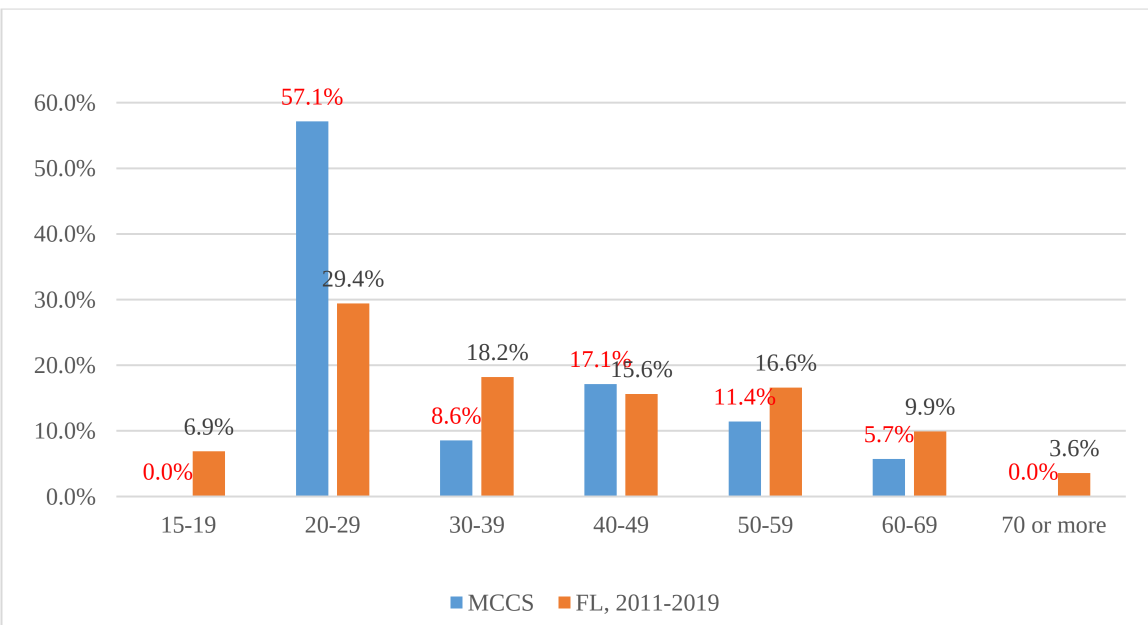


Figure 11 Age of motorcyclists in ROR crashes, MCCS and Florida, 2011–2019

Table 57 Types of Helmet Coverage in ROR Crashes and Paired Controls

Type of Helmet Coverage	ROR Crashes (%)	Controls (%)
Partial coverage	8.57	28.57
Full coverage	2.86	2.86
Full-facial coverage, integral chin bar but no face shield	2.86	4.29
Full-facial coverage, retractable chin bar	0.00	5.71
Full-facial coverage, integral chin bar and face shield	51.43	50.00
Open-face helmet with flat wraparound face shield	0.00	1.43
Open-face helmet with visor/face shield combo	0.00	4.29
Open-face helmet with removable gravel guard	0.00	1.43
Not applicable, no helmet	5.71	0.00
Other	28.57	1.43
Unknown	100.00 (35)	100.00 (70)

4.5 Findings and Summary

Through detailed data review and analysis, the CUTR research team built an in-depth understanding of MCCS data. Due to the limited sample size (351), statistical models could not be employed for MCCS data. The descriptive statistics provide an in-depth comparison between the three crash types, and the enriched MCCS database provides exclusive information about crash causations and contributing factors. Major findings are the following:

- Overall, the 351 crashes in Orange County could mirror the motorcycle exposure in California, as the percentages are similar to those in Florida data.
- Overall, there were 23 LTAP crashes, 26 FTC, crashes and 35 ROR crashes in the period of 2011–2019.
- Young riders have larger shares of all three types of crashes.
- Appropriate braking strategies could reduce collisions dramatically. In addition, innovative technology—for example, an antilock braking system (ABS)—can protect riders and prevent injuries.
- Rider clothing, footwear, gloves, and other accessories have positive effects on motorcycle rider injury prevention and reduction.

5. Florida LTAP Crash Modeling and Analysis

After analyzing the MCCS dataset, it was learned that adding the selected MCCS variables to Florida Crash data would be a challenging (but feasible) task. The research team believed that it would be worth the effort if Florida Traffic Homicide Investigation (THI) reports could be obtained, as those reports include more detailed narratives and diagrams to scale. Florida DHSMV was contacted, and two meetings were held to discuss the request. However, the task was cancelled due to a delay in getting the reports. Instead, the analysis focused on existing crash data, with the consideration of MCCS findings.

Based on Florida crash data from the FDOT Crash Analysis Reporting System (CARS), LTAP crashes were found to be the most dangerous type of motorcycle crash in the state between 2011 and 2019, accounting for over 30 percent of all fatal motorcycle crashes. Statistical models were developed in this study to address factors contributing to Florida LTAP crash risks, including occurrence and outcomes (injury severity).

5.1 Data Preparation

An LTAP crash is a collision event that involves a left-turning vehicle hitting a motorcycle. LTAP crashes usually occur at two kinds of roadway facilities: signalized intersections and unsignalized intersections (stop signs, roundabouts, others). Due to different traffic patterns and driving and riding behaviors at these two intersection types, separate models were developed to address them. Non-LTAP crashes were used to provide a baseline.

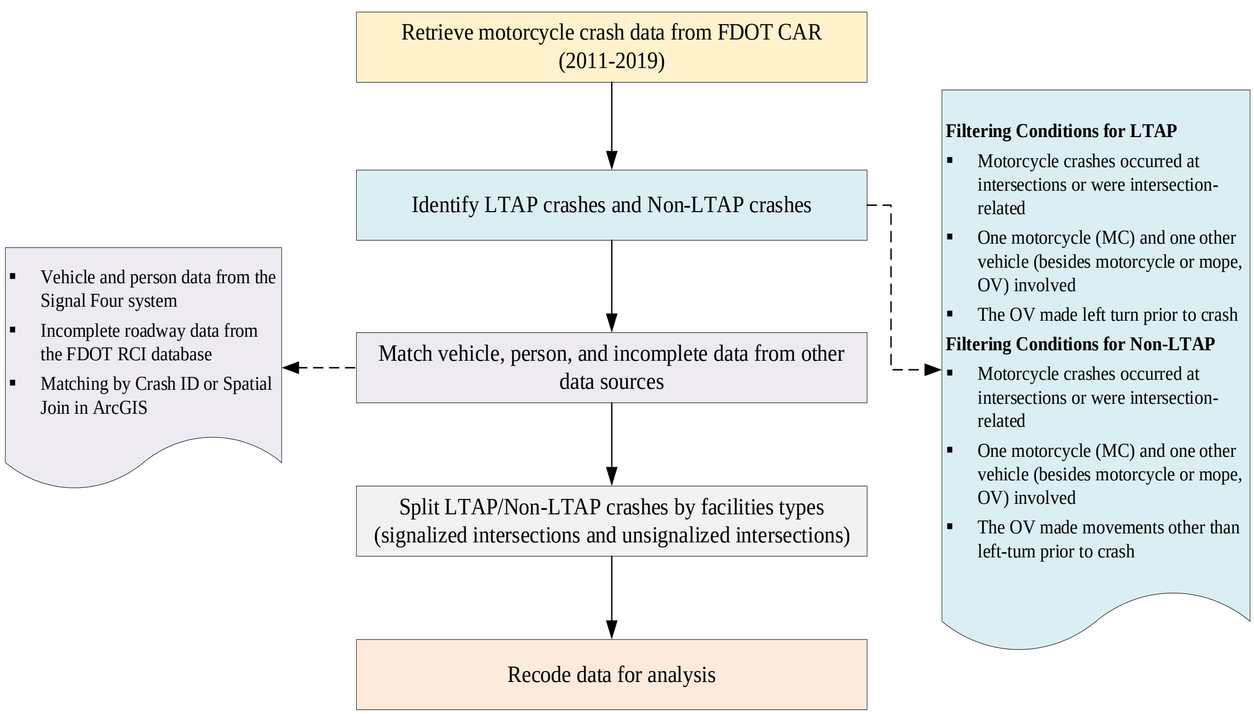


Figure 12 Data preparation procedure for LTAP crash modeling

Figure 12 exhibits the data preparation procedure for LTAP crash analysis. The CUTR research team retrieved motorcycle crash data for 2011–2019 using FDOT CARS. Filtering conditions were applied to identify LTAP crashes and non-LTAP crashes. Complementary data (e.g., vehicle features, driver/rider characteristics, incomplete roadway data) were matched from other data sources. The LTAP/non-LTAP data were split into two datasets by facility type—signalized intersections and unsignalized intersections. The research team recoded the datasets (categorization, normalization, and missing data removal) for statistical analysis and modeling.

Figure 13 shows a comparison of the injury severity distribution between LTAP and non-LTAP crashes. A Chi-square test was used to examine the significance of the two crash types. Results showed that LTAP crashes are more likely to cause severe injuries and fatalities than non-LTAP crashes.

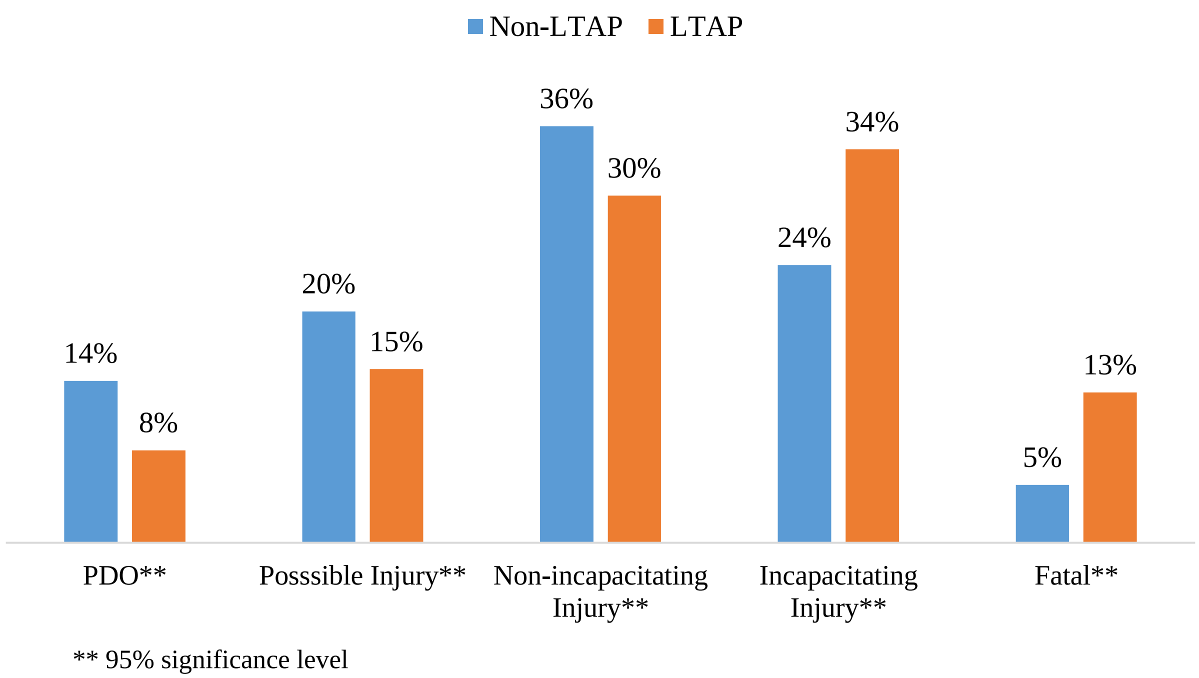


Figure 13 Factor analysis between LTAP and non-LTAP crashes: Accident injury severity

5.2 Modeling Relative Risk for LTAP Occurrence

A major objective of this study was to delineate risk factors that contribute to the occurrence of LTAP crashes in Florida and quantify their effects. To achieve this, this study adopted the binary logistical model to compare the likelihoods of LTAP and non-LTAP crashes at the crash level. Compared to traditional site-level analyses, which organize data by sites and predict crash frequencies by given site characteristics, the crash-level model, which organizes data by crashes and estimates the likelihood of LTAP relative to non-LTAP by given site, vehicle, and person characteristics, can investigate more detailed information such as vehicle and person features. However, crash-level modeling provides an estimation of the relative risk of LTAP occurrence (risk of LTAP occurrence over non-LTAP) rather than the absolute risk (likelihood of LTAP occurrence or numbers).

5.2.1 Methodology

For each crash that involved one motorcycle (MC) and one other vehicle (OV) at an intersection, a binary variable was defined to indicate if the crash was LTAP (=1, OV making left-turn) or non-LTAP (= 0, OV making movement other than left-turn). To fit this binary variable, the binary logistic model is a natural technology. The model formula is given as

$$\Pr(y_i = 1|X_i) = \Phi(X_i\beta) = \frac{\exp(X_i\beta)}{1 + \exp(X_i\beta)} \tag{1}$$

where $\Pr(\cdot)$ denotes the probability of the *i*th crash observation (y_i) being LTAP; β is the vector of regression coefficients; X_i is the vector of explanatory variables for crash observation i; and Φ is the cumulative distribution function (CDF) of the logistic distribution. The maximum likelihood estimation (MLE) technique was used to estimate the coefficients of the logistic model.

The odds were used to interpret the relative risk of LTAP occurrence over non-LTAP occurrence, given a motorcycle-vehicle crash occurred at an intersection. The formula of odds is given as

$$Odds = \frac{P(LTAP)}{P(Non - LTAP)} \tag{2}$$

If a factor changes from B → A, the change of the relative risk of LTAP occurrence compared to non-LTAP occurrence is odds ratio (OR):

$$OR = \frac{Odds_A}{Odds_B} = \frac{P_A(LTAP) \times P_B(Non - LTAP)}{P_B(LTAP) \times P_A(non - LTAP)} \tag{3}$$

If OR is greater than 1, it could be explained that the factor change tends to increase the relative risk of LTAP occurrence; if OR is less than 1, it indicates that the factor change is more likely to decrease the relative risk of LTAP occurrence. If it is close to 1, it means that the factor does not have an impact on the relative risk of LTAP occurrence.

5.2.2 Estimated Relative Risk LTAP Model for Signalized Intersections

Table 58 shows the estimated binary logistic model for signalized intersections. The distribution of dependent variables (LTAP) indicates that approximately half of motorcycle-vehicle crashes at signalized intersections could be identified as LTAP.

Table 58 Relative Risk Model for LTAP at Signalized Intersections

Logistic Regression			Number of observations = 3,280		
Log likelihood	-1813.3438		Pseudo R^2	0.1978	
Variable Name	**OR**	**S.E.**	**p-Value**	**Frequency**	**Percent (%)**
Dependent variable (LTAP)	--	--	--	1322	40.29
Constant	1.096	0.236	0.00	--	--
Crash Time					
0-18:00	--	--	--	3,692	66.05
18:00-21:00***	1.983	0.206	0.000	1,166	20.86
21:00-24:00***	1.654	0.204	0.000	732	13.09
Shoulder Width					
0-2 ft	--	--	--	3,683	65.89
2-4 ft***	0.775	0.074	0.008	1,140	20.39
4-6 ft***	0.566	0.0724	0.000	481	8.60
6-8 ft***	0.568	0.117	0.006	144	2.58
Over 8 ft	0.974	0.175	0.481	142	2.54
AADT					
0—20,000	--	--	--	733	21.82
20,000-40,000**	0.798	0.086	0.038	1,571	46.76
40,000-60,000**	0.728	0.088	0.007	889	26.46
60,000-1000,000**	0.652	0.135	0.039	167	4.97
Motorcyclist Movement Conditions					
Straight ahead	--	--	--	3,915	70.04
Turning left***	0.205	0.029	0.000	576	10.30
Turning right***	0.061	0.010	0.000	234	4.19
Changing lanes***	0.183	0.070	0.000	63	1.13
Making U-turn***	0.034	0.035	0.000	27	0.48
Overtaking/passing***	0.374	0.213	0.000	52	0.93
Slowing***	0.015	0.006	0.000	504	9.02
Negotiating a curve***	0.068	0.027	0.000	118	2.11
Motorcycle Approach Speed Limit					
0-30 mph**	0.694	0.096	0.011	885	15.83
30-40 mph	--	--	--	1,896	33.92
Over 40 mph***	0.719	0.067	0.000	2,809	50.25
Motorcyclist Age Group					
Under 20	0.898	0.139	0.517	504	9.21
20-30	--	--	--	1632	29.82
30-40*	0.808	0.104	0.085	839	15.33
40-50*	0.795	0.100	0.067	898	16.41
50-60***	0.728	0.089	0.008	958	17.51
Over 60**	0.735	0.114	0.037	641	11.71
Male rider indicator***	1.859	0.320	0.000	5,154	92.20
Older OV driver***	1.301	0.108	0.001	2,173	38.87
Local OV driver***	1.294	0.120	0.005	4,228	75.64

*= 90% significance level, **= 95% significance level, ***= 99% significance level

Through the estimated model (**Table 58**), the following findings were obtained:

- LTAP crashes are more likely to occur during the evening (18:00–21:00) and early night (21:00–24:00). The relative risk of LTAP during the two-time windows is 1.983 times and 1.654 times as high as that for other times of day (0:00–18:00). The possible causes include (1) reduced visibility and relatively high-risk driving behaviors (i.e., high speed, impaired driving, etc.) compared to daytime [6:00–18:00], and (2) relatively high traffic compared to after midnight ([0:00–6:00]).
- A shoulder width of 2–8 ft experiences a lower relative risk of LTAP (0.775 times for 2–4 ft, 0.566 times for 4–6 ft, 0.568 times for 6–8 ft) compared to a narrow shoulder (<2 ft). A wider shoulder is usually related to high-level roadways with better sight distance and avoidance space, which allow drivers and riders to detect each other much earlier and take actions to avoid collisions. It is interesting to find that if shoulders are wider than 8 ft, the relative risk of LTAP is not significantly different than what is observed for narrow shoulders.
- High AADT is associated with a low relative risk of LTAP. Compared to low-traffic conditions (AADT < 20,000), higher AADTs (20,000–40,000, 40,000–60,000, and >60,000) are more likely to experience a relative risk of LTAP of 0.798 times, 0.728 times, and 0.652 times, respectively. AADT is the design criteria for intersection geometry and traffic signal timing. High AADTs correspond to major intersections with better sign distances and protected left-turn signals. Thus, the risk of LTAP is lower at a major intersection.
- If motorcyclists make movements other than going straight (turn, slow, negotiate a curve, overtake), the relative risk of LTAP is much lower. The most common movement for motorcyclists involved in LTAP crashes is going straight.
- It is interesting to find that a speed limit on motorcycle approach of 30–40 mph experiences the highest relative risk for LTAP. It is intuitive that motorcyclists riding at a relatively low speed (<30 mph) have more reaction time to avoid left-turning vehicles. A speed limit on motorcycle approach higher than 40 mph is more likely to be associated with a protected left-turn signal. The relative risk of LTAP should be lower for these intersections.
- Rider age has a significant impact on the relative risk of LTAP. Motorcyclists ages 30–40, 40–50, 50–60, and over 60 are less likely to be involved in an LTAP crash (0.808 times, 0.795 times, 0.728 times, and 0.735 times, respectively) compared to younger riders (age <30). Relatively high safety consciousness and unaggressive riding behaviors for middle-age and older adult riders are the causes of this phenomenon.
- Male riders are more likely to be involved in LTAP crashes compared to female riders. Male riders experience a relative risk of LTAP that is 1.859 times higher than for females. Relatively poor safety consciousness and aggressive riding behaviors for males may cause their high LTAP risks.

- Older drivers of the other vehicle (OV) are more likely to be involved in an LTAP crash. Their relative risk for LTAP crashes is 1.301 times as high as that for adult and young drivers. Older drivers have relatively poor abilities to detect and react to motorcycles when they make a left turn.
- Local drivers are more likely to be involved in an LTAP crash. As they are familiar with intersections and tend to be overconfident when they make left turns, local drivers are more likely to engage in high-risk behaviors such as neglecting to scan the surrounding environment, operating their vehicles at high speeds, and running through yellow lights. These high-risk behaviors may increase the risk of LTAP crashes.

5.2.3 Estimated Relative Risk LTAP Model for Unsignalized Intersections

The estimated model for the relative risk of LTAP at unsignalized intersections is given in **Table 59**. At unsignalized intersections, LTAP crashes have a share of 46.32 percent, which is more than the share at signalized intersections (40.29%).

Table 59 Relative Risk Model for LTAP at Unsignalized Intersections

Logistic Regression			Number of observations =4,429		
Log likelihood -2977.5104			Pseudo R^2 0.0301		
Variable Name	**OR**	**S.E.**	**p-Value**	**Frequency**	**Percent (%)**
Dependent Variable (LTAP)				2,069	46.72
Constant	1.096	0.236	0.43	--	--
Crash Time					
0-3:00	--	--	--	436	3.91
3:00-9:00**	1.566	0.278	0.011	1,209	10.84
9:00-12:00	1.272	0.238	0.199	1,355	12.15
12:00-18:00**	1.429	0.241	0.034	5,050	45.28
18:00-21:00**	1.383	0.228	0.049	2,135	19.14
21:00-24:00*	1.422	0.258	0.052	969	8.69
Shoulder Width					
0-2 ft	--	--	--	308	6.95
2-4 ft***	0.643	0.082	0.001	2,453	55.38
4-6 ft***	0.631	0.086	0.001	1,391	31.41
Over 6 ft	0.783	0.137	0.161	277	6.25
Motorcycle Approach Speed Limit					
0-30 mph	--	--	--	3,119	27.96
30-40 mph***	1.860	0.210	0.000	3,342	29.96
40-50 mph***	2.190	0.240	0.000	3,741	33.54
Over 50 mph***	2.048	0.263	0.000	952	8.54
Rider age over 60 indicators***	0.784	0.070	0.006	1,601	14.35
Male rider indicator***	1.738	0.269	0.000	10,364	92.92
Local rider indicator*	1.154	0.082	0.051	8,681	77.83
Other Vehicle Approach Traffic Way Conditions					
Two-way, not divided	--	--	--	6,463	57.94
Two-way, not divided, with continuous left turn lane***	1.504	0.188	0.001	646	5.79
Two-way, divided, unprotected (painted >4 ft) median	0.887	0.097	0.266	824	7.39
Two-way, divided, positive median barrier***	0.832	0.061	0.006	2,924	26.21
Unknown	0.372	0.257	0.106	254	2.28
Older motor vehicle driver indicator (age > 60)***	1.188	0.075	0.008	4,594	41.19
Male motor vehicle driver indicator***	0.836	0.052	-2.88	5,789	51.90

*= 90% significance level, **= 95% significance level, ***= 99% significance level

Through the estimated model (**Table 59**), the following findings were obtained:

- Different times of day have different relative risks of LTAP at unsignalized intersections. Afternoon (12:00–18:00), evening (18:00–21:00), night (21:00–24:00), and early morning (3:00–9:00) experience high relative risks of LTAP compared to morning (9:00–12:00) and late-night (0:00–3:00).

- Shoulder widths of 2–6 ft are associated with a significantly lower relative-risk of LTAP compared to narrow shoulders (<2 ft). If the shoulder is greater than 6 ft, the reduction of LTAP risk is insignificant, although its OR (0.783) is still less than 1.
- A high speed limit on major approach is linked to a high relative-risk of LTAP. The relative risks of LTAP for speed limits of 30–40 mph, 40–50 mph, and >50 mph are 1.86 times, 2.19 times, and 2.048 times, respectively, as high as for a speed limit of 30 mph or less. High speeds result in drivers having a short timeframe to detect and react to motorcycles when turning left. Unlike that observed for signalized intersections, high speed limits at unsignalized intersections are not associated with protected left-turn phases.
- Older riders (age >60) have a higher safety consciousness and demonstrate more careful riding behaviors and are less likely to be involved in an LTAP crash. Male riders, who have less safety consciousness and tend to engage in risky riding behaviors, are more likely to be involved in an LTAP crash.
- Local riders, who tend to be overconfident at intersections, experience a higher relative-risk of LTAP at unsignalized intersections.
- TWLTLs, which do not physically separate turning in/out traffic, have a high relative-risk of LTAP crashes (1.504 times as high as the undivided design). Raised median design, which physically separates opposite traffic, experiences a lower relative-risk of LTAP (0.832 times as high as the undivided design).
- Older OV drivers, who may have poor detection and reaction abilities, are more likely to be involved in LTAP crashes at unsignalized intersections. Male OV drivers, unlike male riders, are less likely to be involved in LTAP crashes at unsignalized intersections.

5.3 Modeling Injury Severity for LTAP Crashes

In addition to identifying factors that contribute to the relative risk of LTAP occurrence, this study investigated the risk factors that influence the injury severity of LTAP crashes at two different intersection types (signalized and unsignalized). Because "property damage only" crashes have serious under-reporting issues, they were excluded from statistical models.

5.3.1 Methodology

In crash reports provided by investigating officers, injury severity is classified into five levels—Property Damage Only, Possible Injury, Non-Incapacitating Injury, Incapacitating Injury, and Fatality. Discrete outcome models suit the analysis of severity outcome prediction well; in many studies, this approach has been employed in motorcycle safety research.

An ordered probit model (OPM) dominates in modeling for ordinary injury outcomes. OPM can determine the contributing factors that affect motorcycle injury outcomes and quantify the detailed effects of each variable. In other words, in a given crash, OPM can be used to evaluate how the variation of factors would increase or decrease the probability that the most severely-injured person will suffer an injury at a specific level.

In this study, to better capture the effects of variables on injury severity outcomes, injury outcomes were regrouped into three levels by combining Incapacitating Injury and Fatality into one group, Severe Injury. Thus, the three levels could be defined as 1 = Possible Injury, 2 = Non-Incapacitating Injury, and 3 = Severe Injury and Fatal.

Let i (i = 1, 2, …, I) be an index of crash observation and j ($j = 1, 2, 3, \ldots, J$) be an index to represent the level of injury severity. The observed injury severity Y_i of the ith crash observation is assumed to be associated with an underlying continuous latent variable Y_i^* which can be specified as a linear function, as shown below:

$$Y_i^* = \boldsymbol{X_i \beta} + \varepsilon_i \tag{44}$$

where $\boldsymbol{X_i}$ is a vector of explanatory variables, $\boldsymbol{\beta}$ is a vector of coefficients, and ε_i is the error term that is standard-normally distributed with zero mean and standard deviation (σ). The observed injury severity Y_i can be defined as,

$$Y_i = j \ if \ \mu_{j-1} < Y_i^* \leq \mu_j \tag{55}$$

where μ_j are unobservable cut-off thresholds defining the observed injury severity level Y_n. To ensure the well-defined intervals and natural ordering of observed injury severity, the thresholds are assumed to be ascending in order (i.e., $\mu_{n,0} = -\infty < \mu_{n,1} < \mu_{n,2} < \cdots < \mu_{n,J-1} < \mu_{n,J} = \infty$).

The coefficient sign ($\boldsymbol{\beta}$) indicates the impacts of contributing factors. A positive coefficient implies that the factor tends to increase the injury severity of LTAP crashes, and a negative coefficient means that the factor is more likely to decrease the injury severity of LTAP crashes.

5.3.2 Ordered Probit Model for LTAP Crash Injury Severity at Signalized Intersections

The CUTR research team fitted an ordered probit model for LTAP crashes at signalized intersections. Accident severity was categorized using three levels —Property Damage Only (PDO), Injury, and Fatal. The majority of these LTAP crashes (78.95%) caused injuries; however, 11.4 percent of crashes occurring at signalized intersections caused a fatality.

The distribution of injury severity at the three levels is shown in **Table 60**, and the fitted ordered probit model results are shown in **Table 61**. From this table, the likelihood of LTAP crash injury severity at signalized intersections can be predicted using roadway characteristics and rider and driver information.

Table 60 Injury Severity Levels of LTAP Crashes at Signalized Intersections

Severity Level	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury and Fatal (%)
Percentage	19.77	73.27	6.96

Table 61 Fitted Ordered Probit Model for LTAP Injury Severity at Signalized Intersections

Ordered Probit Model	Crash Injury Severity		Number of observations = 2,586		
Log Likelihood = -1372.4495			Pseudo R^2 = 0.2254		
Variable Name	**Coef.**	**S.E.**	***p*-Value**	**Frequency**	**Percent (%)**
Crash Year					
2011	--	--	--	260	9.94
2012	-0.100	0.122	0.415	275	10.51
2013	-0.158	0.125	0.205	250	9.56
2014*	-0.217	0.122	0.074	276	10.55
2015	-0.022	0.121	0.855	286	10.93
2016*	-0.213	0.122	0.080	274	10.47
2017	-0.137	0.117	0.241	332	12.69
2018***	-0.353	0.115	0.002	350	13.38
2019*	-0.215	0.118	0.068	313	11.96
Daylight indicator***	-0.204	0.055	0.000	1,419	54.24
Rough roadway surface friction indicator (friction test > 30)*	-0.100	0.056	0.075	1.489	56.92
Urban area indicator***	-0.705	0.197	0.000	2,559	97.82
Motorcyclist Age Group					
Under 30	--	--	--	289	11.18
30-40***	0.244	0.093	0.009	872	33.72
40-50*	0.203	0.107	0.057	397	15.35
50-60**	0.245	0.098	0.013	645	24.94
Over 60***	0.284	0.109	0.009	383	14.81
Motorcycle Riding Speed					
Under 15 mph	--	--	--	191	7.3
15-30 mph***	-0.603	0.128	0.000	268	10.24
30-45 mph	0.090	0.105	0.390	1,862	71.18
Over 45 mph***	1.094	0.137	0.000	295	11.28
Rider alcohol-impaired driving indicator***	1.854	0.205	0.000	137	5.24
Rider drug-impaired driving indicator***	1.230	0.361	0.001	83	3.17
Motorcycle Approach Speed Limit					
Under 35 mph***	0.175	0.060	0.003	933	35.67
35-55 mph	--	--	--	1,523	58.22
Over 55 mph*	-0.189	0.134	0.057	160	6.12
Other motor vehicle driver alcohol use indicator***	0.953	0.195	0.000	73	2.79
Cut 1	-1.851	0.246	--	--	--
Cut 2	1.083	0.244	--	--	--

*= 90% significance level, **= 95% significance level, ***= 99% significance level

Based on the model, the following findings were obtained:

- The injury severity of LTAP crashes tends to decrease over years at signalized intersections. Compared to 2011, the injury severity of LTAP crashes is more likely to be significantly reduced in 2014, 2016, 2018, and 2019. Several temporal factors might result in this, such as driving behavior improvement over the years, active collision avoidance technologies on new cars, and changed left-turn traffic patterns. More data are needed to address the causation for LTAP injury severity change over years.

- Poor lighting conditions (dark, dawn, dusk) are more likely to increase the injury severity of LTAP crashes.
- High friction surfaces, which provide more friction force for vehicles and motorcycles, could shorten stopping distance and, consequently, tend to reduce the injury severity of LTAP crashes.
- Urban area tends to decrease the injury severity of LTAP crashes. The relatively low speed and high safety design standard of signalized intersections in urban areas may reduce the risk of injury in an LTAP crash.
- Compared to young riders (age <30), adult and older adult riders are more likely to experience a high risk of severe injury in LTAP crashes. Young riders have better detection and reaction abilities and stronger bodies, so they could avoid or bear severe collisions.
- It is interesting to find that different speed choices have varying effects on injury prediction in an LTAP crash at a signalized intersection. Specifically, riding over 45 mph at a signalized intersection is more likely to involve severe injuries and fatalities than riding under 15 mph, but riding between 15–35 mph reduces the likelihood of severe injuries and fatalities even further.
- It is not surprising that impaired riding, including alcohol- and drug-impaired, tended to result in severe injuries and fatalities in LTAP crashes at signalized intersections. The results demonstrated the necessity of zero tolerance for impaired driving.
- Speed limit is related to the speed choices of motorcyclists. Riders tend to operate their vehicles at a lower speed on approaches with relatively low-speed limits and are less likely to avoid approaching motor vehicles. Conversely, relatively high speed limits (over 55 mph) tend to reduce severe injuries in LTAP crashes. LTAP crashes at signalized intersections are more likely to occur on intersections with intermediate and lower speed limits. High speed limits are correlated with protected left-turn phases, which may be the cause of this phenomenon.
- Often, other motor vehicles in an LTAP crash are regarded as the primary responsible party, as motorcycles have the right-of-way at the time of the crash. Consistent with several prior studies (*16–19*), alcohol-impaired driving of the motor vehicle tends to increase severity level in an LTAP crash at a signalized intersection. Significantly impaired reaction and judgment time and reduced sight distance may be explanations.

5.3.3 Ordered Probit Model for LTAP Crash Injury Severity at Unsignalized Intersections

An ordered probit model for LTAP crash injury severity at unsignalized intersections was developed. The distribution of injury severity at the three levels is shown in **Table 62**, and the fitted ordered probit model results are presented in **Table 63**.

Table 62 Injury Severity Levels of LTAP Crashes at Unsignalized Intersections

Severity Level	Possible Injury (%)	Non-Incapacitating Injury (%)	Incapacitating Injury and Fatal (%)
Percentage	14.30	78.68	7.02

Table 63 Fitted Ordered Probit Model for LTAP Crashes at Unsignalized Intersections

Ordered Probit Model	Crash Injury Severity		Number of observations =5,676		
Log Likelihood =-2,612.841			Pseudo R^2 =0.2538		
Variable Name	**Coef.**	**S.E>**	**t-Value**	**Frequency**	**Percent (%)**
Crash Year					
2011	--	--	--	538	9.39
2012	-0.048	0.089	0.588	566	9.88
2013	-0.102	0.087	0.241	612	10.68
2014	-0.163	0.086	0.058	628	10.96
2015	-0.133	0.087	0.123	622	10.85
2016	-0.012	0.086	0.888	658	11.48
2017	0.044	0.085	0.600	673	11.74
2018**	-0.189	0.082	0.022	752	13.12
2019**	-0.178	0.084	0.034	682	11.9
District					
District 1	--	--	--	789	13.77
District 2***	-0.342	0.082	0.000	566	9.88
District 3	-0.142	0.086	0.100	470	8.2
District 4	0.027	0.076	0.719	706	12.32
District 5**	-0.131	0.067	0.049	1,377	24.03
District 6**	-0.196	0.080	0.014	596	10.4
District 7	-0.021	0.068	0.759	1,225	21.37
Daylight indicator***	-0.155	0.042	0.000	3,761	65.63
Rough roadway surface friction indicator (Test > 30)***	-0.161	0.043	0.000	2,269	39.59
Cloudy weather condition indicator***	0.151	0.058	0.009	792	13.82
Dry roadway surface indicator**	0.169	0.081	0.039	5,389	94.03
Urban area indicator***	-0.659	0.092	0.000	5,378	93.84
Motorcyclist Speed					
0-15 mph	--	--	--	406	7.08
15-30 mph***	-0.744	0.095	0.000	429	7.49
30-45 mph	0.020	0.074	0.792	4,009	69.95
Over 45 mph***	0.553	0.094	0.000	887	15.48
Motorcyclist Age Group					
Under 20	--	--	--	569	10.02
20-30**	0.173	0.070	0.013	1,792	31.57
30-40**	0.186	0.077	0.016	928	16.35
40-60	0.105	0.072	0.144	1,461	25.74
Over 60*	0.145	0.078	0.062	926	16.31

Table 63 Fitted Ordered Probit Model for LTAP Crashes at Unsignalized Intersections (Continued)

Variable Name	Coef.	S.E>	t-Value	Frequency	Percent (%)
Rider alcohol-impaired driving indicator***	2.150	0.152	0.000	289	5.04
Rider drug-impaired driving indicator***	1.603	0.333	0.000	171	2.98
Other motor vehicle driver alcohol use indicator***	1.031	0.215	0.000	146	2.55
Other motor vehicle driver drug use indicator*	0.584	0.311	0.060	94	1.64
Cut 1	-1.876	0.168	--	--	--
Cut 2	1.277	0.167	--	--	--

*= 90% significance level, **= 95% significance level, ***= 99% significance level

Based on the model, the following findings were obtained:

- As with LTAP crashes at signalized intersections, LTAP crashes at unsignalized intersections were also less likely to result in severe injury in 2018 and 2019.
- Different from LTAP crashes at signalized intersections, crashes that occurred in Districts 2, 5, and 6 were less likely to result in severe injuries.
- The effects of the rough roadway surface indicator and urban area indicator on injury severities of LTAP crashes at unsignalized intersections were similar to those observed at signalized intersections. Higher friction indicates a shorter stopping distance and less likelihood of severe injuries and fatalities.
- Good lighting conditions are more likely to reduce the injury severity of LTAP crashes.
- A dry surface is associated with a high risk of injury severity in LTAP crashes. Driver safety compensation—the tendency of drivers to drive more aggressively when they feel safe on a dry surface—may explain this.
- Consistent with other previous studies on motorcycle crashes (*20*, *21*), cloudy weather conditions may cause severe injuries at unsignalized intersections.
- The effects of older riders are consistent in these two models. This may be explained as the result of multiple psychological factors related to driving behaviors, such as different speed profiles for signalized and unsignalized intersections, driving attention under different traffic control measures, and so on.
- The rider alcohol use indicator is a significant factor contributing to crash injury severity, along with the drug use indicator.
- The effects of impaired driving for motor vehicle drivers at unsignalized intersections are similar to the injury prediction effects observed for LTAP crashes at signalized intersections.

6. Conclusions and Recommendations

6.1 Summary

During the last decade, Florida observed an increasing trend in motorcycle registrations and the number of drivers with a motorcycle endorsement. This has also led to more motorcycle crashes in Florida. Although motorcycle crash occurrences are complex events involving riders, drivers, and motorcycle mechanical factors, this research project aimed to provide an in-depth understanding of motorcycle crash causation in Florida. To achieve that objective, this study completed the following tasks:

- Systematically reviewed literature of the MCCS dataset and associated studies. In total, 7 completed research studies were identified using the MCCS dataset. The review provided a full understanding of MCCS data.
- Reviewed selected police crash reports of fatal and serious injury motorcycle crashes in Florida for 2011–2019. By comparing MCCS data to Florida motorcycle crash data, the research team identified the three highest-risk crash types—left-turning across path crashes (LTAP), following too close crashes (FTC), and roadway departure crashes (ROR).
- Conducted detailed descriptive analyses for the three primary motorcycle crash types using the MCCS dataset. In this project, the 351 motorcycle crashes and corresponding 702 controls were analyzed in different dimensions including pre-crash, crash, and post-crash characteristics; rider and driver demographic and driving and riding behavioral factors; motorcycle mechanical factors; and crash scenery information.
- Conducted detailed descriptive analyses for the three primary motorcycle crash types using Florida data. Comparisons between MCCS data and Florida data were conducted to identify unique MCCS information and provide suggestions for Florida motorcycle crash database updates in the future.
- Developed statistical models to identify the significant factors contributing to LTAP, which is the primary motorcycle crash type in Florida. Crash-level analyses provided detailed information about LTAP risks in occurrence and outcomes (severity).
- Developed recommendations to address the risk factors identified in descriptive analysis and statistical modeling.

6.2 Conclusions

Studies using the MCCS dataset are summarized and compiled in Chapter 2. In total, there are five papers and two reports related to MCCS that use the motorcycle crash data and additional investigation information provided by Oklahoma State University:

- Three out of seven studies used the total allotment of 351 motorcycle-involved injury crashes and 702 controls to control for the characteristics related to motorcycle exposure. Both descriptive statistics and logistic regression models were employed in these studies to identify riders, vehicle attributes, crash scenery factors, and motorcycle rider injury levels.

- Different from other studies, the case-control experiment design of the MCCS can be used to control for rider or riding features caused by imbalanced motorcycle exposure in terms of time and space.
- Only one study used a medical score system (ISS) to evaluate injury levels and developed a Tobit model to account for the factors contributing to crash injury severity.
- Detailed clothing information for motorcycle crashes provided by the MCCS dataset, including helmet color, motorcycle-specific shoes, gloves, and eye protection equipment, functions uniquely in crash analysis. For example, it was found that riders with partial helmet coverage had a significantly lower risk of injury-crash involvement. It is suggested that in Florida, riders with USDOT-compliant helmets (with partial coverage) should be compared with riders with other types of helmets (*1*).
- In most studies of motorcycle crash cases, a turning driver was thought to have difficulty noticing the presence of a motorcycle. This inspired the research team to classify the specific type of crashes, called left-turning across path crashes (LTAP).
- Multiple engineers and researchers from different states, including Arizona, Michigan, Virginia, Minnesota, and others, track motorcycle crash data. Some provided useful and insightful suggestions; for example, a program director in Virginia pointed out the insufficiency of alcohol data in crash reports.

A detailed review and analysis of crash report data in Florida during 2011–2019 was conducted and is presented in Chapter 3. The research team analyzed these crashes by focusing on their injury severity levels, primary crash types, and multiple causal factors. Results of this analysis are as follows:

- Around one-fourth of all crashes between 2015 and 2019 resulted in a fatality or incapacitating injury.
- Individuals ages 20–29 had with the largest proportion of Florida motorcycle crashes from 2015–2019, with this particular age group accounting for 25.8% of all crashes.
- The three primary types of motorcycle crashes identified by multiple previous motorcycle studies are left turn approaching across the path of a motorcycle (LTAP), motorcycle following too closely (FTC), and single motorcycle running off roadway (ROR). In Florida, during 2011–2019, LTAP crashes had a share of 18.45 percent, with FTC at 23.04 percent, and ROR at 11.27 percent.
- Motorcycle riders are more likely to be involved in single motorcycle crashes. Among these, lane departure crashes (running off roadway crashes) with motorcyclists leaving the riding lane and hitting other objects were identified as the most common circumstances. Previous studies also indicated most ROR crashes occurred on horizontal curves.

- Alcohol and drug-impaired riding is highly correlated with severe injuries and fatalities. Over half of Florida's alcohol-involved LTAP crashes during 2011–2019 resulted in severe injuries or fatalities. Moreover, around 80 percent of all drug-involved crashes led to the same outcomes. When considered collectively, it is strikingly clear that alcohol-, drug-, and alcohol- and drug-impaired crashes accounted for a significantly larger proportion of LTAP motorcycle fatalities (27.9%) than for LTAP motorcycle crashes in general (4.1%).
- It is generally thought that the MCCS is the most comprehensive study on data collection procedures in motorcycle safety research (*1*, *2*). Chapter 4 presents a detailed examination of MCCS data. The research team selected MCCS crash cases corresponding to the identified primary crash types in Florida with their matched controls and analyzed the crash observations using a case study with professional motorcycle crash investigators and appropriate statistical methods to identify the risk factors. Highlighted findings note that enriched MCCS databases can provide exclusive information about motorcycle crash causations and their contributing factors. In total, there were 23 LTAP crashes, 26 FTC crashes, and 35 ROR crashes in the MCCS database. In terms of exposure, the 351 MCCS motorcycle crashes mirror Florida crashes, as the temporal and spatial characteristics are similar.
- For all three crash types, young riders have a higher risk of being involved in a crash, especially a fatal crash.
- Sports motorcycles are the most dangerous type of motorcycle; sports-motorcycle riding may be related to speed racing or other circumstances.
- Rider clothing, footwear, gloves, and other accessories have various effects on motorcycle rider injury prevention and reduction. In some LTAP crashes, a bright-colored helmet can prevent injuries and fatalities; this may be related to rider conspicuity.
- Appropriate braking strategies can reduce collisions dramatically. In addition, innovative technology—for example, an antilock braking system (ABS)—can protect riders and prevent injuries. In some crash investigations in the MCCS, innovative technologies helped riders prevent injuries and take avoidance maneuvers in time.
- Lack of exposure is the biggest challenge in motorcycle safety analysis; in the MCCS, a case-control matching procedure was used to address this. Comparison between crash-involved riders and controls indicated that lighting condition, weather condition, and roadway functions, which once were considered contributing factors to crashes, may be related to realistic causal factors that were masked.

After comparing MCCS data with Florida crash data, the research team identified the highest-risk motorcycle crash type—LTAP. There are different characteristics of LTAP and non-LTAP crashes. Chi-square tests on selected factors show that LTAP crashes are more likely to cause severe injuries and fatalities. The detailed statistical analysis included descriptive statistics with comparisons between LTAP and non-LTAP crashes, logistic models for LTAP crash risks, and ordered probit model results for LTAP crash injury severities. The qualified effects of contributing factors to LTAP crash risk are summarized in **Table 64**.

Table 64 Summary of Risk Factors Contributing to LTAP Crash Risk

Factor	Relative Risk of LTAP		Injury Severity	
	Signalized	Unsignalized	Signalized	Unsignalized
Recent years (2018, 2019)			↓	↓
Evening and early night (6:00–24:00)	↑	↑		
Urban areas			↓	↓
Wide shoulder	✖	✖		
Increase in AADT	↓			
Speed limit on MC approach	✖	↑	✖	
District				✖
TWLTL on OV approach		↑		
Raised median on OV approach		↓		
High friction surface (> 30)			↓	↓
Daylight			↓	↓
Cloudy weather				↑
Dry surface				↑
Motorcycle speed			✖	✖
Young riders (< 30)	↑		↓	✖
Older adult riders (> 60)	↓	↓	↑	↑
Motorcycle travels straight before crash	↑			
Male rider	↑	↑		
Rider alcohol or drug involvement			↑	↑
Local rider		↑		
Older adult OV driver	↑	↑		
Local OV driver	↑			

Table 64 Summary of Risk Factors Contributing to LTAP Crash Risk (Continued)

Factor	Relative Risk of LTAP		Injury Severity	
	Signalized	Unsignalized	Signalized	Unsignalized
Male OV driver	↑	↓		
OV driver alcohol or drug involvement			↑	↑

↑ = tends to increase LTAP risk

↓ = tends to decrease LTAP risk

✖ = significant but diverse impacts on LTAP risk

6.3 Recommendations

Based on the identified risk factors, recommendations were developed to improve motorcycle safety in Florida. Recommendations include engineering countermeasures, education countermeasures, and others as follows:

- **Increase visibility at night** – Reduced visibility at night tends to increase the LTAP risks of either occurrence or injury severity. Increasing motorcyclist visibility at intersections is an effective way to prevent LTAP risks. Installing or upgrading street lighting systems to maintain sufficient illumination at intersections is suggested. An education program that encourages motorcyclists to wear retroreflective devices is also recommended.
- **Provide protected left-turn signal phases** – Protected left-turn signal phases can separate left-turning vehicles and motorcycles in time. It is suggested to provide left-turn signal phases at intersections to separate two-direction traffic.
- **Replace TWLTLs with raised medians** – Median design has significant impacts on LTAP crash occurrence at unsignalized intersections. It is suggested to replace TWLTLs with raised medians with directional openings at access points to physically separate left-turning vehicles and motorcycles.
- **Install high friction surface treatment (HFST) at intersections** – Study results indicate that high friction surfaces can significantly reduce the injury severity of LTAP crashes. HFST is an emerging technology that increases the friction number of surfaces. FDOT is implementing HFST on off-ramps and intersections for vehicle and pedestrian safety. This engineering treatment also can improve motorcycle safety at intersections.
- **Establish speed management** – Speed and speed limit are critical factors influencing LTAP risks at signalized and unsignalized intersections although their impacts are diverse due to compounding effects (i.e., high-speed limit may be associated with protected left-turn phases). Speed management that reduces the speed of both left-turn

vehicles and go-straight motorcycles is beneficial to reduce LTAP risks, especially for injury severity.

- **Provide education programs** – Human behaviors and characteristics play important roles in LTAP crashes. Education programs should be provided to specific groups—young riders who tend to increase LTAP risk of occurrence, older adult drivers who experience a high risk of LTAP occurrence, and local riders and drivers who are more likely to involve LTAP crashes due to their over-confidence.
- **Enhance/increase law enforcement** – Alcohol and drug involvement, either for riders or drivers, is a dangerous factor resulting in LTAP crash risks. Enhanced law enforcement and education are needed to reduce impaired driving and riding behaviors.

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