Collaborative Sciences Center for ROAD SAFETY

FINAL REPORT

Strategies for Reducing Motorcyclist Injuries: Engaging Stakeholders to Apply Evidence-Based Countermeasures that Work

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U.S. DOT Disclaimer

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16. Abstract
One of the recent issues in transportation safety is the rise in fatalities and severe injuries among motorcyclists. Since motorcyclists are far more vulnerable than enclosed vehicle users on the road, they are substantially more likely to get injured in a crash. While evidence-based countermeasures are available, this research aims to shorten the implementation cycle in the translation of research into practice at the state level. Especially with insights and information from CSCRS-sponsored analysis of Motorcycle Crash Causation (MCCS) study data, this project aims to accelerate the research to deployment cycle. For this, statewide motorcycle safety plans provide a critical intervention opportunity. Such safety plans often identify risk factors and consider countermeasures. To identify risk factors, recent motorcycle crash data in Tennessee was analyzed. Then motorcycle safety practices across the United States and other countries were reviewed. Promising and new countermeasures such as enhancing rider conspicuity and motorist awareness, new personal protective gear, avoiding impaired driving, and rider education were matched with risk factors. Based on recent motorcycle crash data (N=14,677) in Tennessee, 73.4% resulted in rider injuries, with 5.1% causing a fatality. Statistical analysis reveals that improper use of a DOT-compliant helmet is associated with severer injuries, compared with properly wearing a DOT-compliant helmet. Other injury risk factors were identified along with high-frequency motorcycle crash hotspots including the Great Smoky Mountains National Park, with tight curves and elevation changes. To further support planning efforts, a comprehensive review of motorcycle safety practices suggests that Tennessee can invest in efforts to carry out more robust media campaigns on motorcycle safety and increase communication with motorcyclists via online and printed materials. The findings from this project are a valuable reference for expeditious and timely translation of research into practice with the newest evidence-based countermeasures delivering innovative solutions. Based on input from practitioners, developing a Motorcycle Safety Clearinghouse can improve technology transfer, increase two-way information sharing between researchers and practitioners, and serve as a means to get research into practice much more quickly.

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1. Introduction

BACKGROUND

The recent rise in fatalities and severe injuries among vulnerable road users, particularly motorcyclists, is a concern. Compared to passenger vehicles, motorcycles are not as stable or visible. When involved in a crash, riders of motorcycles lack the protection featured in an enclosed vehicle and are thus more likely to sustain injuries, including fatal ones. When controlled for exposure (per mile traveled in the United States), the number of motorcycle fatalities is 30 times that of passenger vehicle fatalities (National Highway Traffic Safety Administration (NHTSA)). After developing a deeper understanding of the nature of rider injuries, using the Motorcycle Crash Causation Study (MCCS) data, and building on motorcycle research activities in an earlier project (CSCRS Project R-20) and the momentum to translate the research results into practice, this project identifies countermeasures that can potentially reduce injuries in motorcycle crashes. This project enables evidence-based practice and aims to shorten the research to practice cycle. It provides a case-study of assisting stakeholders with diverse backgrounds, motorcycle safety practitioners, and advocates in applying the outcomes of research. Translating research into practice ensures that the benefits of research are fully realized expeditiously through sharing. The state of Tennessee serves as a case-study in translating motorcycle safety research to practice. A key focus of this project is 1) to provide supporting information for Tennessee's Motorcycle Strategic Safety Plan (MSSP) with the aim to translate the CSCRS sponsored motorcycle research into practice at the state level, 2) to analyze Tennessee motorcycle crash data for risk factors and work with Tennessee Highway Safety Office (THSO) in formulating statewide strategies. Additional information is obtained by reviewing effective solutions and countermeasure practices throughout the country, and 3) to develop mechanisms for enhancing the usability of our research efforts.

In addition to conducting a detailed statistical analysis of Tennessee data (N=14,677 from 2016 to 2020), this project examines the research literature on motorcycle safety to extract and synthesize useful information for practice. While there has been considerable work on motorcycle safety over the previous decades, motorcycle injuries still remain a significant concern. An extensive body of literature has focused on analyzing the frequency of motorcycle crashes at specific roadway locations and examining injury outcomes given a crash. Focus areas that support Tennessee's MSSP and the findings from the Motorcycle Crash Causation Study (MCCS) conducted by the research team include:

1. Rider Conspicuity & Motorist Awareness
2. Personal Protective Gear
3. Impaired Driving & Motorcycle Operation Under the Influence of Alcohol/Drugs
4. Rider Education and Training
5. Program Evaluation and Data

Complementary research is reported by analyzing motorcycle crashes collected through MCCS by the Federal Highway Administration (FHWA), which includes comprehensive data from an on-scene investigation of 351 motorcycle crashes in Orange County, California. The research develops an understanding of how different risk factors, especially age, impairment, and experience contribute to crashes with injuries to different body parts of the riders.

SUMMARY OF COUNTERMEASURES FOR MOTORCYCLE SAFETY

This project synthesizes evidence regarding the effectiveness of countermeasures for motorcycle safety in terms of crash risk and injury severity given a crash, summarized in Table 1.1. The new evidence based on studies conducted in a previous Collaborative Sciences Center for Road Safety (CSCRS) project and new analysis of Tennessee data is combined with the effectiveness of relevant countermeasures reported by the National Highway Traffic Safety Administration (NHTSA), USDOT, in a study on countermeasures that work (Venkatraman et al. 2021). The Table also shows the countermeasures mentioned in the 2015 Tennessee Motorcycle Safety Strategic Plan, which are consistent with USDOT guidance. The key takeaways from this study are as follows.

- The analysis of motorcycle crash data in Tennessee reveals that **not wearing a helmet** is associated with a higher chance of injury given a crash, compared to wearing a DOT-compliant helmet. This clearly points to considering countermeasures that will enhance helmet use. One example of a relevant countermeasure is the continuation and enforcement of the **"universal motorcycle helmet laws,"** in Tennessee which are known to be effective for motorcycle safety, according to the NHTSA report (Venkatraman et al. 2021).

- The analysis of motorcycle crash data in Tennessee reveals that **alcohol or drug impairment** by the motorcycle rider is associated with a higher chance of injury given a crash, compared to no impairment. This evidence suggests consideration of **"detection, enforcement, and sanctions concerning alcohol-impaired motorcyclists,"** which are likely to be effective according to the NHTSA report (Venkatraman et al. 2021).

- While **"motorcycle rider training"** is not yet determined to be effective for motorcycle safety according to the NHTSA report (Venkatraman et al. 2021), the analysis of Motorcycle Crash Causation Study (MCCS) data has recently revealed that **experience in rider courses** is associated with a lower injury severity score (ISS) given a crash. Hence, the effectiveness of such countermeasures can be explored further and if appropriate such training can be considered for improving motorcycle safety.

- The analysis of MCCS data reveals that **"retroreflective upper body clothing, motorcycle-oriented clothing, and motorcycle-oriented shoes"** are associated with a lower risk of motorcycle crash. Encouraging retroreflective upper body clothing has not yet been determined to be effective for motorcycle safety according to NHTSA (Venkatraman et al. 2021). Further research in the context of Tennessee is needed on the role of clothing for motorcycle safety improvements.

Table 1.1 Summary of Countermeasures for Motorcycle Safety

Countermeasure	Effectiveness reported by NHTSA	2015 TN Motorcycle Safety Strategic Plan	CSCRS Project (Year 1)		Context from TN motorcycle crash data (2016-2020)
			Evidence on Crash Risk	Evidence on Injury Severity Score (ISS)	
	5-star rating	Covered in plan?	Difference in Means *	Marginal effect **, given a crash (%)	Marginal effect, given a crash (%)
Motorcycle Helmets					
Universal Motorcycle Helmet Use Laws	★ ★ ★ ★ ★	Covered	NA	NA	**+9.13%** in chance of injury with **no helmet (**vs. DOT compliant helmet)
Motorcycle Helmet Use Promotion Programs	☆	Not Covered	NA	NA	
Motorcycle Helmet Law Enforcement: Noncompliant Helmets	☆	Covered	NA	NA	
Alcohol Impairment					
Alcohol-Impaired Motorcyclists: Detection, Enforcement, and Sanctions	★ ★ ★	Covered	NA	NA	**+6.02%** in chance of injury with **alcohol/drug impairment**
Alcohol-Impaired Motorcyclists: Communications	☆	Covered	NA	NA	
Motorcycle Rider Licensing and Training					
Motorcycle Rider Licensing	☆	Covered	NA	NA	NA
Motorcycle Rider Training	☆☆	Covered	NA	**-9.33%**	
Communications and Outreach					
Communications and Outreach: Conspicuity and Protective Clothing	☆	Covered	NA	NA	**+5.55%** in chance of injury in **darkness** with lighting (vs. daylight)
Retroreflective upper body clothing	NA	NA	**-7%**	**-3.44%**	NA
Motorcycle-oriented clothing	NA	NA	**-20%**	NA	NA
Motorcycle-oriented shoes	NA	NA	NA	**-4.56%**	NA
Communications and Outreach: Motorist Awareness of Motorcyclists	☆	Covered	NA	NA	NA

Notes:

★ ★ ★ ★ ★ and ★ ★ ★ ★ indicate "determined to be effective."

★ ★ ★ indicates "promising or likely to be effective."

☆☆ and ☆ indicate "not yet determined to be effective."

* **Difference in Means** refers to the difference in percentages of a factor within crash and non-crash cases. (% within crash cases -% within non-crash cases)

** Concerning **ISS** with a 75-point scale, **marginal effects** have been translated from scores to percentages.

2. Strategies for Reducing Motorcyclist Injuries in Tennessee: Relevance of Evidence-Based Countermeasures that Work

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CHAPTER SUMMARY

One of the recent issues in transportation safety is the rise in fatalities and severe injuries among motorcyclists. Since motorcyclists are far more vulnerable than enclosed vehicle users on the road, they are substantially more likely to be injured given a crash. While countermeasures against motorcycle crashes are available, this chapter aims to shorten the implementation cycle by thoroughly investigating motorcyclist injury severity, exploring flashpoint locations, and relating the findings from this chapter to countermeasures that are based on recent evidence from quality studies. According to recent motorcycle crash data (N=14,677) in Tennessee, 73.4% of motorcycle crashes resulted in rider injuries, with 5.1% causing fatalities. Statistical analysis reveals that improper use of a DOT-compliant helmet is associated with severe injuries, compared with properly wearing a DOT-compliant helmet. Not wearing a helmet and wearing a non-compliant helmet are also associated with higher injury risk, given a crash. Other injury risk factors include impaired riding and riding on undivided two-way roads. The provision of lighting in the dark could help mitigate the severity of motorcyclist injuries. High-frequency motorcycle crash flashpoints are located in large cities, but also on the Great Smoky Mountains National Park with tight curves and elevation changes. The findings from this chapter are a valuable reference to help prepare and apply evidence-based countermeasures that can deal with rider-related and environmental risk factors to prevent motorcyclist injuries in the future.

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INTRODUCTION

Motorcyclists are not as stable, visible, or well protected compared to passenger vehicles and thus are classified as vulnerable road users. When involved in a crash, for instance, motorcyclists do not have the protection featured in enclosed vehicles and are thus more susceptible to injury, including fatal ones. When controlled for exposure (per mile traveled), the annual number of motorcycle fatalities is about 28.6 times that of passenger vehicle fatalities (National Highway Traffic Safety Administration (NHTSA)). One of the recent issues in transportation safety is the rise in severe injuries and fatalities among these vulnerable road users. For example, the annual number of motorcycle fatalities in the United States has gradually increased from 4,518 in 2010 to 5,014 in 2019 (National Highway Traffic Safety Administration (NHTSA)). Particularly, the annual number of motorcyclist fatalities in Tennessee has increased considerably from 115 in 2011 to 151 in 2020 (Tennessee Highway Safety Office). In 2019, notably, Tennessee had the ninth highest number of motorcyclist fatalities (N=155) among the states in the United States (National Highway Traffic Safety Administration (NHTSA)). This ranking is considered quite high, given that Tennessee had the fourteenth highest population among the states in 2019 (United States Census Bureau). To properly address the motorcycle safety issue in Tennessee, it is necessary to deeply understand the nature and characteristics of recent motorcycle crashes in the state by performing a thorough analysis. Notably, forty-five percent of the motorcycle crashes in Tennessee from 2016 to 2020 were single-vehicle crashes, which implies that motorcycle crashes can be explained by the risk factors related to riders themselves and the roadway environment where they are traveling (Tennessee Department of Transportation (TDOT)). This suggests the necessity of exploring rider-related and environmental factors in motorcycle crashes.

While countermeasures against motorcycle crashes have been suggested by the National Highway Traffic Safety Administration (NHTSA) (Venkatraman et al. 2021), this chapter aims to shorten the implementation

cycle in translation of research into practice through a comprehensive investigation of recent motorcycle crashes in Tennessee. This chapter focuses on how motorcyclist injury severity is influenced by rider-related factors such as helmet use and environmental factors such as roadway configuration. Additionally, this chapter identifies hot spot locations of motorcycle crashes in Tennessee to figure out the characteristics of regions where motorcycle crashes occur frequently. The findings from this chapter will provide deep insights into how motorcycle safety would be improved by applying appropriate countermeasures to deal with rider-related and environmental risk factors.

LITERATURE REVIEW

Substantial effort has been devoted to identifying relationships between motorcycle crashes and relevant risk factors. Concerning the motorcycle crash risk, the presence of red-light cameras at signalized intersections has been shown to reduce motorcycle crash frequency, while the presence of a wide median, uncontrolled left-turn lane, or exclusive right-turn lane may increase motorcycle crash frequency at signalized intersections (Haque et al. 2010). It was also found that motorcycle crash risk could be increased by rider-related factors such as young riders and those riders enjoying frequent stunt behaviors (Keall and Newstead 2012, Stephens et al. 2017). When it comes to motorcyclist injury risk given a crash, it was revealed that the chance that a motorcycle crash cause injury to the rider could be reduced by wearing protective equipment such as helmets and motorcycle-oriented lower clothing as well as conspicuous equipment such as bright upper body clothing (Wali et al. 2018). In addition, the chance of injury crash involvement could be decreased by getting formal motorcycle driving training and having sufficient hours of sleep before riding (Wali et al. 2018). Regarding injury severity given a motorcycle crash, wearing protective equipment such as a helmet was found to be effective in decreasing the rider injury severity, while speeding and having alcohol before riding were found to increase the rider injury severity (Schneider and Savolainen 2011, Shaheed and Dissanayake 2011, Testerman et al. 2018, Wali et al. 2019). According to a case study, for example, the chance of fatality for those who were not wearing a helmet in a crash was found to be 4.2 times as high as that for those who were wearing a helmet (Testerman et al. 2018). Those motorcyclists impaired with alcohol were found to be about twice as likely to have a fatal injury in a crash, compared to those without alcohol impairment (Schneider and Savolainen 2011). Further, it was found that a dark condition without streetlights would make the odds of fatality 2.69 times in a motorcycle crash (Shaheed and Dissanayake 2011).

Even though substantial motorcycle safety research was identified for other geographic areas in the literature, very little appears to be available specifically for the state of Tennessee, where the annual number of motorcyclist fatalities has gradually increased over the past ten years (National Highway Traffic Safety Administration (NHTSA)). Focusing on motorcyclist injury severity, thus, this study thoroughly analyzes the recent motorcycle crashes in Tennessee accounting for its regional contexts. Referring to the rider-related and environmental factors identified in recent studies including helmet use, rider impairment, and light conditions, this study closely examines the factors by dividing them into specific categories to obtain deeper insights into their associations with motorcyclist injury severity. For example, “helmet use” is categorized into wearing a DOT-compliant helmet, improper use of a DOT-compliant helmet, wearing a non-compliant helmet, and not wearing a helmet. Likewise, other factors are divided into appropriate categories.

The effectiveness of countermeasures to enhance motorcycle safety has been investigated by NHTSA, documenting coarse estimates of several countermeasures with a five-star rating system (Venkatraman et al. 2021). For example, universal motorcycle helmet use laws were determined to be effective (5 stars), while enforcement and sanctions against alcohol-impaired motorcyclists were considered “promising and likely to be effective” (3 stars) (Venkatraman et al. 2021). While motorcycle rider training was considered “not yet determined to be effective based on current evidence” (2 stars), the other countermeasures were considered “not yet determined to be effective due to limited evidence” (1 star) (Venkatraman et al. 2021). Although outreach for conspicuity and protective clothing was considered “not yet determined to be effective” (1 star) by NHTSA, recent studies have suggested the effectiveness of wearing conspicuous clothing for greater visibility and motorcycle-oriented clothing (Wali et al. 2018, Wali et al. 2019, Venkatraman et al. 2021). Accounting for this information, this study relates the findings from the case study

of Tennessee to potentially effective countermeasures suggested in the literature and provides updated evidence concerning the appropriateness and potential effectiveness of the countermeasures.

METHODOLOGY

Practitioner Meetings

Prior to performing quantitative analysis of crash data, a series of meetings were held with staff members of the Tennessee Highway Safety Office. The purposes of the meetings were straightforward. The research team wanted to gain a better understanding of the existing motorcycle safety challenges in Tennessee, to clarify what countermeasures had been tried/were planned, to identify existing data/resources and to discuss ways that the research team could contribute to the efforts already underway. One result of the initial meeting was that the *2015 Tennessee Motorcycle Safety Strategic Plan* was shared with the research team (Tennessee Department of Transportation Governor's Highway Safety Office 2015). We surmised that the plan had grown stale over time and was not followed as closely as when originally developed. However, given the low level of funding dedicated to motorcycle safety, we also learned that there were no immediate plans to update it. Rather a new pilot initiative was being planned that would likely utilize all available motorcycle safety funding. This new effort was presented as a series of mini grants to law enforcement agencies with jurisdiction over areas with known high motorcycle crash rates. During the first meeting we also learned that the state's motorcycle safety coalition was no longer active. Finally, we learned that NHTSA funds for motorcycle safety were largely required to be spent on the activities intended to encourage the general motoring public to be more aware of and cautious around motorcyclists. Thus, conducting activities focused only on changing motorcyclists' behaviors were not eligible more most available funding. From follow-up meetings we learned that the pilot enforcement effort had mixed results and was being revised in the new grant year. The revised plan targeted daylight hours and weekends but enforcement agencies were given flexibility in selecting the weekends. Additionally, a small social media campaign was being planned to augment the enforcement efforts. The research team tentatively planned to support THSO in updating the strategic plan and re-establishing the coalition. As demonstrated by the analysis documented in this report some foundational analysis suitable for use in an updated plan was completed. However, the lockdowns associated with the pandemic stalled all efforts at re-establishing the motorcycle safety coalition. The key takeaway from the meetings between the research team and the highway safety office staff was that such meetings were not the norm. The practitioners we pleased but surprised that the researcher wanted to help and were willing to work with them. There is not currently a one-stop-shop where motorcycle safety practitioners and researchers can easily share information, data, insights, and experiences.

Data Source

This study utilizes data from the "Enhanced Tennessee Roadway Information Management System (ETRIMS)" of the Tennessee Department of Transportation (TDOT) (Tennessee Department of Transportation (TDOT)). The data consists of 14,677 motorcycle-involved crashes reported by the police in Tennessee from 2016 to 2020 (Tennessee Department of Transportation (TDOT)). Figure 2.1 visualizes the motorcycle crash data. The top map shows the locational distribution of the crashes (N=13,433) for which geocodes are available for the 5 years., while the bottom map shows motorcycle crash density with one-mile buffer zones. As the data are representative of motorcycle-involved crashes throughout Tennessee, the findings from this chapter can provide insights into the prevailing crash risks in Tennessee and can be generalized to the state.

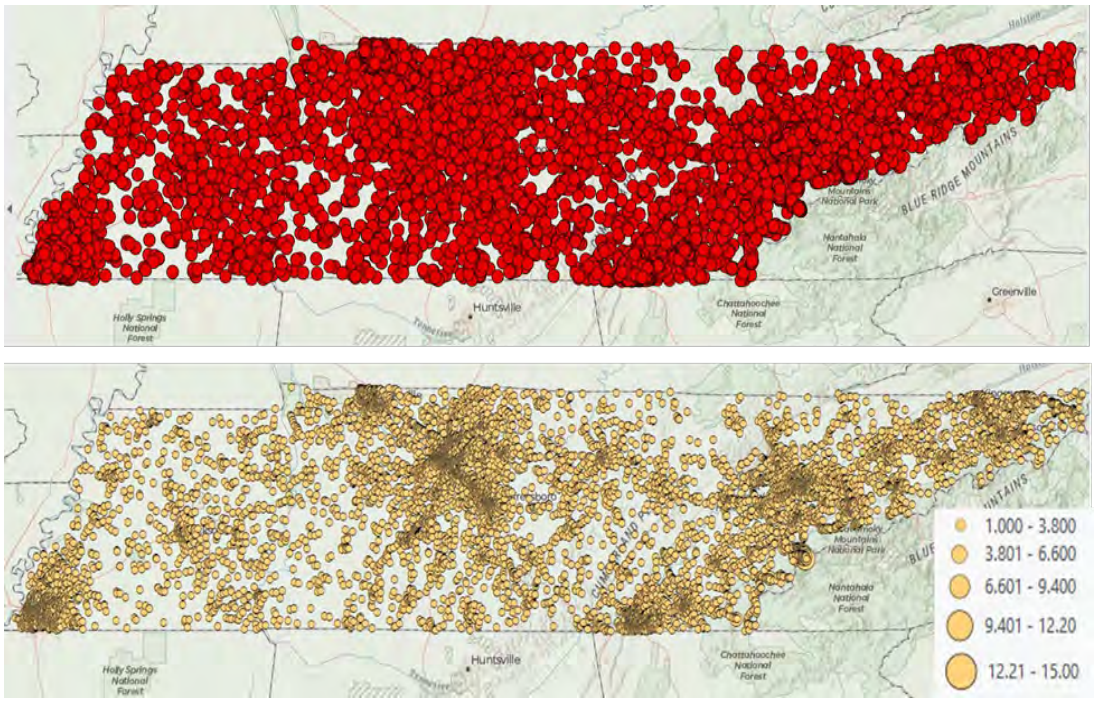

Figure 2.1 Locational Distribution of Motorcycle Crashes in Tennessee

The year-wise distribution of the motorcycle crashes is summarized in Figure 2.2. Since the data has 1,138 missing values out of the 14,677 cases regarding "rider injury severity," they were imputed by referencing the crash severity information that provides the highest level of injury in every crash. That is, as far as the missing values are concerned, this study assumes that the injury severity of a rider was the same as the highest level of injury in a crash. Additionally, it was made sure that the data did not have any other invalid values.

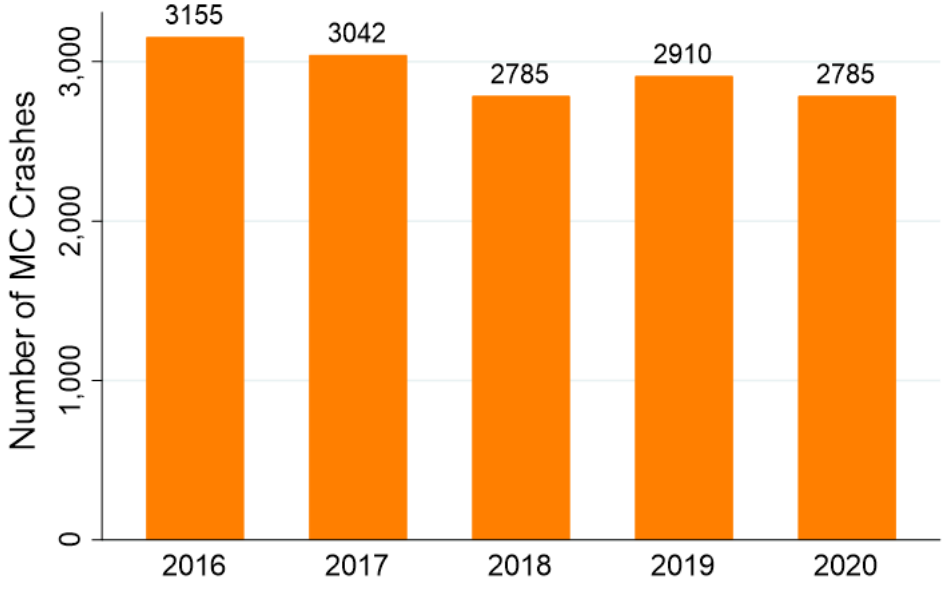

Figure 2.2 Year-wise Distribution of Motorcycle Crashes in Tennessee

Analysis Methods

A descriptive analysis of motorcycle crashes is first performed to investigate the relationships between motorcyclist injury severity and relevant factors including rider-related and environmental factors. Particularly, the motorcycle crash data is cross-tabulated with respect to rider injury severity and helmet use (rider impairment, roadway configuration, and light condition). Given the ordinal nature of motorcyclist injury severity, in addition, an ordered probit model is estimated to uncover the correlation of various factors with rider injury severity given a crash (Kockelman and Kweon 2002). Furthermore, this study conducts a hot spot analysis to evaluate how the motorcycle-involved crashes are geographically distributed across Tennessee and to locate flashpoint locations where motorcycle crashes frequently occurred (Ord and Getis 1995, Getis and Aldstadt 2004). The hot spot analysis is conducted with 13,433 crash cases for which geocodes are available. In the analysis, a one-mile buffer zone was set to identify the locations where the crash frequency is relatively high at least at the 90% confidence level.

RESULTS & DISCUSSION

As shown in descriptive statistics (Table 2.1), there were 14,677 motorcycle crashes in Tennessee from 2016 to 2020. Among those crashes, 73.4% resulted in rider injuries, while 26.6% had no rider injuries. Specifically, the crashes were comprised of 5.1% fatal injuries, 21.7% incapacitating injuries, 30.6% non-incapacitating injuries, and 16.0% possible injuries, while 26.6% of the crashes had no injuries.

The average age of the motorcyclists involved in the crashes was 40.3, while 85.5% of them were wearing a helmet. Specifically, 82.6% of the motorcyclists were properly wearing a DOT-compliant helmet, while 0.4% were improperly using a DOT-compliant helmet. Meanwhile, 2.5% of the motorcyclists were wearing a non-compliant helmet. It is revealed that 5.5% of the motorcyclists were impaired by alcohol or drugs when they crashed. Concerning the environmental factors, 54.1% of the crashes occurred on undivided two-way traffic ways, while 23.5% occurred in dark conditions. The average speed limit was 41.6 (mph). Additionally, 6.1% of the crashes involved careless erratic, or reckless negligent driving by motorcyclists, while 2.0% of the motorcyclists were exceeding the posted speed limit. Further, 13.0% of the crashes involved lane departure, while 3.2% involved an inexperienced motorcyclist.

Table 2.1 Descriptive Statistics of Motorcycle Crashes in Tennessee (N=14,677)

Variable	Frequency / Mean	Percentage (%) /Standard Deviation	Min.	Max.
Motorcyclist Injury Severity				
Fatal injury (K)	754	5.1	0	1
Incapacitating injury (A)	3,187	21.7	0	1
Non-incapacitating injury (B)	4,485	30.6	0	1
Possible injury (C)	2,348	16.0	0	1
No injury (O)	3,903	26.6	0	1
Rider Age (year) *	40.3	15.6	10	90
Helmet Use				
DOT-compliant helmet	12,118	82.6	0	1
Improper use of DOT-compliant helmet	60	0.4	0	1
Non-compliant helmet	365	2.5	0	1
No helmet	857	5.8	0	1
Unknown	1,277	8.7	0	1
Rider Impairment				
No impairment	13,863	94.5	0	1
Impairment	814	5.5	0	1
Roadway Configuration				
Not physically divided (Two-way traffic way)	7,947	54.1	0	1
Other	6,730	45.9	0	1
Light Condition				
Daylight	10,611	72.3	0	1
Dawn	151	1.0	0	1
Darkness with unknown lighting	51	0.3	0	1
Darkness with lighting	1,748	11.9	0	1
Darkness without lighting	1,653	11.3	0	1
Dusk	367	2.5	0	1
Other/Unknown	96	0.7	0	1
Speed Limit (mph) *	41.6	10.6	10	70
Other Rider Behaviors				
Careless Erratic (or Reckless Negligent) Driving (1/0)	899	6.1	0	1
Exceeding Posted Speed Limit (1/0)	304	2.0	0	1
Lane Departure (1/0)	1,909	13.0	0	1
Operator (rider) Inexperience (1/0)	469	3.2	0	1

* indicates that the variable is continuous.

Motorcyclist Injury Severity and Helmet Use

First, it should be noted that the state of Tennessee has a universal helmet law that requires motorcyclists to wear a helmet approved by TDOT (Tennessee Highway Safety Office). As shown in Table 2.2, 12,118 out of the 14,677 motorcyclists (85.5%) were wearing a helmet when they crashed, while 857 (5.8%) were not wearing a helmet and helmet usage was unknown for 1,277 cases (8.7%). A more detailed examination reveals that 82.6% of the motorcyclists were wearing a DOT-compliant motorcycle helmet, while 0.4% were improperly using a DOT-compliant helmet. Meanwhile, 2.5% of the motorcyclists were wearing a non-compliant helmet. Focusing on the relationship between motorcyclist injury severity and helmet use, not wearing a helmet had a positive relationship with injury severity given a crash, which is consistent with previous findings (Schneider and Savolainen 2011, Testerman et al. 2018, Wali et al. 2019). For instance, 10.3% of those motorcyclists who were not wearing a helmet had a fatal injury, whereas 4.7% of those riders wearing a DOT-compliant helmet had a fatal injury. Further, wearing a non-compliant helmet was found to be more dangerous than wearing a DOT-compliant helmet. For example, 38.1% of those who were wearing a non-compliant helmet had a fatal or incapacitating injury, whereas 26.4% of those who were wearing a DOT-compliant helmet had a fatal or incapacitating injury. Unexpectedly, improper use of a DOT-compliant helmet contributed to a much higher percentage (21.7%) of fatal injuries, given a crash, compared to the percentage (10.3%) with “No helmet.” This suggests a potential danger of additional damage from improper use of a DOT-compliant helmet. It may also imply that there were behavioral differences in riding between those who improperly used a helmet and those who did not wear a helmet. Overall, compared with wearing a DOT-compliant helmet, improper use of a DOT-compliant helmet is associated with substantially more severe injuries; not wearing a helmet or wearing a non-compliant helmet is also associated with higher injury risk, given a crash. To further investigate the relationship of helmet types (especially the effects of improper use of DOT compliant helmet) and rider injury severity, we have estimated an Ordered Probit model (please see Appendix A).

Table 2.2 Motorcyclist Injury Severity and Helmet Use

Helmet Use		Injury Severity					Total
		K	A	B	C	O	
DOT compliant helmet	Count	571	2,632	3,886	2,132	2,897	12,118
	% Within Helmet Use	4.71	21.72	32.07	17.59	23.91	100.00
Improper use of DOT compliant helmet	Count	13	19	16	6	6	60
	% Within Helmet Use	21.67	31.67	26.67	10.00	10.00	100.00
Non-compliant helmet	Count	51	88	93	66	67	365
	% Within Helmet Use	13.97	24.11	25.48	18.08	18.36	100.00
No helmet	Count	88	291	240	103	135	857
	% Within Helmet Use	10.27	33.96	28.00	12.02	15.75	100.00
Unknown	Count	31	157	250	41	798	1,277
	% Within Helmet Use	2.43	12.29	19.58	3.21	62.49	100.00
Total	Count	754	3,187	4,485	2,348	3,903	14,677
	% Within Helmet Use	5.14	21.71	30.56	16.00	26.59	100.00

Note: K=Fatal Injury, A=Incapacitating Injury, B=Non-incapacitating Injury, C=Possible Injury, O=No Injury

Motorcyclist Injury Severity and Rider Impairment

As shown in Table 2.3, 814 out of 14,677 motorcyclists (5.5%) were impaired by alcohol or drugs when they crashed, while 13,863 (94.5%) were not impaired. Focusing on the relationship between motorcyclist injury severity and rider impairment, it is shown that having alcohol or drug impairment had a positive relationship with the injury severity of a rider, which is aligned with previous findings (Schneider and Savolainen 2011). For example, 9.0% of motorcyclists who were impaired had a fatal injury, whereas 4.9% of those riders not impaired had one.

Table 2.3 Motorcyclist Injury Severity and Rider Impairment

Rider Impairment		Injury Severity					Total
		K	A	B	C	O	
No Impairment	Count	681	2,868	4,264	2,256	3,794	13,863
	% Within Impairment	4.91	20.69	30.76	16.27	27.37	100.00
Impairment	Count	73	319	221	92	109	814
	% Within Impairment	8.97	39.19	27.15	11.30	13.39	100.00
Total	Count	754	3,187	4,485	2,348	3,903	14,677
	% Within Impairment	5.14	21.71	30.56	16.00	26.59	100.00

Note: K=Fatal Injury, A=Incapacitating Injury, B=Non-incapacitating Injury, C=Possible Injury, O=No Injury

Motorcyclist Injury Severity and Roadway Configuration

As shown in Table 2.4, 7,947 out of 14,677 motorcycle crashes (54.1%) occurred on two-way undivided traffic ways that would have had more opportunities for severe conflicts. The type of facility was found to be an important factor in motorcyclist injury severity, given a crash. Results show that crashes on physically undivided roadways were associated with substantially more severe rider injuries in motorcycle crashes. For example, 31.8% of crashes on two-way traffic ways that are physically undivided contributed to a fatal or incapacitating injury, while 21.0% of crashes on other types of roadways contributed to a fatal or incapacitating injury.

Table 2.4 Motorcyclist Injury Severity and Roadway Configuration

Roadway Configuration		Injury Severity					Total
		K	A	B	C	O	
Not physically divided (Two-way)	Count	473	2,053	2,839	1,221	1,361	7,947
	% Within Roadway Configuration	5.95	25.83	35.72	15.36	17.13	100.00
Other	Count	281	1,134	1,646	1,127	2,542	6,730
	% Within Roadway Configuration	4.18	16.85	24.46	16.75	37.77	100.00
Total	Count	754	3,187	4,485	2,348	3,903	14,677
	% Within Roadway Configuration	5.14	21.71	30.56	16.00	26.59	100.00

Note: K=Fatal Injury, A=Incapacitating Injury, B=Non-incapacitating Injury, C=Possible Injury, O=No Injury

Motorcyclist Injury Severity and Light Condition

As shown in Table 2.5, 10,611 out of 14,677 motorcycle crashes (72.3%) occurred in daylight, while 3,452

(23.5%) occurred in darkness. A more detailed examination shows that 11.9% of the crashes occurred in the darkness with lighting, while 11.3% occurred in the dark without lighting. Focusing on the relationship between motorcyclist injury severity and light condition, dark conditions had a positive relationship with motorcyclist injury severity, which is consistent with previous findings (Shaheed and Dissanayake 2011). For instance, 35.0% of crashes in the dark without lighting conditions had a fatal or incapacitating injury, whereas 25.4% of those crashes in daylight had a fatal or incapacitating injury. Importantly, it is revealed that the provision of lighting in the dark can decrease motorcyclist injury severity. For example, 27.8% of crashes in the dark with lighting contributed to a fatal or incapacitating injury, whereas 35.0% of crashes in the dark without lighting contributed to a fatal or incapacitating injury. Furthermore, riding at dusk is found to be more dangerous than riding during the daytime given that 7.6% of crashes at dusk contributed to a fatal injury, while 4.1% of crashes in daylight contributed to a fatal injury.

Table 2.5 Motorcyclist Injury Severity and Light Condition

Light Condition		Injury Severity					Total
		K	A	B	C	O	
Daylight	Count	437	2,257	3,337	1,678	2,902	10,611
	% Within Light Condition	4.12	21.27	31.45	15.81	27.35	100.00
Dawn	Count	5	29	49	32	36	151
	% Within Light Condition	3.31	19.21	32.45	21.19	23.84	100.00
Darkness with unknown lighting	Count	1	8	12	14	16	51
	% Within Light Condition	1.96	15.69	23.53	27.45	31.37	100.00
Darkness with lighting	Count	118	368	493	331	438	1,748
	% Within Light Condition	6.75	21.05	28.20	18.94	25.06	100.00
Darkness without lighting	Count	152	426	463	226	386	1,653
	% Within Light Condition	9.20	25.77	28.01	13.67	23.35	100.00
Dusk	Count	28	91	117	55	76	367
	% Within Light Condition	7.63	24.80	31.88	14.99	20.71	100.00
Other/Unknown	Count	13	8	14	12	49	96
	% Within Light Condition	13.54	8.33	14.58	12.50	51.04	100.00
Total	Count	754	3,187	4,485	2,348	3,903	14,677
	% Within Light Condition	5.14	21.71	30.56	16.00	26.59	100.00

Note: K=Fatal Injury, A=Incapacitating Injury, B=Non-incapacitating Injury, C=Possible Injury, O=No Injury

To further understand how types of helmets, impairment by rider, light condition, roadway configurations, and other key factors (rider age, speed limit, and pre-crash riding behaviors) relate to rider injury given a motorcycle crash, please refer to the results of the ordered Probit model in the Appendix A (see Table A1).

Hotspot Locations of Motorcycle Crashes in Tennessee

In addition to the statistical analysis, a flashpoint analysis was performed to determine how motorcycle crashes are geographically distributed throughout the state. As shown in Figure 3, six hot spot areas of motorcycle crashes were identified in Tennessee: Memphis, Clarksville, Nashville, Johnson City, Great Smoky Mountains National Park, and Chattanooga. Large cities such as Memphis, Clarksville, Nashville, Johnson City, and Chattanooga are revealed to be hot spots probably because they have a large population (CUBIT, United States Census Bureau). Meanwhile, the Great Smoky Mountains National Park is identified as a flashpoint area of motorcycle crashes (My Smoky Mountain Guide). This might be partially because the region had high exposure to motorcyclists. Particularly, the region might have had a high number of tourists and motorcyclists with little experience with mountain riding. Especially, high-frequency motorcycle crash flashpoints were located along the Tail of the Dragon (Route 129) where tight curves, elevation changes, and thrill-seeking behavior may have increased the risk of a motorcycle crash (My Smoky Mountain Guide).

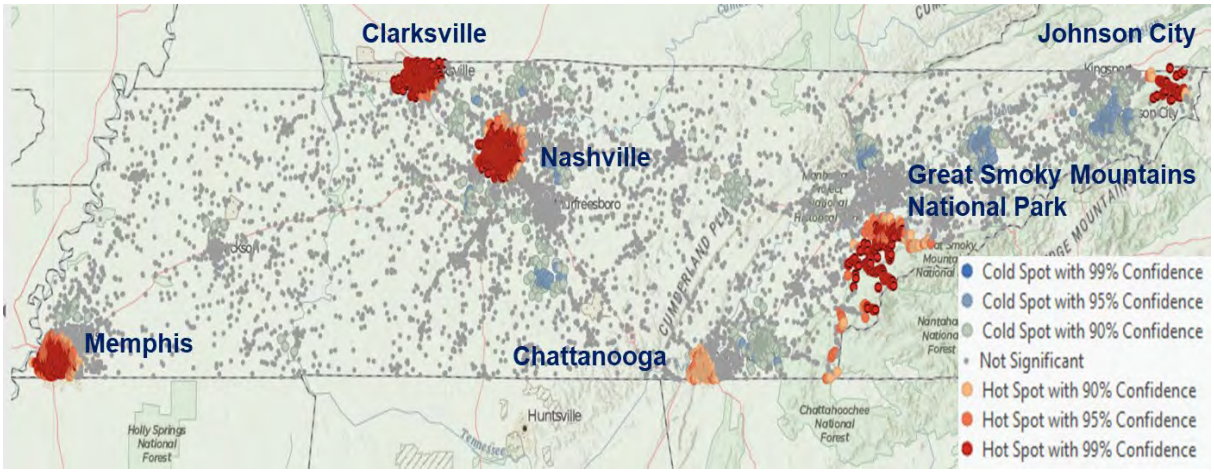

Figure 2.3 Hotspot Locations of Motorcycle Crashes in Tennessee

LIMITATIONS

One of the limitations of this study is that the analyses of motorcycle crashes are based on the sample from a specific region, Tennessee, USA. For this reason, the findings from this chapter should be understood in the context of Tennessee rather than being generalized broadly. As the data covers the motorcycle-involved crashes, the findings from the statistical analysis are valid only for the cases where motorcycle crashes occurred. This means that the findings account for the injury severity given a crash rather than crash risk. Besides, as stated earlier, 1,138 out of 14,667 crashes (7.8%) had missing values regarding rider injury severity. Although they were imputed by referencing the crash severity information, they would have incorrect values of injury severity. Besides, the analysis results are limited to police-reported crashes and an unknown number of motorcycle-involved crashes might be unreported.

CONCLUSIONS

This chapter investigated motorcycle crashes in Tennessee from 2016 to 2020 based on data from the Enhanced Tennessee Roadway Information Management System (ETRIMS) (Tennessee Department of Transportation (TDOT)). The analysis results provide baseline information on recent motorcycle crashes in Tennessee focusing on rider injuries, which helps planners and policymakers make informed decisions on evidence-based countermeasures. Noting that the Hurt Motorcycle Study conducted by NHTSA many years ago serves as the motivation for safety agencies to spend their funds primarily focused on other drivers rather than motorcyclists, this chapter points out that many decisions the motorcyclists make also put them at risk and should be addressed as well (Hurt 1981).

The findings from this chapter offer updated evidence regarding the practicality of the procedure for applying potentially effective countermeasures to deal with rider-related factors. Notably, motorcyclist injury severity can become significantly lower when a rider properly wears a DOT-compliant helmet. This finding is consistent with an NHTSA report suggesting that universal motorcycle helmet use laws are "determined to be effective" (Venkatraman et al. 2021). In addition, improper use of a DOT-compliant helmet was found to be positively associated with motorcyclist injury severity. Within the context of Tennessee, this finding can imply the appropriateness of motorcycle rider training which was considered "not yet determined to be effective" by the NHTSA report (Venkatraman et al. 2021). The analysis results also reveal that motorcyclist injury severity can become considerably higher when a rider is impaired by alcohol or drugs. This finding seems consistent with the NHTSA report suggesting that enforcement and sanctions against alcohol-impaired riding are "likely to be effective" (Venkatraman et al. 2021).

This chapter also provides updated evidence concerning the risk factors that lead to potentially effective countermeasures. Notably, this chapter reveals that two-way traffic ways that are not physically divided have a higher association with severe motorcyclist injuries compared to other types of roadways. Within the context of Tennessee, this finding can imply the appropriateness of outreach to improve motorist awareness of motorcyclists on the road which was considered "not yet determined to be effective" by the NHTSA report (Venkatraman et al. 2021). This finding also implies that motorcyclist safety could be enhanced by applying appropriate countermeasures to reduce the possibility of conflicts between vehicles. Furthermore, dark conditions were found to have a positive relationship with motorcycle injury severity. This finding indicates the potential effectiveness of wearing conspicuous clothing for greater visibility which was suggested by recent studies but considered "not yet determined to be effective" by NHTSA (Wali et al. 2018, Wali et al. 2019, Venkatraman et al. 2021). Besides, investing in lighting infrastructure could be considered for the locations where motorcycle crashes frequently occur at night to enhance motorcyclist safety. The flashpoint analysis offers practical implications that cities with larger populations or locations where motorcyclists seek thrills (e.g., The Tail of the Dragon) can be targeted for reducing the frequency of motorcycle crashes in Tennessee.

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3. Motorcycle Safety Practices across the United States

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CHAPTER SUMMARY

This chapter describes a comprehensive review of motorcycle safety practices throughout the United States and other countries performed to help the state of Tennessee establish state-wide strategies to improve motorcycle safety. The review items comprise a wide variety of motorcycle safety practices including rider training and education programs, motorcyclist operator manuals, media campaigns and motorcycle safety advisory groups. A supplementary review of motorcycle safety practices in other countries was also conducted to identify any outstanding practices outside the United States. Notably, this chapter aims to support swift and timely translation of research into practice at the state level through identification of transferable best practices for motorcycle safety across the United States and other countries. Based on the review and discussions with THSO staff members, Tennessee implements several initiatives including: its Motorcycle Rider Education Program (MREP) consisting of rider training courses for different levels of motorcyclists to promote safe riding, provision of the *Tennessee Motorcycle Operator Manual* to help motorcyclists learn to ride safely on the road, other driver focused media campaigns, occasional targeted law enforcement mini-grants and the Tennessee Highway Safety Office webpage which provides helpful tips for motorists and motorcyclists. Recommendations include additional p practices that Tennessee can undertake for motorcycle safety: (1) Conduct media campaigns targeting riders with motorcycle safety awareness focusing on impaired driving and proper helmet usage, (2) More communication with motorcyclists via online and printed materials, and (3) Need to have a motorcycle safety advisory group or coalition that cold both make specific recommendations on motorcycle safety and help get the messages out to riders.

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INTRODUCTION

In this chapter, a description is provided of a comprehensive review of motorcycle safety practices across the United States. The goals of the review were to find impactful examples of motorcycle safety strategies used in other locations that could be transferred and applied in Tennessee. The types of items reviewed consist of rider training programs, motorcycle operator manuals, media campaigns, and motorcycle safety advisory groups. The review was implemented by conducting an Internet search on the webpages of state highway safety offices from links found on the Governors Highway Safety Association (GHSA) website (Governors Highway Safety Association). Supplementary internet search was conducted by state with standard keywords including “motorcycle safety plan” and “motorcycle safety outreach.” In addition to the review of each state, a limited review of motorcycle safety practices in other countries was also performed to identify similar resources that had proven effective outside the United States.

MOTORCYCLE SAFETY PRACTICES IN TENNESSEE

Key Motorcycle Laws

Before examining other states, motorcycle safety-related practices in Tennessee were reviewed and documented to provide context and a point of reference for the searches. The Tennessee Highway Safety Office is tasked with addressing behavioural challenges in the motorcycle safety realm. A key aspect of THSO’s work is informing the traveling public including motorcyclists of key motorcycle laws and related requirements via its webpage (Tennessee Highway Safety Office). Motorcyclists in Tennessee are required to wear a DOT compliant helmet and eye protection unless they have a windshield on their motorcycles.

According to NHTSA, universal motorcycle helmet use laws have been determined to be effective for improving motorcycle safety (Venkatraman *et al.* 2021). The key motorcycle laws and the associated reference to statutes in Tennessee are as follows (Tennessee Highway Safety Office):

- A safety helmet is required to be worn by motorcyclists. [TCA 55-9-302]
- Approved helmets include DOT (FMVSS 218 Certified), CSPM, SNELL, and SIRC.
- The daytime use of headlight is required. [TCA 55-8-164(b)]
- The motorcyclist must wear eye protection unless his/her motorcycle is equipped with a windshield. [TCA 55-9-304]
- Lane splitting is not legal in Tennessee. [TCA 55-8-182 (b & c)]
- All motorcycles and motor-driven cycles operated upon any highway or public road of this state shall be equipped with a rear-view mirror and securely attached footrests for the operators and passengers on all motorcycles and motor-driven cycles. [TCA 55-9-305]
- Mufflers are required on motorcycles. Cutouts are prohibited. [TCA 55-9-202]
- If the motorcycle is transporting a passenger, then it must be equipped with passenger seating and passenger footrest. [TCA 55-9-305/TCA 55-8-164(a)]

Helpful Tips for Motorists and Motorcyclists

The Tennessee Highway Safety Office also provides some helpful tips for motorists as well as motorcyclists on its webpage (Tennessee Highway Safety Office). Importantly, motorists are encouraged to watch for motorcyclists and share the road with motorcyclists while keeping a sufficient following distance. Motorcyclists are encouraged to wear appropriate protective equipment including a DOT compliant helmet and avoid impaired riding. The helpful tips for motorists and motorcyclists provided by the office are as follows (Tennessee Highway Safety Office):

Helpful Tips for Motorists from Tennessee Highway Safety Office:

- Check your mirrors and blind spots before switching lanes. Motorcycles are smaller than most vehicles, they can be difficult to see.
- The size of a motorcycle can cause other drivers to misjudge the speed and distance away of a motorcycle.
- Always signal your intentions before changing lanes or merging with traffic. This allows motorcyclists to anticipate your movement and find a safe lane position.
- Allow a motorcyclist a full lane width. Share the road, but not the lane. A motorcyclist needs room to maneuver safely.
- Allow ample follow distance - three or four seconds - when following a motorcycle. This provides the motorcycle rider more time to maneuver or stop in an emergency.

Helpful Tips for Riders from Tennessee Highway Safety Office:

- Wear a DOT-compliant helmet and use reflective tape and gear to be more visible.
- Never ride while impaired or distracted. NHTSA-funded research has shown that motorists are distracted more than 50% of the time.
- Always ride with a current motorcycle license.

Motorcycle Rider Education Program (MREP)

Under the administration of the Tennessee Department of Safety, the “Motorcycle Rider Education Program (MREP)” offers rider training courses that consist of the Basic Rider Course (BRC), Basic Rider Course Two (BRC 2), Advanced Rider Course (ARC), and Trike Course (Tennessee Department of Safety and Homeland Security). According to NHTSA, motorcycle rider training has not yet been determined to be effective for improving motorcycle safety due to limited evidence (Venkatraman *et al.* 2021). The BRC is a course designed for beginners and includes classroom discussion along with hands on practice. The BRC2 is for those riders who want to learn advanced skills, while the ARC provides experienced riders with a challenging course to hone their skills. The Trike Course as the name implies is designed for course for trike riders who desire to enhance their skill operating a trike. In the training courses, instructors certified by Motorcycle Safety Foundation (MSF) help course participants develop their skills in an off-street

environment. According to the Department of Safety and Homeland Security, there are 18 rider education locations in Tennessee as of October 2021 (Tennessee Department of Safety and Homeland Security). Notably, those who complete either course from an approved training site will get a certificate that permits their knowledge tests and license skills tests requirements to be waived.

Figure 3.1 Tennessee Motorcycle Rider Education Program

Tennessee Motorcycle Operator Manual

The best source for Tennessee motorcyclists desiring basic guidance on safe riding is provide by Tennessee Department of Safety and Homeland Security is the "Tennessee Motorcycle Operator Manual" developed by the National Public Services Research Institute (NPSRI), National Highway Traffic Safety Administration (NHTSA) and Motorcycle Safety Foundation (MSF) (Tennessee Department of Safety and Homeland Security). The latest version of the manual as of October 2021 is the seventeenth edition published in 2014. It includes chapters on preparing to ride with the motorized equipment, safe riding tips, guidance for manoeuvring the vehicle safely in various conditions, being in shape to ride, and license requirements. Emphasis is placed on the challenges and dangers to motorcyclists of intersections due to the potential for many conflict points between motorcyclists and other road users. It also offers guidance on how to riders should deal with common challenging situations at intersections. The section "being in shape to ride," not only discusses basic physical requirements of operating a motorcycle but informs motorcyclists of the dangers of riding under the influence of drugs or alcohol and provides and overview of the relevant laws.

MOTORCYCLE SAFETY PRACTICES ACROSS THE UNITED STATES

Motorcycle safety practices across the United States were identified and documented in the review conducted for this project. A summary table was generated providing brief descriptions of resources and web links on a state-by-state basis in alphabetical order. The first portion of that summary is shown as an example in Table 3.1 below (Governors Highway Safety Association). The remainder of able is in Appendix B. A quick review of the states shows that the most common practices throughout the country are (1) Rider Training and Education Programs, (2) Motorcycle Operator Manuals, and (3) Media Campaigns. In addition, some states are found to have a motorcycle safety advisory group, while other states communicate with motorcyclists through various types of online and printed resources.

Table 3.1 Summary of Motorcycle Safety Practices by State (1/12-see Appendix B)

State	Key Practices
Alabama	*Alabama Motorcycle Safety Program* ▪ Providing Motorcycle Safety Foundation (MSF) training courses ▪ Available at: https://www.montevallo.edu/campus-life/around-campus/alabama-traffic-safety-center/motocycle-safety-program/ *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.alea.gov/sites/default/files/inline-files/motorcyclemanual_0.pdf
Alaska	*Alaska Strategic Highway Safety Plan 2018-2022* ▪ Dealing with education and awareness practices ▪ Available at: https://dot.alaska.gov/stwdplng/shsp/assets/AKDOT_SHSP_2018_2022.pdf *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://doa.alaska.gov/dmv/dlmanual/mcman.pdf
Arizona	*Arizona Motorcycle Safety and Awareness Foundation (AMSAF)* ▪ Promoting media campaigns. ▪ Developing motorcycle education and training programs ▪ Available at: https://www.amsaf.org/mission/ *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://apps.azdot.gov/files/mvd/mvd-forms-lib/99-0129.pdf
Arkansas	*"Motorcycle Safety Program" suggested in the "Arkansas Highway Safety Plan" in 2017* ▪ Increasing enforcement of helmet law ▪ Improving public information and education on protective riding gear and alcohol & drugs ▪ Increasing skills training opportunities ▪ Available at: https://static.ark.org/eeuploads/asp/AR_FY17HSP_Final.pdf
California	*California Motorcyclist Safety Program (CMSP)* ▪ Providing motorcycle training. ▪ Educating the public how to interact with motorcycles ▪ Encouraging riders to wear protective gear ▪ Available at: https://cmsp.msi5.com/index.php *Vision Zero Mission in San Francisco* ▪ A motorcycle safety outreach campaign with free motorcycle safety training ▪ Available at: https://www.visionzerosf.org/motorcycles/ *California Motorcycle Handbook* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.dmv.ca.gov/portal/file/motorcycle-driver-handbook-pdf/

Rider Training and Education Programs

Most states were found to have rider training and education programs that are somewhat like those described for the state of Tennessee. However, not all states offer all the same courses, the number of locations and frequency differs from one to another and the specific content of the courses varies though no in-depth comparison was performed. Rather than comparing what is available from each state a couple of illustrative examples are provided. In the state of California, for example, “Motorcycle Training Course (MTC)” is provided for beginner motorcyclists and those riders under 21 while “1-Day Premier Course (1DPC)” is provided for experienced riders under California Motorcyclist Safety Program (CMSP) (California Highway Patrol). According to the CMSP, California has more than 100 training locations for motorcyclists to take a course and more than 1.2 million motorcyclists have received training at one of the training sites (California Highway Patrol). In the state of Connecticut, for instance, Connecticut Rider Education Program (CONREP) offers rider training courses for motorcyclists with different levels including Basic Rider Course (BRC), Intermediate Rider Course (IRC), Experienced Rider Course (ERC), Advanced Rider Course (ARC) and 3-Wheel Basic Rider Course (3WBRC) (Connecticut Department of Transportation).

Motorcycle Operator Manuals

As summarized in Table 3.1, most states were found to have their own motorcycle operator manual and the content of most manual was developed based on information from the Motorcycle Safety Foundation (MSF). These manuals typically cover general instructions for motorcyclists including what to in preparation for riding and how to ride safely. The core content of many state’s manuals is well aligned with the Tennessee version described in “Tennessee Motorcycle Operator Manual” above. However, the content is often tailored to state/regional contexts. For instance, the Motorcycle Handbook (Figure 3.2) of California where lane splitting is legal provides instructions on how to safely perform lane splitting between lanes on the road, whereas many other states do not include this type of guidance since lane splitting is illegal.

Figure 3.2 California Motorcycle Handbook

(Available at: https://www.dmv.ca.gov/portal/file/motorcycle-driver-handbook-pdf/)

Media Campaigns

Conducting media campaigns of various types to promote motorcycle safety was found to be a common practice in many states. Based on the review of the campaign content of state highway safety offices and related links, the advertisements can be classified into three categories of messaging: (1) Emotion-based, (2) Instructional or safety tip focused, and (3) Informative statistics-oriented advertisements, Examples of each are described in the following section.

Emotion-based Advertisements

As shown in Figures 3.3 to 3.4 and Figures C.1 to C.7 in Appendix C, advertisements designed to illicit strong emotions through slogans, messages, or images are used in media campaigns in the states of Colorado, Illinois, Iowa, Michigan, Missouri, Rhode Island, and Utah. Some advertisements emphasize the dangers of not wearing a helmet (Colorado and Rhode Island) or the dangers of impaired riding under the influence of alcohol (Florida, Missouri, and Utah), while some stress the dangers of speeding (Florida) or the importance of safe riding in general (Illinois, Iowa, and Michigan). Although this shock tactic might make motorcyclists feel uncomfortable, it is expected to make a strong impression on them so that they become more aware of safe riding.

Figure 3.3 Advertisements on Wearing a Helmet (Colorado)

(Available at: https://www.codot.gov/safety/motorcycle)

Figure 3.4 Advertisements on Wearing a Helmet (Rhode Island)

(Available at: https://www.youtube.com/watch?v=SRUhEOQmcqU)

Instructional or Safety Tip Focused Advertisements

Advertisements with important tips for safe riding are used in media campaigns in the states of Kansas, Maryland, Missouri, New York, and Virginia as shown in Figures 3.5 to 3.7 below and Figures C.8 to C.9 in Appendix C. Most of the advertisements advise motorists to be aware of motorcyclists on the road (Kansas, Maryland, Missouri, and New York), while some request motorcyclists to wear appropriate protective gear and keep themselves in control (Kansas and Virginia). This tactic can be effective to some target groups in encouraging motorists and motorcyclists to behave in a safe manner on the road.

Figure 3.5 Instructional or Safety Tip Focused Advertisements (Kansas)

(Available at: https://www.ktsro.org/motorcycle-safety)

Figure 3.6 Instructional or Safety Tip Focused Advertisements (Maryland)

(Available at: https://zerodeathsmd.gov/road-safety/motorcycle-safety/)

Figure 3.7 Instructional or Safety Tip Focused Advertisements (Missouri)

(Available at: https://www.youtube.com/watch?v=4KYXBGn4Dl8)

Informative Statistics-Oriented Advertisements

As shown in Figures 3.8 to 3.9 and Figure C.10 in Appendix C, informative advertisements with statistics concerning motorcycle safety are used in media campaigns in the states of Oklahoma, South Carolina, and Washington. Some advertisements highlight the vulnerability of motorcyclists on the road by showing statistics about injuries and fatalities (Oklahoma and Washington), while others show the impacts of rider behavior such as wearing a helmet, rider error, and alcohol and drug impairment (South Carolina and Washington). In the case of Washington, the advertisement reminds people of training and safety classes for motorcyclists. This tactic with specific statistics could be a highly persuasive way of inducing motorcyclists to be more aware of the dangers of riding motivate them to take actions to protect themselves.

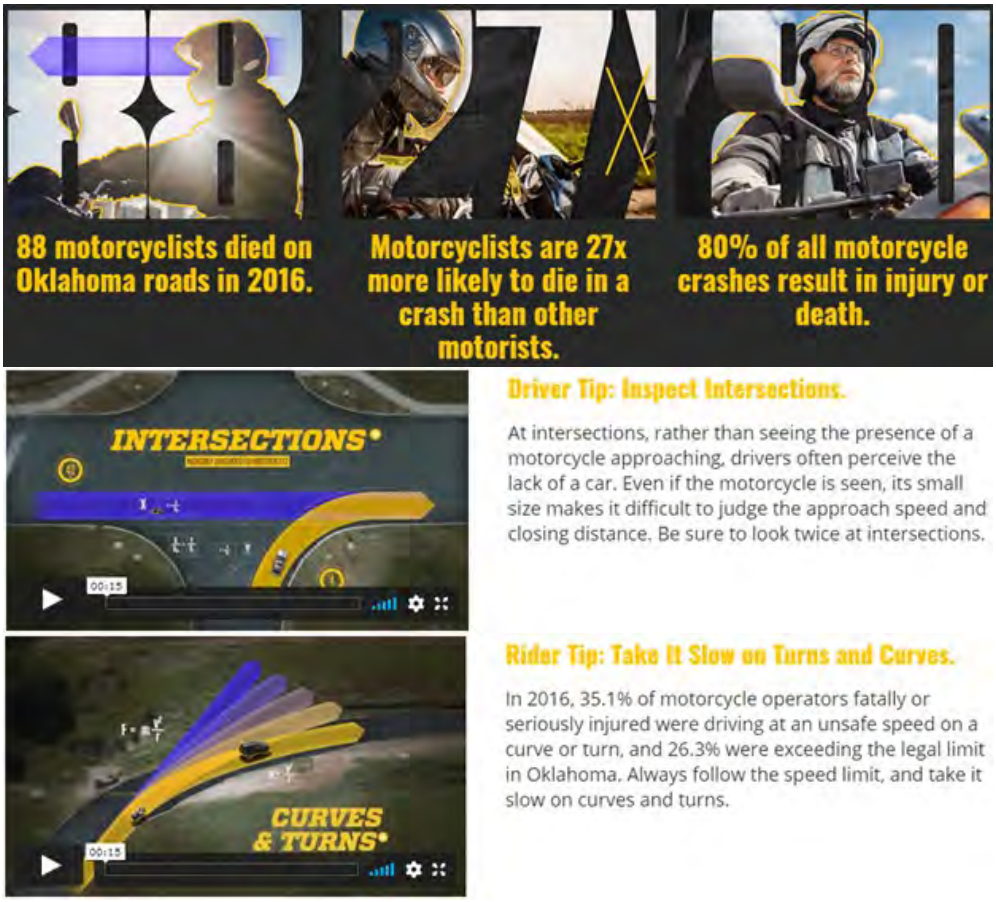

Figure 3.8 Informative Statistics-Oriented Advertisements (Oklahoma)

(Available at: https://www.okhighwaysafety.com/motorcycle-safety/)

Figure 3.9 Informative Statistics-Oriented Advertisements (Washington)

(Available at: https://www.youtube.com/watch?v=bSFcFaYdQyI)

Motorcycle Safety Advisory Groups

Based on our review, as summarized in Table 3.2, motorcycle safety advisory groups are currently operating in 13 states: Arizona, Colorado, Delaware, Florida, Idaho, Minnesota, Montana, New Mexico, Oklahoma, Oregon, Texas, Washington, and Wisconsin (Arizona Governor's Office of Highway Safety, Colorado State Patrol, Delaware General Assembly, Florida Motorcycle Safety Coalition, Idaho Coalition for Motorcycle Safety, Minnesota Department of Public Safety, Montana State Legislature, New Mexico Motorcyclist Rights Organization, Oklahoma Highway Safety Office, Texas Department of Licensing and Regulation, The State of Oregon, Washington State Department of Licensing, Wisconsin Department of Transportation). Tennessee did not have an active motorcycle safety advisory group when writing this report. A key role common to most of these groups is to provide specific recommendations on motorcycle safety to their state governments. However, their origins, level of activity, and their organizational structures vary from state to state. For instance, the "Motorcycle Operator Safety Advisory Board" of Colorado consists of members from several different organizations such as the Department of Transportation, the State Patrol, retail motorcycle dealers and motorcycle riding community. This group primarily makes recommendations on motorcycle training program content and the expenditures of funds (Colorado State Patrol). In the case of Texas, the "Motorcycle Safety Advisory Board" is associated with the Texas Department of Licensing and Regulation and has regular meetings for discussions on motorcycle-related issues such as licensing, rider education and enforcement (Texas Department of Licensing and Regulation).

Table 3.2 Summary of Motorcycle Safety Advisory Groups by State (1/2)

State	Description
Arizona	**Motorcycle Safety Advisory Council** ▪ Associated with the "Governor's Office of Highway Safety" ▪ Had public meetings from 2010 to 2016, the last of which was in June 2016. Those meetings covered motorcycle safety awareness, media campaigns, impaired riders, motorcycle manuals, and rider education.
Colorado	**Motorcycle Operator Safety Advisory Board** ▪ Stakeholders consist of members from the Department of Transportation, the Department of Revenue, the State Patrol, retail motorcycle dealers, motorcycle riding community, motorcycle training providers, etc. ▪ Makes recommendations on training methods, improvements to the training program, and expenditures of highway safety funds
Delaware	**Delaware Motorcycle Rider Education Advisory Committee** ▪ Stakeholders consist of members from the senate, house, DelDOT, the Delaware Office of Highway Safety, and public members ▪ Makes recommendations on rider education and legislation
Florida	**Florida Motorcycle Safety Coalition** ▪ Stakeholders consist of Florida Department of Transportation, Florida Highway Safety and Motor Vehicles, Center for Urban Transportation Research (CUTR) at the University of South Florida, Ryder Trauma Center in Miami, etc. ▪ Covers topics including data-driven research, implementation, and evaluation of countermeasures against motorcycle injuries and fatalities
Idaho	**Idaho Coalition for Motorcycle Safety** ▪ A state motorcycle rights organization that monitors the federal, state, and local governmental agencies/bodies to protect the rights of motorcycle riders

Table 3.2 Summary of Motorcycle Safety Advisory Groups by State (2/2)

State	Description

Minnesota	**Minnesota Motorcycle Safety Advisory Task Force** ▪ Established by Office of Traffic Safety in the Department of Public Safety ▪ Provides input to the Department of Public Safety on the operation of the Minnesota Motorcycle Safety Program and motorcycle safety in general ▪ Represents Minnesota motorcyclists and the diversity of the motorcycling community
Montana	**Motorcycle Safety Advisory Committee** ▪ Associated with the board of regents for administrative purposes ▪ Consists of one peace officer appointed by the governor, one instructor of motorcycle safety training, two motorcycle riders from riding groups, and one representative from the department of justice ▪ Advises the board of regents and the Department of Justice concerning motorcycle safety such as motorcycle safety training and motorcycle endorsement testing
New Mexico	**New Mexico Motorcycle Rights Organization** ▪ A state motorcycle rights organization ▪ Monitors current political and legislative activities that affect the motorcycling community ▪ Makes recommendations regarding the possible introduction of laws or regulations that will benefit the motorcycling community
Oklahoma	**Advisory Committee for Motorcycle Safety and Education** ▪ Stakeholders consist of members from the Oklahoma Highway Patrol, private sector motorcycle rider education schools, the Oklahoma Insurance Dept., Motorcycle Safety Foundation, Motorcycle Safety and Education, etc. ▪ Have meet periodically to address motorcycle safety issues ▪ Serve as the discretion of the Commissioner of Public Safety
Oregon	**Governor's Advisory Committee on Motorcycle Safety** ▪ Established by Oregon's state government ▪ Provides advice regarding motorcycle safety issues and legislation to the Governor and the Oregon Department of Transportation (ODOT) Safety Division ▪ Topics include rider education, impaired riding, road hazards, motorist awareness of motorcycles, etc.
Texas	**Motorcycle Safety Advisory Board** ▪ Established for the "Texas Department of Licensing and Regulation" ▪ Meet regularly regarding licensing, rider education, enforcement, etc.
Washington	**Motorcycle Safety Education Advisory Board** ▪ Associated with the Washington State Department of Licensing ▪ Helps develop rider training programs, safety education and outreach
Wisconsin	**Motorcycle Safety Advisory Council** ▪ Stakeholders consist of members from the American Bikers Against Totalitarian Enactments (ABATE) of Wisconsin, Wisconsin Motorcycle Safety Program, American Motorcyclist Association, Wisconsin DOT, etc. ▪ Advises the secretary of the Wisconsin DOT on motorcycle safety issues including motorcycle crashes, fatalities, rider training, impaired riders, sharing the road, and riding gear

Other Practices

In addition to common activities such as rider training programs and media campaigns, other practices for motorcycle safety were also identified by the comprehensive review shown in Table 1. The review found

that some states communicate with motorcyclists through online media and materials.

- The states of Montana, Pennsylvania and Wyoming have Facebook pages to provide updates on motorcycle safety-related statistics and their motorcycle safety practices such as training programs (Montana Motorcycle Rider Safety, Pennsylvania Department of Transportation, Wyoming Motorcycle Safety Program).
- In Pennsylvania, the "Motorcycle Safety Video Project" is underway to solicit video submissions on motorcycle maintenance, riding tips and safety from the public (Pennsylvania Department of Transportation).
- South Dakota conducts online survey of motorcyclists via the web page of South Dakota Office of Highway safety to collect information on how motorcyclists ride in the state (South Dakota Office of Highway Safety).
- Oklahoma launched the "Road Science Campaign" in 2018 focusing on educating motorists to better interact with motorcyclists and encouraging motorcyclists to be extra vigilant (Oklahoma Highway Safety Office). This campaign is based on a scientific approach that shows statistical information and graphics online. This campaign also provides safe riding tips covering specific situations and items, e.g., intersections, blind spot, following distance, curve and turns, and blinkers.

Some states also traditional printed materials to remind motorcyclists of safe riding.

- For instance, Massachusetts offers "Rider Responsibility Postcards" to keep riders aware of safe riding (Massachusetts Department of Transportation).
- Rhode Island has developed informational pocket cards to bring motorcycle safety awareness (Rhode Island Department of Transportation). The pocket cards are distributed at local events by community groups.
- In Minnesota and Missouri, brochures for safety awareness of motorcyclists and motorists are provided (Minnesota Department of Public Safety, Missouri Department of Transportation).

Motorcyclist Fatalities by State

To compare quantitatively other states to Tennessee in terms of motorcycle safety performance, we derived the "Annual Motorcyclist Fatalities per 10,000 Motorcycle Registrations" for every state. These fatality rates were calculated based on statistics on motorcyclist fatalities from the "Motorcycle Traffic Safety Fact Sheets" by National Highway Traffic Safety Administration (NHTSA), Federal Highway Administration (FHWA) and statistics on motorcycle registrations from the "Highway Statistics" by FHWA (Federal Highway Administration (FHWA), National Highway Traffic Safety Administration (NHTSA), National Highway Traffic Safety Administration (NHTSA), National Highway Traffic Safety Administration (NHTSA)). From 2017 to 2019, as shown in Figures 3.10 to 3.12, Tennessee had about 8-10 fatalities per 10,000 motorcycle registrations annually being ranked 12th, 9th, and 11th places in 2017, 2018 and 2019, respectively. Specifically, Tennessee was ranked 12th h in 2017 with a rate of 8.07, 9th p in 2018 with a rate of 9.28, and 11th in 2019 with a rate of 8.38.

According to the statistics shown in Figures 3.10 to 3.12, Montana and South Dakota had the lowest and the second lowest motorcyclist fatality rates three year in a row from 2017 to 2019. The state of Minnesota stayed in the bottom five during the three-year period studied in terms of motorcycle fatality rates. The states with low fatality rates commonly use online and printed materials to actively communicate with motorcyclists according to the comprehensive review conducted in this chapter. This implies that the state of Tennessee may have the opportunity to improve motorcycle safety by benchmarking those states that have an active communication with motorcyclists within the state. A comparative analysis of the roadway environments, motorist/motorcyclist culture, climate and other factors of each state as compared to the motorcycle safety practices could provide additional insights into the effectiveness of implemented practices.

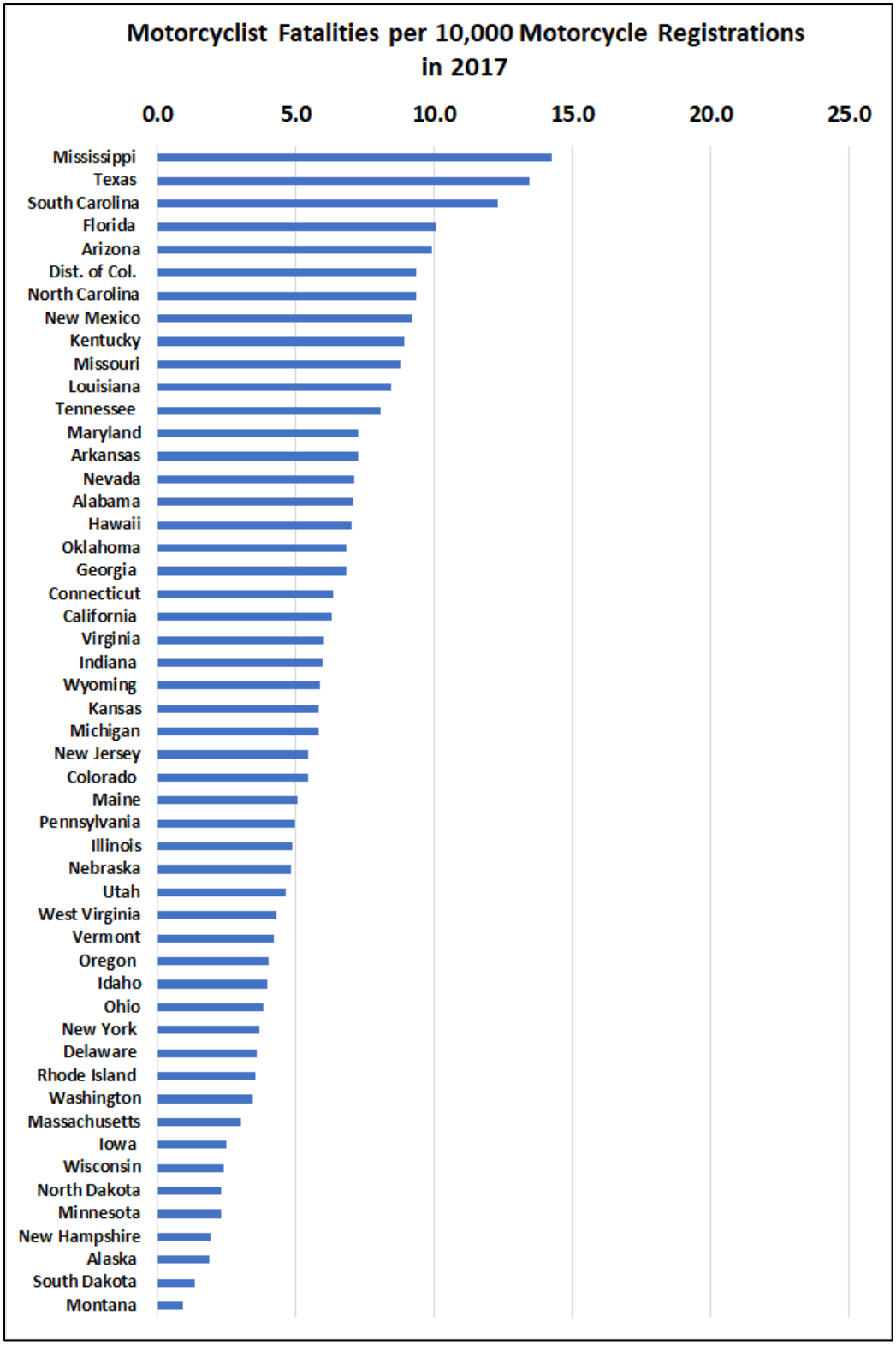

Figure 3.10 Motorcycle Fatality Rates by State in 2017

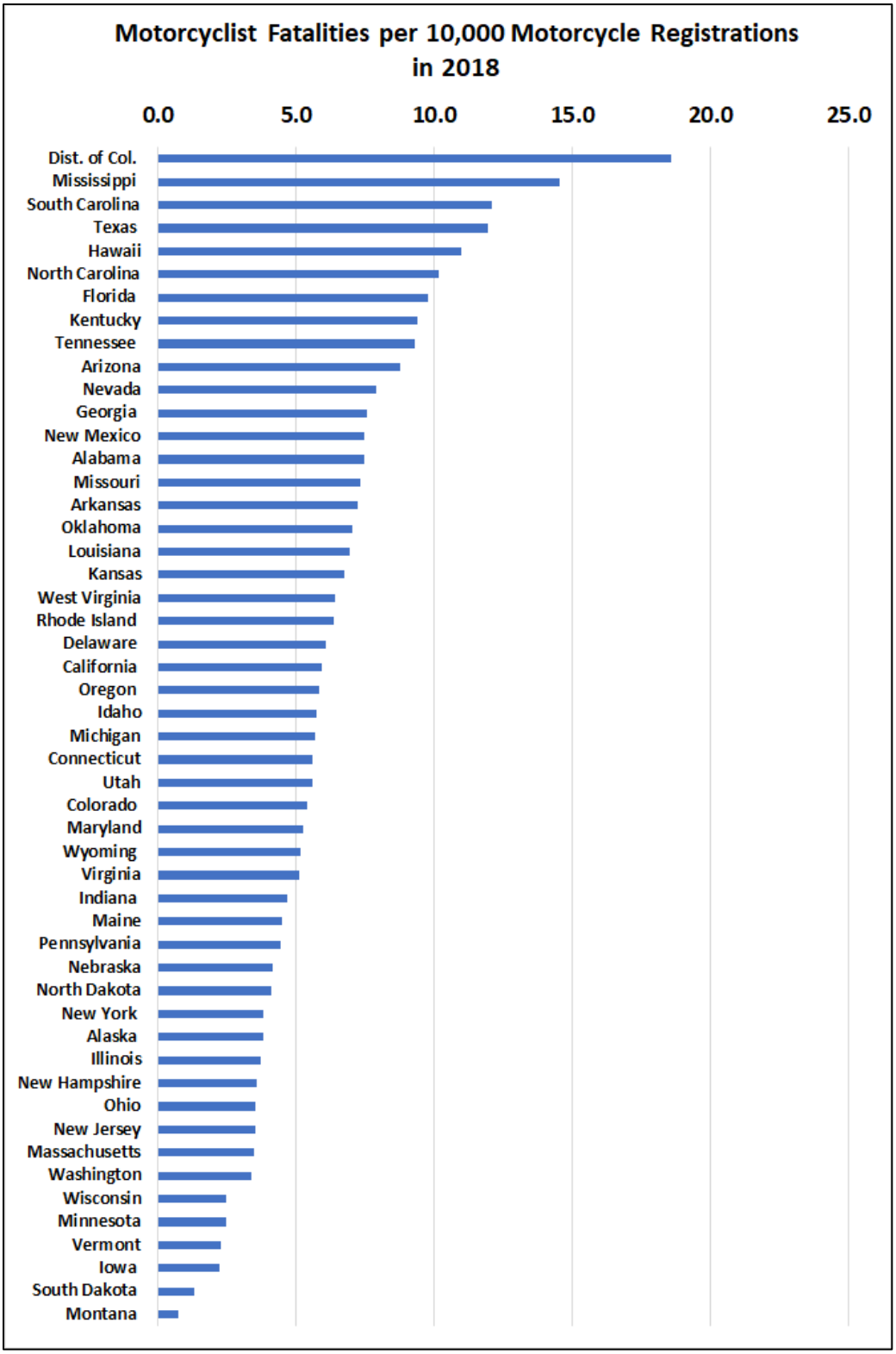

Figure 3.11 Motorcycle Fatality Rates by State in 2018

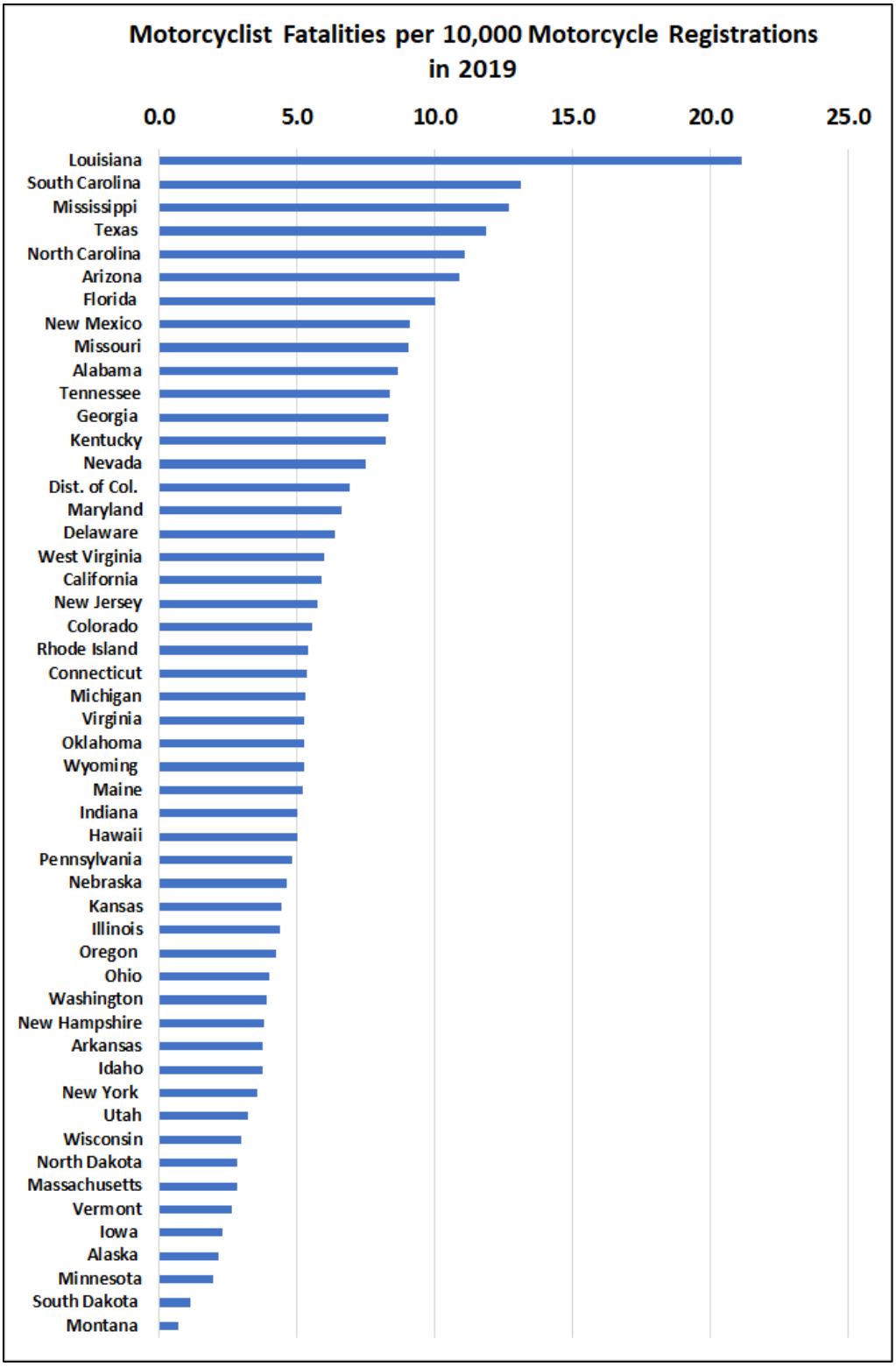

Figure 3.12 Motorcycle Fatality Rates by State in 2019

MOTORCYCLE SAFETY PRACTICES IN OTHER COUNTRIES

In addition to the review on the United States, a targeted review of motorcycle safety practices in select other countries was also performed to identify relevant practices for motorcycle safety outside the United States. This review was conducted on Canada, Australia, and the United Kingdom (Canada Safety Council, Government of South Australia, New South Wales (NSW) Centre for Road Safety, Transport for London (TfL)), as summarized in Table 3.3. As in the United States, these countries are attempting to improve motorcycle safety with rider training programs, media campaigns, rider's handbooks, or motorcycle safety action plans. For example, as shown in Table 3.3, Canada and London, the United Kingdom, offers motorcycle training courses (Canada Safety Council, Transport for London (TfL)). Notably, they take advantage of online courses as well as onsite courses, which could be adopted in Tennessee. In the case of Australia, both South Australia and New South Wales have published a safety action plan suggesting improvements in road design or infrastructure for motorcyclists (Government of South Australia, New South Wales (NSW) Centre for Road Safety). These examples, though limited, provide examples of motorcycle safety actions taken in other countries that may have merit for use in Tennessee.

Table 3.3 Summary of Motorcycle Safety Practices in Other Countries

Country	Key Practices
Canada	*Motorcycle Rider Training Program (Gearing Up)* ▪ Providing rider training courses *Motorcycle Safety Online Training* ▪ Providing online courses for beginners or those who want a refresher
South Australia, Australia	*Road Safety Action Plan 2013-2016 (Toward Zero Together)* ▪ Priority actions include improving infrastructure, developing the "Sharing the Road" campaigns, providing a motorcycle skills refresher training course, and promoting the benefits of wearing protective motorcycle clothing. *Rider's Safety Handbook* ▪ Providing instructions for motorcyclists
New South Wales (NSW), Australia	*NSW Motorcycle Safety Action Plan 2017-2019 (Towards Zero)* ▪ Suggests improving road design, improving rider awareness regarding impairment and speeding, improving enforcement of motorcycle speeding ▪ Suggesting developing consumer information on protective gear *"Ride to Live" Campaign* ▪ Includes advertisements for awareness of motorcycle safety
London, United Kingdom	*Motorcycle Safety Action Plan* ▪ Suggests actions to reduce speed-related collisions and right-turning vehicle collisions, increased enforcement, and compliance with the rules of the road, increases in the use of personal protective equipment, and improve motorcyclist skills and riding behavior *Compulsory Basic Training (CBT)* ▪ Consisting of a classroom-based theory element and an on-road riding element ▪ A short online course is provided to help prepare for the CBT. *Free Practical Training Courses* ▪ One-to-one motorcycle skills session for urban riding ▪ Training session for delivery riders

CONCLUSIONS

A comprehensive review of motorcycle safety practices across the United States and a target review of practices in other countries were performed to assist the state of Tennessee in formulating strategies to reduce motorcycle crashes and injuries. The review items encompassed a wide variety of motorcycle safety practices such as rider training and education programs, motorcyclist operator manuals, media campaigns and motorcycle safety advisory groups.

The analysis reported in the chapter indicates that Tennessee was in the top 12 of most deadly states for motorcyclists as measured by fatalities per 10,000 motorcycle registrations during the period studied. Tennessee relies heavily on its Motorcycle Rider Education Program (MREP) consisting of rider training courses for different levels of motorcyclists to improve motorcycle safety. An additional resource that is made available is the "Tennessee Motorcycle Operator Manual" which is provided to help motorcyclists better prepare to ride with proper equipment, be in shape to ride, and ride in a safe manner on the road. The state of Tennessee also provides helpful tips for motorists and motorcyclists via the webpage of the Tennessee Highway Safety Office (THSO). Further, the THSO has in recent years implemented as enforcement campaign targeting high-crash areas and times along with some limited social media advertising. Due to NHTSA expectations and limitations, however, motorcycle safety media advertising in Tennessee mostly focuses on other motorists not motorcyclists. Based on identified practices in other states, Tennessee may have some opportunities to expand its motorcycle safety program. For example, several states make use of more robust media campaigns with different messaging much of which targets motorcyclists. Another opportunity for Tennessee is enhanced communication with motorcyclists via online and printed materials given that the states with the lowest motorcycle fatality rates in recent years, i.e., Montana, South Dakota, and Minnesota, communicate actively with motorcyclists via online and printed materials. Examples to consider include the state of Montana managing a Facebook webpage devoted to motorcycle safety, South Dakota performing online surveys of motorcyclists, and Minnesota distributing different types of printed educational materials. Finally, there is value in re-establishing the motorcycle safety coalition, creating a motorcycle safety advisory group or some similar entity to seek recommendations on motorcycle safety as well as establishing a wider network for distribution of safety information to riders.

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APPENDIX A: Relationship of Key factors with Rider Injury-Tennessee Motorcycle Crashes

Given the ordinal nature of the rider injury severity measured as fatal injury (K), incapacitating injury (A), non-incapacitating injury (B), possible injury (C), no injury (O), we have estimated an ordered Probit model to understand how various factors including rider age, helmet types, light conditions, roadway configuration, speed limit, and especially pre-crash riding behaviors relate to rider injury severity given a motorcycle crash (see Table A1). The final model was systematically derived while considering statistical significance, specification parsimony, and theoretical justification. All the variables were evaluated via 95% confidence level criteria. Note that some categories (dawn, darkness without lighting) of the light condition variable did not show statistical significance; however, these indicator variables were kept in the model for the sake of completeness. The marginal effects reveal the change in the probability of specific category of the response variable (in this case rider injury severity) due to a unit increase in continuous variable (speed limit, rider age) or if an indicator variable switches from 0 to 1 while keeping other variables at their constant values. Marginal effects when multiplied with 100 can be interpreted as chance. Based on the estimation results, compared to DOT compliant helmet, there is 8.86%, 4.37%, 3.10% higher chance of rider fatality due to improper use of DOT compliant helmet, no helmet, non-compliant helmet (Table A1). As discussed earlier, these findings indicate that that improper use of a helmet such as untying the chain strap might additionally damage a rider when a crash occurs. It may also imply there might have been behavioral differences in riding between those riders who improperly used a helmet and those riders without a helmet. Overall, compared with wearing a compliant helmet, improper use of a compliant helmet is associated with more severe injuries; not wearing a helmet or wearing a non-compliant helmet are also associated with higher injury risk, given a crash. The findings also suggest that rider age (years) and speed limit (miles per hour) are positively correlated with rider injury severity. Furthermore, our findings indicate that there is 4.81% higher chance of rider fatality on physically undivided roadway segments compared to other wise. Referring to the pre-crash behaviors of the rider, we have found that there is an 8.43%, 3.26%, 1.83%, and 1.44% higher chance of rider fatality if the rider exceeds posted speed limit, the rider departs the lane in a crash, rider is involved in careless or reckless behaviors, and if an operator (rider) is inexperienced, respectively.

Table A1. Estimation Results of Ordered Probit Model (Rider Injury: Motorcycle Crashes in TN)

Explanatory Variables	Coeff.	t-stats	Chance "%" (Marginal Effects*100)				
			O	C	B	A	K
Rider Age (Years)	0.0022	3.64	-0.06	-0.01	0.01	0.04	0.02
Helmet (Base = DOT Compliant Motorcycle Helmet)							
Improper use of DOT compliant helmet	0.5981	4.33	-14.04	-5.68	-1.13	11.99	8.86
Non-compliant helmet	0.2642	4.68	-7.13	-2.23	0.65	5.61	3.10
No helmet	0.3499	9.06	-9.13	-3.07	0.46	7.37	4.37
Unknown	-0.7739	-14.56	26.97	1.01	-10.20	-13.70	-4.09
Rider Impairment with alcohol/drug (Yes/No)	0.2073	5.10	-6.02	-1.41	1.10	4.26	2.06
Light Conditions (Base = daylight)							
Dawn	0.0269	0.31	-0.79	-0.18	0.16	0.55	0.26
Darkness with unknown lighting	-0.2644	-1.69	8.43	1.25	-2.39	-5.24	-2.05
Darkness with lighting	0.1993	6.92	-5.55	-1.50	0.74	4.12	2.20
Darkness without lighting	0.0404	1.35	-1.19	-0.27	0.23	0.83	0.40
Dusk	0.1578	2.74	-4.46	-1.16	0.66	3.26	1.69
Other/Unknown	-0.5121	-5.17	17.13	1.49	-5.76	-9.57	-3.29
Roadway Configuration							
Not physically divided (Two-way) (Yes/No)	0.4838	24.78	-14.04	-3.28	2.57	9.95	4.81
Speed limit (miles per hour)	0.0189	21.12	-0.55	-0.13	0.10	0.39	0.19
Rider Behaviors							
Careless Erratic Driving or Reckless Negligent Driving (Yes/No)	0.1845	4.76	-5.35	-1.25	0.98	3.79	1.83
Exceeding Posted Speed Limit (Yes/No)	0.8484	13.37	-24.63	-5.75	4.51	17.44	8.43
Lane Departure (Yes/No)	0.3276	11.80	-9.51	-2.22	1.74	6.74	3.26
Operator (rider) Inexperience (Yes/No)	0.1452	2.85	-4.22	-0.98	0.77	2.99	1.44
Threshold Parameters							
μ_1	0.5168	10.64	---	---	---	---	---
μ_2	1.0303	21.09	---	---	---	---	---
μ_3	1.9112	38.23	---	---	---	---	---
μ_4	3.0064	56.47	---	---	---	---	---
Summary Statistics							
LL (Convergence)	-19870.07						
McFadden R-Squared	0.0519						
AIC	39784.14						
BIC	39950.18						

Note: K=Fatal Injury, A=Incapacitating Injury, B=Non-incapacitating Injury, C=Possible Injury, O=No Injury

APPENDIX B: Motorcycle Safety Practices Nationwide

The table below summarizes motorcycle safety practices in United States.

Table 3.1 Summary of Motorcycle Safety Practices by State (2/12)

State	Key Practices
Colorado	*CDOT Motorcycle Safety Campaign* ▪ Bringing awareness of the importance of wearing the proper equipment ▪ Available at: https://www.codot.gov/safety/motorcycle *The "Live to Ride Campaign"* ▪ Providing the "Motorcycle Safety Training (MOST)" ▪ Available at: https://csp.colorado.gov/community-outreach/most-motorcycle-safety-training *Colorado Motorcycle Operator's Handbook* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.colorado.gov/pacific/sites/default/files/DR2336.pdf *An advertisement for wearing a helmet* ▪ Available at: https://www.codot.gov/safety/motorcycle
Connecticut	*Connecticut Rider Education Program* ▪ Providing rider training courses ▪ Available at: https://portal.ct.gov/DOT/Programs/CONREP_Course-Info#41217 *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://portal.ct.gov/-/media/DMV/20/29/cycmanpdf.pdf
Delaware	*"Respect Your Ride & Share the Road" Motorcycle Safety Campaigns* ▪ Encouraging motorists to look twice and share the road with motorcyclists through billboards, terrestrial radio broadcast and digital advertising ▪ Encouraging motorcyclists to have proper training and tools ▪ Available at: https://ohs.delaware.gov/motorcycle.shtml *ARRIVE ALIVE DE* ▪ Providing motorcycle training courses ▪ Available at: https://www.arrivealivede.com/respect-the-ride/ *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.dmv.de.gov/forms/driver_serv_forms/pdfs/dr_frm_motorcycle_manual.pdf

Table 3.1 Summary of Motorcycle Safety Practices by State (3/12)

State	Key Practices
Florida	*The "2016 Florida Motorcycle Strategic Safety Plan"* ▪ Suggesting strategies for rider training and licensing, law enforcement and emergency services ▪ Available at: http://ridesmartflorida.com/wp-content/uploads/2018/10/Florida-MSSP-2016.pdf *Communication Program* ▪ Ensuring motorist watch for motorcyclists ▪ Enhancing compliance of traffic laws involving motorcyclists ▪ Available at: https://www.fdot.gov/Safety/programs/motorcycle-safety.shtm *Advertisements on speeding and alcohol* ▪ Available at: https://www.youtube.com/watch?v=naJ18us_ymo, https://www.fdot.gov/Safety/programs/motorcycle-safety.shtm
Georgia	*Georgia Motorcycle Safety Program (GMSP)* ▪ Providing rider education programs with proper training ▪ Available at: https://dds.georgia.gov/gmsp-riders *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://online.flipbuilder.com/hatf/yptu/
Hawaii	*Motorcycle Safety Foundation (MSF) Training Courses* ▪ Available at: https://ocewd.org/oahuridercourse/ *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://hidot.hawaii.gov/highways/files/2016/05/3-21-16-Dft-Rider-Manual.pdf
Idaho	*Idaho Skills Training Advantage for Riders (STAR)* ▪ Providing rider training courses ▪ Available at: https://idahostar.org/ *Idaho Motorcycle Rider's Handbook* ▪ Providing instructions for motorcyclists ▪ Available at: https://itd.idaho.gov/wp-content/uploads/2016/06/motorcycle_manual.pdf
Illinois	*Cycle Rider Safety Training Program* ▪ Providing rider training courses ▪ Available at: https://idot.illinois.gov/transportation-system/safety/roadway/ssm/index *2020 Illinois Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.ilsos.gov/publications/pdf_publications/dsd_x140.pdf *An advertisement for motorcycle safety* ▪ Available at: https://www.youtube.com/watch?v=8wfEVDb6fI0&t=30s

Table 3.1 Summary of Motorcycle Safety Practices by State (4/12)

State	Key Practices
Indiana	*Ride Safe Indiana (RSI)* ▪ Providing rider training courses ▪ Available at: https://www.in.gov/rsi/ *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.in.gov/rsi/files/motorcycle-operators-manual.pdf
Iowa	*Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://iowadot.gov/mvd/motorcycle/mcmanual.pdf *An advertisement for motorcycle safety* ▪ Available at: https://www.youtube.com/watch?v=iYcOjeiepnE&t
Kansas	*Kansas Motorcycle Education Programs* ▪ Providing education courses at community colleges and commercial motorcycle schools ▪ Available at: https://www.ktsro.org/files/Motorcycle-Education-Program-Locations-2021-4.pdf *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.ksrevenue.org/pdf/mchdbk.pdf *Advertisements for motorcycle safety and sharing the road* ▪ Available at: https://www.ktsro.org/motorcycle-safety
Kentucky	*Kentucky Motorcycle Rider Education Program* ▪ Providing rider training courses and motorcycle safety courses ▪ Available at: https://ride.ky.gov/Pages/index.aspx *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://kentuckystatepolice.org/wp-content/uploads/2017/11/motorcycle_rev_03_13_12_op.pdf
Louisiana	*Louisiana Operator Training Courses* ▪ Providing rider training courses ▪ Available at: http://www.lsp.org/motorcycle.html
Maine	*Motorcycle Rider Education* ▪ Providing motorcycle safety courses at motorcycle rider education schools ▪ Available at: https://www.maine.gov/sos/bmv/driverridereducation/index.html *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.maine.gov/sos/bmv/licenses/motorcyclemanual.pdf

Table 3.1 Summary of Motorcycle Safety Practices by State (5/12)

State	Key Practices
Maryland	*Motorcycle Training Courses* ▪ Available at: https://zerodeathsmd.gov/road-safety/motorcycle-safety/ *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://mva.maryland.gov/Documents/DL-001.pdf *An advertisement on "watch for motorcycles"* ▪ Available at: https://zerodeathsmd.gov/road-safety/motorcycle-safety/
Massachusetts	*Massachusetts Rider Education Program (MREP)* ▪ Providing rider training courses ▪ Available at: https://www.mass.gov/info-details/massachusetts-rider-education-program-mrep *Motorcycle Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.mass.gov/doc/motorcycle-manual/download *"Rider Responsibility" Postcards* ▪ Available at: https://www.mass.gov/doc/eopssmassdot-motorcycle-rider-responsibility-postcard/download
Michigan	*Michigan Motorcycle Safety Action Plan (2017-2022)* ▪ Suggesting education, enforcement, engineering, and emergency response for motorcycle safety ▪ Available at: https://www.michigan.gov/documents/msp/MC_Safety_Action_Plan_12-01-2014_478724_7.pdf *Michigan Rider Education Program (Mi-REP)* ▪ Providing rider training courses ▪ Available at: https://www.michigan.gov/sos/0,4670,7-127-1627_46351---,00.html *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.michigan.gov/documents/moopman_16311_7.pdf *An advertisement for motorcycle safety* ▪ Available at: https://www.youtube.com/watch?v=bVGOJIz1UIw

Table 3.1 Summary of Motorcycle Safety Practices by State (6/12)

State	Key Practices
Minnesota	*Rider Training Courses* ▪ Available at: https://dps.mn.gov/divisions/ots/mmsc/rider-training/Pages/default.aspx *Motorcycle and Motorized Bicycle Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://driving-tests.org/minnesota/minnesota-motorcycle-manual/ *Educational Materials (Orders should be placed.)* ▪ A brochure, "Sharing the Road" ▪ Motorcycle Rider Checklist ▪ Available at: https://www.four51.com/UI/Customer.aspx?p=catalog&catid=IjyePWOajrnQXHSDCMnJ4CWcCvFlw7npCYq3hl-ssw-pPzTE-pM7QurXg-e-e&catinteropID=A54ED484-A2D9-43D6-AD94-C24C6B3F14E0&CEI=1ece366f-0f36-4d42-9115-cd84ce9d2d53
Mississippi	*Rider Training Courses* ▪ Available at: https://www.dps.ms.gov/public-safety-planning/highway-safety/motorcycle *"State of Mississippi-Highway Safety Plan Federal Fiscal Year 2021"* ▪ Partially covering motorcycle safety ▪ Aiming to reduce motorcyclist fatalities from impaired driving and not wearing a helmet ▪ Available at: https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/ms_fy21_hsp.pdf
Missouri	*Missouri Motorcycle Safety Program (MMSP)* ▪ Providing rider training courses ▪ Available at: https://mmsp2.msi5.com/index.php *Motorcycle Safety Brochure* ▪ Providing concise riding tips for motorcyclists ▪ Available at: https://www.modot.org/sites/default/files/documents/motorcycle%20brochure2.pdf *Advertisements for motorcycle awareness* ▪ Available at: https://www.savemolives.com/mcrs/motorcycle-awareness-month
Montana	*Montana Motorcycle Riders Safety (MMRS) Training Program* ▪ Providing rider training courses ▪ Available at: http://motorcycle.msun.edu/ *Montana Motorcycle Supplement* ▪ Providing instructions for motorcyclists ▪ Available at: https://dojmt.gov/wp-content/uploads/25-1500.pdf *A Facebook webpage, "Montana Motorcycle Rider Safety"* ▪ Available at: https://www.facebook.com/MontanaMotorcycleRiderSafety

Table 3.1 Summary of Motorcycle Safety Practices by State (7/12)

State	Key Practices
Nebraska	*Rider Training Courses* ▪ Available at: https://dmv.nebraska.gov/dl/nebraska-motorcycle-safety-education-sponsors *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://dmv.nebraska.gov/sites/dmv.nebraska.gov/files/doc/manuals/mcmanual.pdf
Nevada	*Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://dmvnv.com/pdfforms/dlbookmotorcycle.pdf
New Hampshire	*New Hampshire Motorcycle Rider Training Program* ▪ Providing rider training courses ▪ Available at: https://www.nh.gov/safety/divisions/dmv/driver-licensing/motorcycle/training.htm *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://driving-tests.org/new-hampshire/new-hampshire-motorcycle-manual/
New Jersey	*Rider Training Courses* ▪ Available at: https://www.state.nj.us/mvc/license/njridesafe/training-courses.html *New Jersey Motorcycle Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.state.nj.us/mvc/pdf/license/mcm996.pdf
New Mexico	*New Mexico Motorcycle Safety Program* ▪ Providing rider training courses ▪ Available at: https://nm-msp.org/
New York	*New York State Motorcycle Safety Program* ▪ Providing rider training courses ▪ Available at: https://nysmsp.org/ *New York Motorcycle Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://driving-tests.org/new-york/new-york-motorcycle-manual/ *Advertisements on watching for motorcycles and sharing the road* ▪ Available at: https://www.youtube.com/watch?v=7G8tWq7nvVQ, https://www.youtube.com/watch?v=yJYq0GbpCEE, https://www.youtube.com/watch?v=bijlHECbXOc

Table 3.1 Summary of Motorcycle Safety Practices by State (8/12)

State	Key Practices
North Carolina	*North Carolina Motorcycle Safety Education Program* ▪ Providing rider training courses ▪ Available at: http://ncmotorcyclesafety.org/ *Motorcyclists' Handbook* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.ncdot.gov/dmv/license-id/driver-licenses/new-drivers/Documents/motorcyclist-handbook.pdf
North Dakota	*North Dakota Motorcycle Safety Program* ▪ Providing rider training courses ▪ Available at: https://www.ndmsp.com/ *Motorcycle Operators Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.dot.nd.gov/divisions/driverslicense/docs/motorcycle-operators-manual.pdf
Ohio	*Ohio Motorcycle Safety Strategic Plan* ▪ Made in the context of 2004 ▪ Including awareness campaign regarding impaired riding, protective equipment, and rider training ▪ Available at: https://motorcycle.ohio.gov/wps/wcm/connect/gov/98e4f181-8f87-4a68-bdcb-3c3613131639/mo_safety_plan.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_M1HGGIK0N0JO00QO9DDDDM3000-98e4f181-8f87-4a68-bdcb-3c3613131639-nsWyeGy *Motorcycle Ohio* ▪ Providing rider training courses ▪ Available at: https://motorcycle.ohio.gov/wps/portal/gov/motorcycle/ *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://motorcycle.ohio.gov/wps/wcm/connect/gov/cddaaa06-dd33-46d8-9c96-cd7c42c0d9a7/MO-operator-manual.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_M1HGGIK0N0JO00QO9DDDDM3000-cddaaa06-dd33-46d8-9c96-cd7c42c0d9a7-nqQGJfq
Oklahoma	*Rider Training Courses* ▪ Available at: https://ohso.ok.gov/motorcycle-safety *Road Science Campaign* ▪ Educating vehicle drivers to better interact with motorcycles ▪ Encouraging motorcyclists to be extra vigilant ▪ Providing safe riding tips with statistical information and graphics ▪ Available at: https://www.okhighwaysafety.com/motorcycle-safety/ *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://driving-tests.org/oklahoma/oklahoma-motorcycle-manual/

Table 3.1 Summary of Motorcycle Safety Practices by State (9/12)

State	Key Practices
Oregon	*2018-2024 Strategic Plan* ▪ Suggesting motorcycle rider education and training, communications program, program evaluation, and highway engineering ▪ Suggesting messaging about rider conspicuity, motorists' awareness of motorcycles, impaired riding, and personal protective equipment ▪ Available at: https://www.oregon.gov/ODOT/Safety/Documents/GAC-MS_2018-2024_Strategic_Plan.pdf *Team Oregon (Motorcycle and Scooter Training)* ▪ Providing rider training courses ▪ Available at: https://team-oregon.org/ *2020-2021 Oregon Motorcycle & Moped Manual* ▪ Providing instructions for motorcycle and moped riders ▪ Available at: https://www.oregon.gov/odot/forms/dmv/6367.pdf
Pennsylvania	*Pennsylvania Motorcycle Safety Program* ▪ Providing rider training courses ▪ Available at: https://www.dmv.pa.gov/Driver-Services/Motorcyclists/PAMSP/Pages/default.aspx *Motorcycle Safety Campaign, "Live Free Ride Alive"* ▪ On social media (Facebook) ▪ Available at: https://www.facebook.com/LiveFreeRideAlive/ *Motorcycle Safety Video Project* ▪ Receiving video submissions from the public ▪ Available at: https://www.dmv.pa.gov/Driver-Services/Motorcyclists/PAMSP/Pages/Motorcycle-Safety-Video-Project.aspx *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.dot.state.pa.us/Public/DVSPubsForms/BDL/BDL%20Manuals/Manuals/motorcycle%20Operators%20Manual/English/PUB%20147.pdf
Rhode Island	*Rider Training Courses* ▪ Available at: http://www.dot.ri.gov/Safety/motorcycle_safety.php *Informational pocket cards* ▪ To bring awareness of motorcycle safety ▪ Given to law enforcement and community groups to hand out at events and to bring to local businesses for distribution ▪ Available at: http://www.dot.ri.gov/Safety/motorcycle_safety.php *An advertisement for wearing a helmet* ▪ Available at: https://www.youtube.com/watch?v=SRUhEOQmcqU

Table 3.1 Summary of Motorcycle Safety Practices by State (10/12)

State	Key Practices
South Carolina	*South Carolina Rider Education Program* ▪ Providing rider training courses ▪ Available at: https://www.scridered.org/ *South Carolina Motorcycle & Moped Operator's Manual* ▪ Providing instructions for motorcycle and moped riders ▪ Available at: https://driving-tests.org/south-carolina/south-carolina-motorcycle-manual/ *An advertisement with safety tips for motorcyclists* ▪ Available at: https://www.youtube.com/watch?v=iZEFXMOxp3I
South Dakota	*Rider Training Courses* ▪ Available at: https://southdakotarides.com/ *South Dakota Motorcycle Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://dps.sd.gov/application/files/3115/0161/2426/Motorcycle-Operator-Manual-July.2015.pdf *An online survey of riders* ▪ Collecting information on how motorcyclists ride ▪ To use the data to shape future campaigns and education programs ▪ Available at: https://southdakotarides.com/motorcycle-safety/safety-survey/
Tennessee	*Motorcycle Rider Education Program* ▪ Providing rider training courses ▪ Available at: https://www.tn.gov/safety/driver-services/classm/mrep.html *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.tn.gov/content/dam/tn/safety/documents/MotorcycleManual.pdf
Texas	*2016-2021 Texas Strategic Action Plan for Motorcycles* ▪ Suggesting conducting outreach and education on gear use ▪ Suggesting providing training programs ▪ Suggesting encouraging dealer participation to incentivize helmet use ▪ Available at: https://www.looklearnlive.org/wp-content/uploads/2020/04/TTI-2016-11_Texas-Motorcycle-Safety-Plan-2016-through-2021.pdf *Motorcycle Operator's Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://driving-tests.org/texas/texas-motorcycle-manual/

Table 3.1 Summary of Motorcycle Safety Practices by State (11/12)

State	Key Practices
Utah	*"Ride to Live" Campaign* ▪ Providing rider training courses ▪ Providing tips for riding including lane filtering on the webpage ▪ Available at: https://ridetolive.utah.gov/ *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://dld.utah.gov/wp-content/uploads/sites/17/2019/10/Motorcycle-Handbook-2019.pdf *An advertisement on impaired riding* ▪ Available at: https://ridetolive.utah.gov/
Vermont	*Vermont Rider Education Program (VREP)* ▪ Providing rider training courses ▪ Available at: https://dmv.vermont.gov/VREP *Vermont Motorcycle Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://dmv.vermont.gov/sites/dmv/files/documents/VN-008-Motorcycle_Manual.pdf
Virginia	*Rider Training Courses* ▪ Available at: https://tzdva.org/motorcycle-safety/ *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.dmv.virginia.gov/webdoc/pdf/dmv2.pdf *An advertisement for wearing the proper gear* ▪ Available at: https://www.youtube.com/watch?v=Zf0-LDlYz68
Washington	*Rider Training Courses* ▪ Available at: https://itsafineline.com/ *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://www.dol.wa.gov/driverslicense/docs/motomanual.pdf *YOUTUBE videos to bring awareness of safe riding* ▪ Available at: https://www.youtube.com/user/itsafinelinewa/videos
West Virginia	*West Virginia Motorcycle Safety Program* ▪ Providing rider training courses ▪ Available at: https://transportation.wv.gov/DMV/Safety/MSP/Pages/default.aspx *Motorcycle Operator Manual* ▪ Providing instructions for motorcyclists ▪ Available at: https://transportation.wv.gov/DMV/DMVFormSearch/Motorcycle%20Operator%20Manual.pdf

Table 3.1 Summary of Motorcycle Safety Practices by State (12/12)

State	Key Practices
Wisconsin	*Strategic Plan 2009* ▪ Defined projects in general for motorcycle safety. ▪ Available at: https://wisconsindot.gov/Documents/dmv/motorcycles/mc-safety/mosac-plan.pdf *Wisconsin Motorcycle Safety Program (WMSP)* ▪ Providing rider training courses ▪ Available at: https://wisconsindot.gov/Pages/dmv/motorcycles/mc-safety/default.aspx *Wisconsin Motorcyclists' Handbook* ▪ Providing instructions for motorcyclists ▪ Available at: https://wisconsindot.gov/Documents/dmv/shared/bds110-mc-manual.pdf
Wyoming	*Wyoming Motorcycle Safety Program* ▪ Providing rider training courses ▪ Available at: https://www.facebook.com/Wyoming-Motorcycle-Safety-Program-1030431926999736/ *"Rules of the Road for Motorcyclists"* ▪ Providing instructions for motorcyclists ▪ Available at: http://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Driver_Services/Help%20Documents%20and%20Manuals/2017MotorcycleManual%20.pdf

APPENDIX C: Media Campaigns on Motorcycle Safety

The images below summarize media campaigns related to motorcycle safety.

Figure C.1 Advertisements on Impaired Riding (Florida)

(Available at: https://www.fdot.gov/Safety/programs/motorcycle-safety.shtm)

Figure C.2 Advertisements on Impaired Riding (Missouri)

(Available at: https://www.youtube.com/watch?v=1T201MyUcDA)

Figure C.3 Advertisements on Impaired Riding (Utah)

(Available at: https://ridetolive.utah.gov/)

Figure C.4 Advertisements on Speeding (Florida)

(Available at: https://www.youtube.com/watch?v=naJ18us_ymo)

Figure C.5 Advertisements on Safe Riding (Illinois)

(Available at: https://www.youtube.com/watch?v=8wfEVDb6fI0&t)

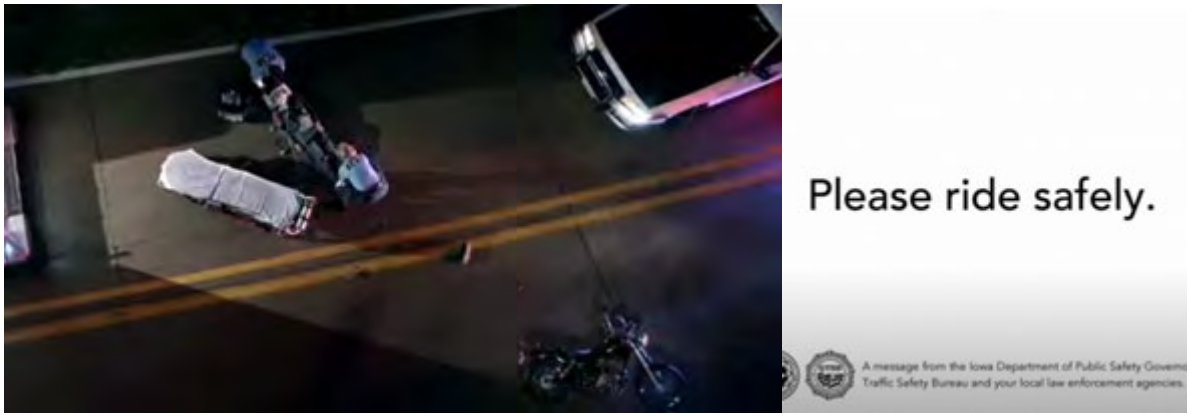

Figure C.6 Advertisements on Safe Riding (Iowa)

(Available at: https://www.youtube.com/watch?v=iYcOjeiepnE&t)

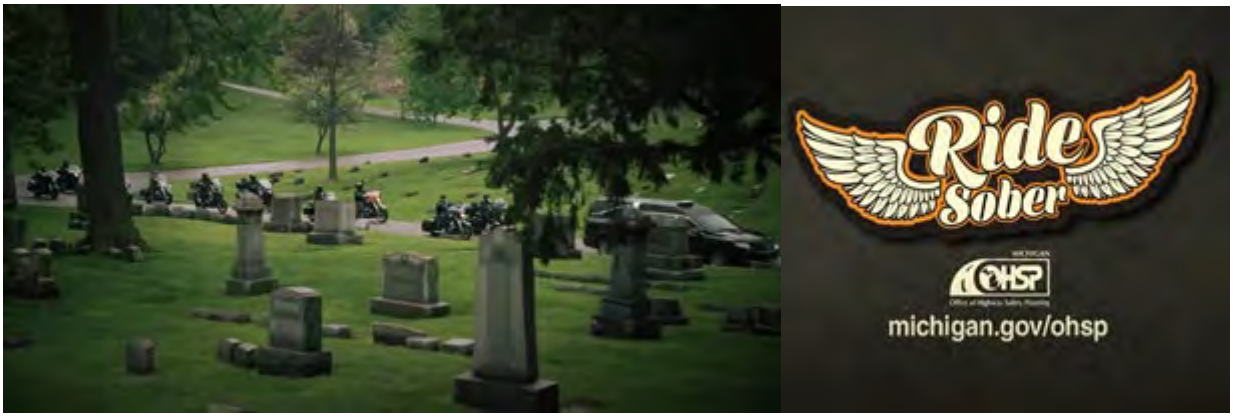

Figure C.7 Advertisements on Safe Riding (Michigan)

(Available at: https://www.youtube.com/watch?v=bVGOJIz1Ulw)

Figure C.8 Instructional or Safety Tip Focused Advertisements (New York)

(Available at: https://www.youtube.com/watch?v=7G8tWq7nvVQ)

Figure C.9 Instructional or Safety Tip Focused Advertisements (Virginia)

(Available at: https://www.youtube.com/watch?v=Zf0-LDlYz68)

Figure C.10 Informative Statistics-Oriented Advertisements (South Carolina)

(Available at: https://www.youtube.com/watch?v=iZEFXMOxp3I)

APPENDIX D: Exploring the Effects of Rider Age and Riding Experience on Motorcycle Crash Risk- Evidence from A Case-Control Study

AUTHORS

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CHAPTER SUMMARY

Compared to automobiles, the relationships between age, inexperience, and injury risk for motorcyclists – who are at a substantially heightened risk of receiving injuries – are less examined. Using comprehensive matched case-control data on rider demographics, kinematics, and clinical end points obtained through scientific reconstruction of motorcycle crashes, interviews, and hospital records, this study analyzes the dependencies of injury crash risk on age and inexperience after controlling for demographics. Data on 350 cases (crash-involved riders) vis-à-vis 700 controls (similarly-at-risk non-crash involved riders) from the unique U.S. Motorcycle Crash Causation Study collected by the FHWA are used. Based on a conditional logit analysis accounting for the matched case-control structure of the data, "risk curves" are created to gain a fuller understanding of the relationships between rider age and injury risk. Results suggest that young riders are at a heightened crash risk, which reduces non-linearly with increasing age. Our findings reveal that experience (captured through age and years of riding) and participation in training programs during recent years are both protective factors against injury risk and associated with lower crash risks. Practical implications of the study suggest a greater emphasis on significance of age and riding experience in licensing specifically for riders who are younger and inexperienced. Interestingly, participation in refresher or remedial training courses can help riders (especially those who are frequent traffic offenders) to enhance their skills and safety perceptions.

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INTRODUCTION

Motorcycle injuries and fatalities are found to be the key public health issues causing significant economic loss in the U.S. as well as worldwide. During 2002-2015, motorcycle-involved fatalities increased 48% while those related to passenger vehicles (cars and light trucks) decreased by 32% (NHTSA 2016). Motorcycles are used as cheaper, fuel-efficient, and easier forms of transport. In terms of parking and maneuvering, motorcycles are found to be more appealing and flexible compared to regular motor vehicles in densely populated areas (Lin and Kraus 2009). Motorcycles, being a two-wheelers mode of transportation, differ from motor vehicles in terms of physical operations, weight, size, and exposure of operator (driver/rider). Due to factors like smaller size, more powerful engine, and lack of adequate rider protection, motorcycles are found to be highly unstable and vulnerable to crashes (Daniello *et al.* 2010). Compared to driving vehicles, riding a motorcycle is physically challenging where visibility and stability of riders is affected due to their direct exposure to climatic conditions (Horswill and Helman 2002). In addition, the availability of powerful motorcycles and their increasing use for recreational trips have increased the risk of motorcycle injuries and fatalities (Deasy *et al.* 2012). Besides loss of valuable lives and associated health care costs, motorcycle crashes put an extra burden on the society in form of costs associated with emergency response and insurance (Derrick and Faucher 2009). Previous studies explored factors affecting injury severity of motorcycle crashes – shedding light on important correlated factors like rider behaviors, roadway-environmental, and motorcycle characteristics (McKnight and Robinson 1990, Wong *et al.* 1990, Shankar and Mannering 1996, Savolainen and Mannering 2007, Shaheed *et al.* 2013, Wali *et al.* 2019). While the previous studies provide useful insights about factors affecting injury severity (given a motorcycle crash), analysis of injury crash risk using more objective data remains relatively rare. In particular, obtaining a fuller understanding of injury crash risk is complicated by the need for appropriate data that allow quantification

of “relative risks”. That is, comprehensive and objective data are required not only for crash-involved riders but also for non-crash involved riders. Some studies investigated the effects of key factors affecting motorcycle crash risk (Haworth *et al.* 2000, Mullin *et al.* 2000, Wells *et al.* 2004, Lin and Kraus 2009, Yeh and Chang 2009, Bjørnskau *et al.* 2012, Haque *et al.* 2013, Sakashita *et al.* 2014, Wali *et al.* 2018, Möller *et al.* 2020). The U.S. Motorcycle Crash Causation Study is a first-of-its-kind comprehensive data source allowing objective examination of key correlates of motorcycle injury risk in United States.

Rider characteristics like gender, age, and experience may significantly influence rider’s behavior and attitudes. Crash risk is found to be higher for riders who are young and inexperienced due to their risky behaviors (Yeh and Chang 2009). For instance, experienced riders are found to have lower crash risk compared to less experienced riders (Haworth *et al.* 2000, Mullin *et al.* 2000, Möller *et al.* 2020). Studies suggest that young and inexperienced riders have higher crash risk due to their risky behaviors (Yeh and Chang 2009, Wali *et al.* 2018). Note that these studies assume a constant change in crash risk with a unit change in specific explanatory variables like rider age (years). The effect of rider age on crash risk however maybe non-linear. Hence, there is a need to account for the non-linearity in the effects of rider age on crash risk – which has received relatively little focus specifically in case-control motorcycle studies. Impairment and substance use are also associated with an increased crash risk (Soderstrom *et al.* 1990, Wali *et al.* 2018). Referring to formal riding training, studies suggest that crash risk reduces for riders who have participated in training courses (Wali *et al.* 2018). Most of the aforementioned studies are related to other parts of the world which might have their own riding behaviors, socio-economic, motorcycle training programs and opportunities, and post-crash evaluation protocols. This study adds to the motorcycle safety literature in the context of the U.S. providing useful insights about the effects of key factors like rider age, experience, motorcycle training programs, and alcohol use on rider injury risk.

While case-control design is one of the most appropriate approaches to exploring motorcycle crash risk associated with key factors, very few studies use data on cases and controls as it requires resources and time (Haque *et al.* 2013, Wali *et al.* 2018, Möller *et al.* 2020). In case-control framework, crash risk is computed while comparing cases (crash-involved riders) with controls (not-crash involved riders) matched on temporal and spatial factors (Haworth *et al.* 2000, Mullin *et al.* 2000, Connor *et al.* 2001, Cummings *et al.* 2001, Yeh and Chang 2009, Haque *et al.* 2013, Wali *et al.* 2018, Möller *et al.* 2020). While some of the studies used analyzed data on cases and controls to quantify crash risk, their data in most cases are based on limited sample size or traditional questionnaires which may not service the purpose. On the other hand, Motorcycle Crash Causation Study (MCCS) data are more reliable and include extensive information allowing a more detailed analysis of the associations of experience and age with crash risks. Note that MCCS data are more objective in the sense that they were collected through scientific reconstruction of the crash scenes by trained investigators. Compared to coarse injury measures in police-reports, MCCS data are more reliable since it includes clinical end points based on hospital records.

This study contributes by exploring safety risk (crash risk) associated with younger and inexperienced riders while using MCCS data which include extensive hospital-based information on crashes and detailed interview conducted for controls by well-trained teams of experts in Orange County, California. Recent studies have used the comprehensive MCCS database to gain a fuller understanding of the correlates of crash risk and anatomical injury measures (Wali *et al.* 2018, Wali *et al.* 2019). However, the studies did not focus on gaining a deeper understanding of the role of age and inexperience on injury risk. Through a conditional logit analysis capturing the matching structure in the data, we model the non-linearity in the effects of rider age on motorcycle crash risk. The associations of alcohol use and motorcycle training programs with crash risk are also quantified.

METHODOLOGY

Data source and Study Design

This study uses MCCS data which is a comprehensive data source funded by the United States Department of Transportation (FHWA 2017). The MCCS data include detailed information about 351 motorcycle injury crashes collected through on-scene investigations in Orange County, California and interviews of 702 control riders (FHWA 2017, Wali *et al.* 2018). For each case (injury crash), data on two controls are obtained which are matched with cases based on day of the week, time of the day, roadway type, location

(rural/urban), travel direction, and weather conditions (Wali *et al.* 2018). Using triplet (including one case with two controls) as a unit of analysis in a matched case-control framework, the associations of policy sensitive factors (with emphasis on rider age and experience, sleeping hours) with injury crash risk are quantified (Figure D.1). For detailed information about MCCS data, please see (Wali *et al.* 2018).
The MCCS data include detailed information about crash sites and riders for certain time spans like during crash, before crash, and after crash (FHWA 2017, Wali *et al.* 2018). It also includes comprehensive data on roadway conditions, traffic controls, and environmental details which might have contributed to the occurrence of a crash (FHWA 2017, Wali *et al.* 2018). Crash data based on police reports exhibit subjectivity and bias – especially as it relates to injury information (Wali *et al.* 2018, Ahmad *et al.* 2019). MCCS provides a unique and objective source of in-depth injury information collected through rigorous post-crash evaluation protocols – linking information from hospital discharge reports, emergency room records, and medical reports from private clinics (Wali *et al.* 2018). For details, see (Wali *et al.* 2018). Motorcycle crash risk is defined as the probability of rider to get involved in a crash. Risk factors indicate factors which contribute to occurrence of motorcycle crash or increase probability of motorcycle crash. While crash frequency data may provide useful insights into how key factors relate to motorcycle crash frequency (Chin and Quddus 2003, Schneider *et al.* 2012); such studies may not unveil the exposure of population to motorcycle crashes (Wali *et al.* 2018). This study applies matched case-control design to quantify the effects of variables of interest (i.e., rider age, rider experience, hours of sleep before riding, and speed) on motorcycle crash risk. In the MCCS data, each case (crash) is matched with two controls. After linking the two controls to their respective case, we model the binary response outcome via a conditional logit model where the unit of analysis is a triplet (including 1 case and 2 controls).

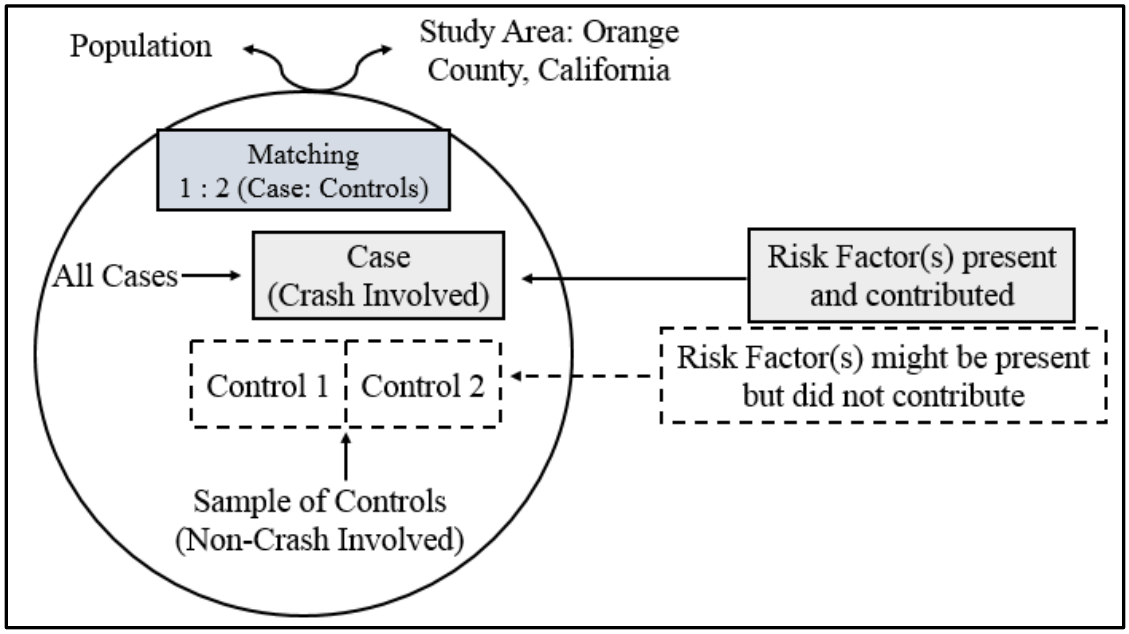

Figure D.1 Matched Case-Control Framework

Note: The arrow indicates that it is a subsample for controls selected from a population in the study area and may not be considered as whole population of the motorcyclists in the study area.

Conditional Logistic Regression: Case-Control Framework

Statistical models are developed to explore the crucial links between motorcycle crash risk and its key correlates focusing on experience and age. To account for the matched case-control structure in the data, conditional logistic regression has been widely used (Rothman *et al.* 2017, Wali et al. 2018). Note that conditional logistic regression accounts for variation and dependence within the triplet (including one case and two controls) which cannot be achieved via unconditional logistic regression (Wali *et al.* 2018). The general equation for conditional logit model can be given as (Tay 2016, Boakye *et al.* 2018, Wali *et al.* 2018):

$$Y_i^* = \beta X_i + \mu_i \quad (1)$$

Where: Y_i^* indicates latent unobserved crash propensity of any rider i, β indicates vector of parameters to be estimated for a set of explanatory variables (X_i); and μ_i indicates random disturbance. Note that the latent unobserved crash propensity (Y_i^*) can be related to the observed crash propensity (Y_i) (Tay 2016, Boakye *et al.* 2018, Wali *et al.* 2018):

$$Y_i = \begin{cases} 1 & if\ Y_i^* > 0 \\ 0 & otherwise \end{cases} \quad (2)$$

Here, $Y_i = 1$ indicates a case (when a rider is involved in injury motorcycle crash) while $Y_i = 0$ indicates the control observation (non-crash involved rider). The following equations can be used to determine the likelihood of rider (i) to get involved in crash (Wali *et al.* 2018):

$$\begin{aligned} P_i &= prob\ [\beta X_i + \mu_i > 0] \\ P_i &= prob\ [\mu_i > (\beta X_i)] \\ P_i &= 1 - F(-\beta X_i) \end{aligned} \quad (3)$$

Note that F indicates cumulative density function. The coefficients obtained from the logit models provide useful information about the direction of the association with the response variable; however, it does not facilitate easier interpretation. To have a more intuitive understanding of the association between the response variable and specific explanatory variable(s), odds ratio is generally computed:

$$Odds\ Ratio = \frac{\left(\frac{p(Y=1|X+1)}{p(Y=0|X+1)}\right)}{\left(\frac{p(Y=1|X)}{p(Y=0|X)}\right)} \quad (4)$$

Note that an odds ratio of greater than one indicates that the chances of $Y = 1$ (rider involved in an injury crash) increases with an increase in X (i.e., explanatory variable) and vice versa. The percent change in odds of response outcome with a unit change in the explanatory variable can be determined as:

$$\%\ Change\ in\ Odds\ (Crash\ Risk) = 100\ (Odds\ Ratio - 1) \quad (5)$$

While odds ratios provide direct and meaningful insights of the case-control logit model in terms of probabilities. The predictive margins command in STATA can be used to compute the predicted probabilities of the response outcome at any specific value of explanatory variable or over a range of values of the specific explanatory variable.

RESULTS

Descriptive Statistics

Statistics reveal that mean experience (in years) of riders in not-crash involved group is 20.52 years which is significantly higher than crash-involved riders (13.04 years) (Table D.1). Referring to rider age (years), mean age of rider within crash- and control groups are found to be 36.55 and 45.01 years respectively which indicates the relative safety risk for younger riders (Table D.1). For more details about distribution of riders based on riding experience and age (both in case and control groups), please refer to Figure D.2 and Figure D.3 respectively. It can be noticed that the proportions of older and experienced riders are higher in the non-crash involved group (control groups) (Figure D.2-D.3). Statistics also reveal that 40% of the crash involved riders had negative BAC which is significantly higher than that in non-crash involved group (16.5%) (Table D.1). Note that based on independent group t-test, we noticed significance difference in means of all variables (except indicator for Asian riders) while comparing case (crash involved riders) and controls (not-crash involved riders) groups (Table D.1). It should be noted that all of the 350 crashes reported in MCCS data comes out to be injury crashes (among which < 0.5% were fatal crashes) including no property damage only (PDO). The reason for having no PDO crashes may either that motorcycle crashes mostly include some sort of injuries (ranging from minor to fatal injury) due to their higher vulnerability or might have not been reported to police or hospital (due to no injury) from where crashes details were extracted.

Also, motorcycle crashes typically include some sort of injuries thus including relatively lower percentage of PDO crashes (Turner *et al.* 2013).

Table D.1 Descriptive Statistics of Key Variables

Variable	Crash Involved Riders (N = 350)			Not Crash Involved Riders (N = 700)			Independent group t-test (H_a: μ_2- μ_1>0)
	Mean	S.D	Min/Max	Mean	S.D	Min/Max	
Motorcycle riding experience (years)	13.039	14.155	0/47	20.516	17.048	0/69	Pass
Rider age (years)	36.546	14.260	16/73	45.066	14.558	17/84	Pass
Speed (miles per hour) Prior to Crash or Interview	36.971	15.062	0/90	46.353	10.911	0/85	Pass
Negative blood alcohol concentration (BAC)* (1 if yes, 0 otherwise)	0.165	0.372	0/1	0.398	0.489	0/1	Pass
Year of Training							
Training between 2001–2010*	0.091	0.289	0/1	0.290	0.454	0/1	Pass
Training between 2011–2015*	0.069	0.253	0/1	0.196	0.397	0/1	Pass
Race of rider							
Hispanic*	0.1057	0.3079	0/1	0.0386	0.1927	0/1	Pass
White American*	0.7343	0.4423	0/1	0.8671	0.3396	0/1	Pass
African American*	0.0429	0.2028	0/1	0.0171	0.1298	0/1	Pass
Asian*	0.0429	0.2028	0/1	0.0586	0.2349	0/1	Fail
Others/not reported*	0.0743	0.2626	0/1	0.0186	0.1351	0/1	Pass

Note: * indicates binary variables for which their "mean" values if multiplied with 100% will show the corresponding percentages. Where N indicates sample size; μ1 and μ2 indicate mean of crash and control group respectively; S.D indicates the standard deviation, Ho indicate null hypothesis (μ2- μ1= 0) and Ha indicates alternative hypothesis (μ2- μ1>0). Note that "Pass" shows that Ha can be accepted at 95% confidence level instead of H0 and vice versa.

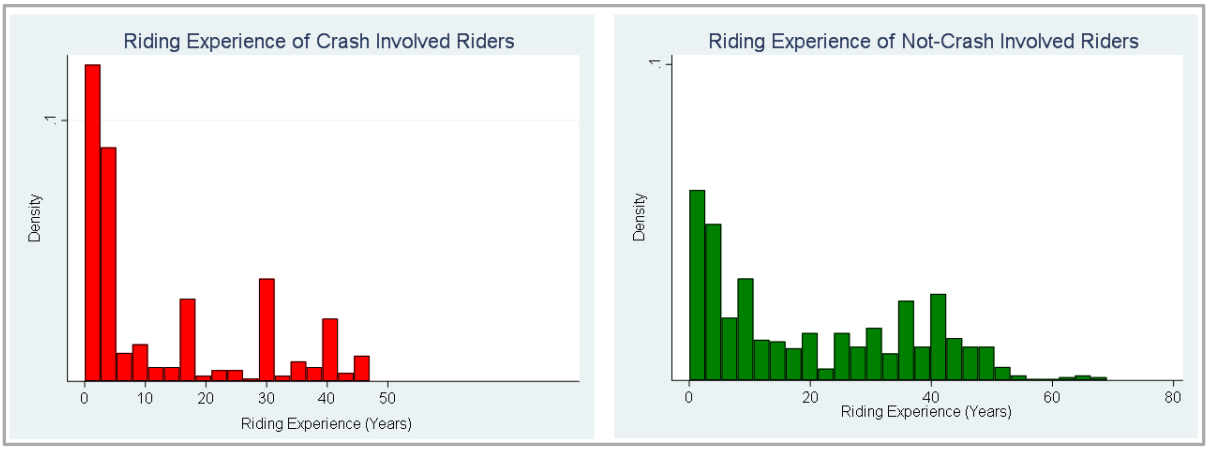

Figure D.2 Distribution of Riders on basis of Riding Experience (Years)

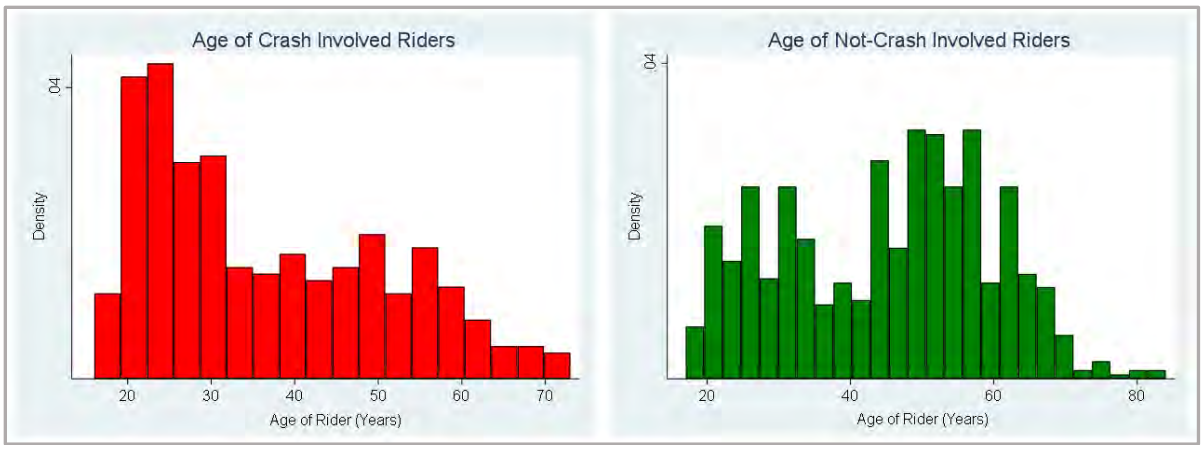

Figure D.3 Distribution of Riders on basis of Rider Age (Years)

Correlational Analysis

Based on Pearson Correlation, we found that rider age, experience, and speed have significant correlations with motorcycle injury crashes per 95% confidence level (Table D.2). Note that only rider age (years) and riding experience (years) show positive significant correlation with each other as per 95% confidence level (Table D.2). We checked the variance inflation factor (VIF) for all variables included after fitting our final model (as shown in Table D.3). VIF for all other variables were found to be less than 3 which warrants no collinearity issues among the three key explanatory variables included in the model (Table D.2). Note that VIF lower than 10 is acceptable and lower than 5 if good (Kim 2019).

Table D.2 Correlation Matrix of Crash and Important Explanatory Variables

	Crash	Speed Prior to Crash or Interview	Rider age (years)	Motorcycle riding experience (years)
Crash	1			
Speed Prior to Crash or Interview	-0.3351*	1		
Rider age (years)	-0.2679*	-0.0410	1	
Motorcycle riding experience (years)	-0.2135*	-0.0199	0.7874*	1.0000

Note: It should be noticed that * indicates that correlation between corresponding variables was found to be significant as per 95% confidence level.

Estimation Results

To gain deeper insights, we conducted conditional logit analysis while accounting for case-control setup. The models are systematically derived while considering statistical significance, specification parsimony, and theoretical justification. The key correlates of motorcycle crash propensity include rider age, rider experience, speed (prior to crash event or interview), participation in motorcycle training programs, and indicator of blood alcohol concentration (Table D.3). A 90% confidence level criterion is used to retain variables in the final model specification. We also included interaction terms for gender (1 if female, 0 otherwise) and rider age to explore the presence of statistically significant interactions between age and gender (Table D.3). To capture the potential non-linearities associated with age, polynomial terms are added to the conditional logit link function. Polynomial terms up till order 5 were considered for the age variable with order-2 polynomial giving the best-fit based on AIC and BIC criteria. The results of the linear-in-parameters logit model (Model 1) and non-linear model (based on order-2 polynomial term for age) (Model 2) are shown in Table D.3. Note that rider age along with its square term both show statistically significant correlation with crash risk (Table D.3). Also, based on AIC, BIC, and log-likelihood value, Model 2 showed superior fit to the data compared to Model 1 (Table D.3). Note that a model based on fine-grained age categorizations was also developed but showed no significant improvement compared to Model 2 in

terms of AIC and BIC (results not shown for brevity). Based on the results of Model 2, both rider age (years) and riding experience (years) show statistically significant and negative correlations with crash risk indicating that younger and inexperienced riders have higher odds of getting involved in an injury crash (Table D.3). Results of the best-fit model (Model 2) also suggest that compared to no training or if training received before 2001, injury crash risk reduces for those riders who received riding training during 2001-2010 or 2011-2015, i.e., in recent years (Table D.3). Importantly, our findings show that sober riders (tested negative for BAC) have statistically significantly lower injury crash risk (Table D.3). Other important results related to demographic factors can be found in Table D.3.

Table D.3 Estimation Results of Conditional Logit Model

Variable	**Model 1**		**Model 2**			
	Coef.	**t-stat**	**Coef.**	**t-stat**	**Odds**	**% Change in Odds**
Motorcycle riding experience (years)	-0.0208	-1.76	-0.0258	-2.12	0.97	-2.54
Rider gender indicator (1 if female, 0 otherwise)	-1.0710	-0.75	-1.8269	-1.24	0.16	-83.91
Rider age (years)	-0.0448	-3.44	-0.2252	-4.76	0.80	-20.16
Squared term for rider age (rider age*rider age)	**---**	---	0.0021	4.06	1.00	0.21
*Interaction of rider age*rider gender (1 if female)*	0.0073	0.21	0.0272	0.77	1.03	2.76
Speed (miles per hour) prior to crash/interview	-0.0717	-7.71	-0.0737	-7.80	0.93	-7.11
Negative blood alcohol concentration (BAC)* (1/0)	-1.1149	-4.69	-1.1509	-4.71	0.32	-68.37
Year of Training (base = no training or training received before 2001)						
Training between 2001–2010*	-1.6279	-5.91	-1.7780	-6.13	0.17	-83.10
Training between 2011–2015*	-2.0241	-6.23	-2.2967	-6.64	0.10	-89.94
Race of rider (Base = While American)						-100.00
Others/not reported	0.9682	1.96	0.9761	1.93	2.65	165.42
Hispanic	0.9684	2.50	1.0023	2.48	2.72	172.44
African American	1.6401	2.92	1.8348	3.13	6.26	526.39
Asian	-0.5440	-1.26	-0.5593	-1.26	0.57	-42.84
Model Summary						
Number of Observations	1,050		1,050			
Number of triplets	350		350			
Degrees of Freedom	12		13			
Log-likelihood at convergence (L_c)	-198.6507		-190.5247			
AIC	421.3014		407.0494			
BIC	480.7799		471.4845			

DISCUSSION

Referring to the results, several useful insights can be obtained based on the best-fit model (Model 2). Note that results discussed in the subsequent paragraphs refer to the best-fit model (Model 2). Our findings indicate that the odds of rider getting involved in crash reduces by 20.16% with a unit increase in rider age (year) (Table D.3). This finding suggests relative higher crash risk associated with younger rider which is intuitive and can be attributed to their potentially risky riding behaviors. Similar findings are suggested by previous studies (Cooper 1990, Mullin *et al.* 2000, Lin *et al.* 2003, Wali *et al.* 2018). The odds-ratio do not capture the intrinsic non-linearity associated with the S-shaped curve fitted by the conditional logit model. Due to the fitted S-shaped curve underpinned in logit models, the association of explanatory variable (e.g., age) with injury risk varies across the range of age. To explore the varying level of associations, Figure D.4 visualizes the predicted probabilities of crash computed at different values of rider age (while keeping all other covariate at their mean values) for Model 1 (linear-in-parameters and linear-in-variables) and Model 2 (linear-in-parameters but non-linear-in-variables) to assess the true effects of age on crash risk (Figure D.4). Referring to the plot for Model 1 in Figure D.4, the potential decrease in injury risk as a function of age follows a non-linear decreasing trend (Figure D.4). As is evident, this intuitive non-linear negative association for age is an outgrowth of the intrinsic non-linearity due to the S-shaped curve in logit model and does not necessarily reflect non-linearity attributed to the variable age itself. The second plot in Figure D.4 visualizes the non-linearity attributable to the variable rider age itself obtained from a non-linear-in-variables model (Model 2 including polynomial terms for age). Referring to the predictive margin plot for Model 2 in Figure D.4, the relationship between age and injury risk follows a U-shaped pattern – providing useful insights. For instance, compared to riders with ages between 40-60 years, the probability of crash is higher for riders with ages lower than 40 years and higher than 60 years (Figure D.4). Note that younger riders (shown on extreme left side in Model 2 plot) have relatively higher crash risk compared to older riders (illustrated on extreme right side in Model 2 plot) (Figure D.4). Based on our findings, it can be seen that both younger and older riders are at a higher crash risk, whereas crash risk for younger riders is even higher (Figure D.4). Conceptually, the statistically significant quadratic term for rider age included in Model 2 suggests that ignoring non-linearity in the effects of rider age could hide important patterns embedded in the data.

One of the other key hypotheses of this study is that riders who received training during recent years might have lower crash risks compared to riders who either did not receive formal motorcycle training or received it prior to 2001. Referring to participation in motorcycle training course, our findings suggest that the odds of a rider involving in an injury crash reduces by 83% and 90% if the rider got training during 2001-2010 and 2010-2015 respectively (compared to those who either did not get participated in riding training or got training prior to 2001) (Table D.3). This indicates the significance of motorcycle training courses in reducing crash risk. These findings were expected as participation in formal training programs can help riders enhance their safety perception and riding skills. Results of the best-fit model also suggest that inexperienced riders are at a higher crash risk (Table D.3). For instance, our findings reveal that with unit increase in riding experience, the odds of rider getting involved in an injury crash reduces by 2.54% (Table D.3). This is expected as experienced riders may respond in a more skillful manner avoiding any safety critical situations compared to inexperienced riders. Similar findings are reported in previous studies (Cooper 1990, Mullin *et al.* 2000, Lin *et al.* 2003, Wali *et al.* 2018). Finally, our findings also indicate that with a unit increase in speed (miles per hour), the odds of rider getting involved in an injury crash reduces by 7.11% (Table D.3). This finding is intuitive as riders may attain higher speed on higher classification roadways (freeways and arterials) with higher speed limits thus reducing crash risk; however, speed may increase their injury severity given a crash (Quddus *et al.* 2002, Wali *et al.* 2018, Ahmad *et al.* 2019). Referring to the effects of impairment, the odds of riders decrease by 68.37% if a rider is tested negative for BAC (Table D.3). This indicates that impairment or drink-riding increase the odds of riders getting involved in a crash. This finding is intuitive and aligned with previous studies (Creaser *et al.* 2007). Compared to white American riders, African American and Hispanic riders have higher odds of getting involved in a crash (Table D.3).

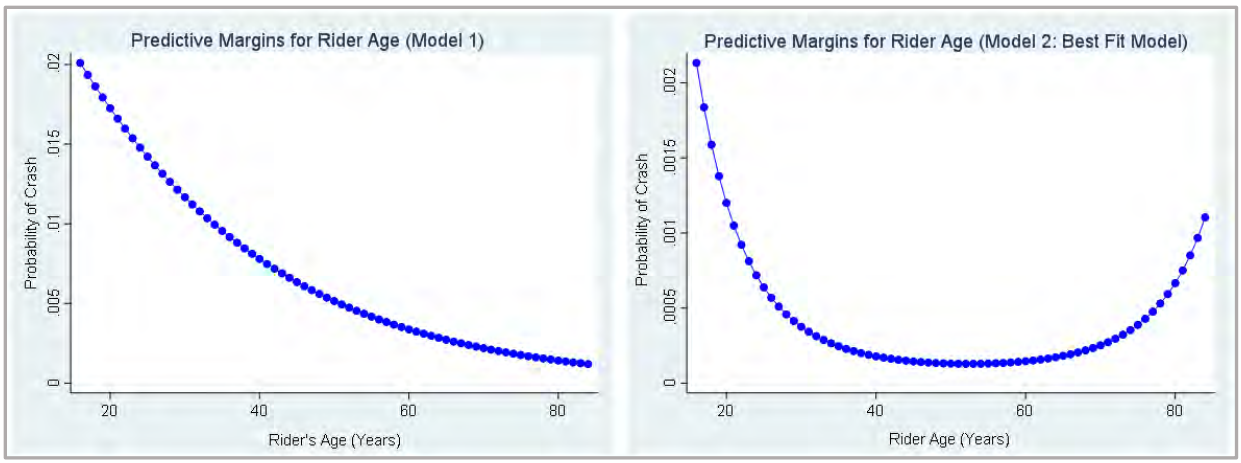

Figure D.4 Predicted Probabilities of Crash versus Rider Age (Model 1 and Model 2)

LIMITATIONS

This study uses data from MCCS which were carefully collected not only including extensive details (rider related factors, roadway environment, and motorcycle related factors) but also include information about controls which were collected via detailed interview. While this study provides useful insights, it should be noted that MCCS data were collected in Orange County, California with its unique socio-demographic and riding behavioral characteristics. Therefore, our findings are based on data of Orange County, California and may not be generalized to other parts of California or U.S. Also, note that all crashes included in MCCS data are injury crashes while including only 1-2 fatal crashes (<0.1% of total crashes). Also, the MCCS data include limited sample size for crashes; hence, with increasing sample size it may happen that some of the PDO crashes would also be reported. Data on important factors like rider age, rider experience, speed (before crash event or interview), and hours of sleep (before riding) were missing. For instance, MCCS data do not include speed (before crash event or interview), experience, sleep hours (before riding), and rider age for 11.52% (N = 121), 15.62% (N = 164), 17.14% (N = 180), 0.57% (N = 6) of the riders respectively. To utilize these significant percentage of observations, we imputed median values of these variables based on various age groups. First, all the riders were categorized into various age groups including (15 – 25 years], (25 – 35 years], (35 – 45 years], (45 – 55 years], (55 – 65 years], (65 – 75 years], and greater than 75 years. The median values for each of the aforementioned variable(s) within each age group were determined based on non-missing values which were then used to replace the missing values for each variable within each age group. The final data, after cleaning and imputation, considered in this analysis include 1,050 observations (riders) which include 350 cases (crash-involved riders) and 700 controls (non-crash involved riders). In future, it would be better to collect complete data for all riders (both cases and controls) which can help in appropriate exploration of the effects of these factors on crash risk.

CONCLUSIONS

The key focus of this study was to explore safety risk associated with younger and inexperienced riders. Moreover, the study also explored how participation in motorcycle training programs and alcohol use could affect a rider's propensity of involvement in an injury crash. We analyze extensive data collected via Motorcycle Crash Causation Study by the U.S. Department of Transportation (DOT) and Federal Highway Administration (FHWA). Note that MCCS data used in this study include 1,050 observations including 350 cases (crash-involved riders) and 700 controls (not-crash involved riders). For each case (injury crash), data on two controls are obtained which are matched with cases based on day of the week, time of the day, roadway type, location (rural/urban), travel direction, and weather conditions. MCCS data provide a better opportunity to quantify crash risk which is not possible using data based on police crash reports which are more subjective and vulnerable to biases. To achieve study objectives, a conditional logit model is developed to fully account for the matched case-control data structure. To capture the non-linear association of rider age with crash risk, polynomial terms are used for rider age while controlling for other covariates. The non-linear model based on polynomial terms showed a significant improvement compared

to the linear-in-variables counterpart based on AIC and BIC statistics. Accounting for non-linearity in the effects of age on crash risk not only improved model performance but also led to several useful insights.

Our findings indicate that compared to riders with ages between 40-60 years, younger and older riders are at higher crash risk (whereas younger riders have even greater crash risks compared to older riders). Our findings also reveal that inexperienced riders have higher odds of getting involved in a crash. Referring to the effectiveness of motorcycle training programs in reducing crash risk, we found that crash risk reduces if rider did formal motorcycle training in recent years (2001-2010 and 2010-2015) compared to those who got motorcycle training prior to 2001. Importantly, we found that riders who were tested negative for BAC have lower odds of getting involved in a crash which indicate that sober riding (without impairment and alcohol use) can help reduce crash risk.

From practical implications standpoint, more emphasis is needed on the significance of rider age and riding experience in licensing regulations specifically for riders who are younger, inexperienced, and older riders (60+ years). Participation in training courses can help riders to enhance their skills and safety perceptions. Furthermore, conducting awareness campaigns to advocate safety risk associated with alcohol use and risky riding (especially for younger riders) may help in reducing motorcycle crashes. As part of future work, the dependencies between rider age, riding experience, speed and injury severity given a crash can be explored.

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