Select Risk Factors Associated with Causes of Motorcycle Crashes

Safety Report

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Select Risk Factors Associated with Causes of Motorcycle Crashes

National Transportation Safety Board

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Washington, D.C. 20594

National Transportation Safety Board. 2018. ***Select Risk Factors Associated with Causes of Motorcycle Crashes*****. Safety Report NTSB/SR-18/01. Washington, DC.**

Abstract: In this safety report, the National Transportation Safety Board (NTSB) assesses select risk factors associated with the causes of motorcycle crashes in the United States. The Federal Highway Administration provided the data analyzed in this report from its 2016 *Motorcycle Crash Causation Study* (*MCCS*). The *MCCS* represents the most recent data available for studying motorcycle crashes and risk factors in the United States since the US Department of Transportation published its comprehensive *Motorcycle Accident Cause Factors and Identification of Countermeasures*, commonly known as the Hurt Report, in 1981.

The NTSB identified four motorcycle safety issue areas in this report: (1) crash warning and prevention, (2) braking and stability, (3) alcohol and other drug use, and (4) licensing procedures. This report analyzes issues associated with motorcycle crash causation and prevention; therefore, many well-established injury prevention issues, such as helmet use, are not included.

As a result of this safety report, the NTSB makes recommendations to the National Highway Traffic Safety Administration, the Federal Highway Administration, the Motorcycle Industry Council, the American Motorcyclist Association, and the Motorcycle Safety Foundation.

For more detailed background information on this report, visit the NTSB investigations website and search for NTSB accident ID DCA18SS001. Recent publications are available in their entirety on the Internet at the NTSB website. Other information about available publications also may be obtained from the website or by contacting:

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Contents

Figures

Tables

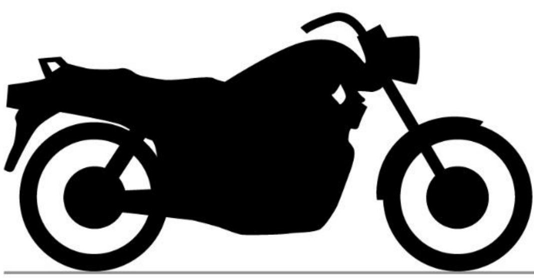
Acronyms and Abbreviations

AAMVA	American Association of Motor Vehicle Administrators
ABS	antilock braking system
BAC	blood alcohol concentration
cc	cubic centimeters
ESC	electronic stability control
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
FMVSS	Federal Motor Vehicle Safety Standard
g/dL	grams per deciliter
GDL	graduated driver licensing
GHSA	Governors Highway Safety Association
HLDI	Highway Loss Data Institute
IIHS	Insurance Institute for Highway Safety
MAIDS	*Motorcycle Accident In-Depth Study*
MCCS	*Motorcycle Crash Causation Study*
NAMS	National Agenda for Motorcycle Safety
NHTSA	National Highway Traffic Safety Administration
NPRM	notice of proposed rulemaking
NTSB	National Transportation Safety Board
OECD	Organisation for Economic Co-operation and Development
SWITRS	Statewide Integrated Traffic Records System
THC	tetrahydrocannabinol
TTI	Texas A&M Transportation Institute
VMT	vehicle miles traveled

Motorcycle Types

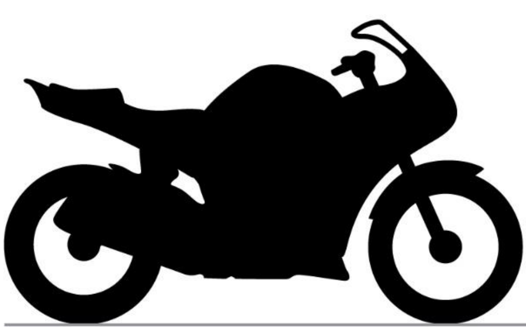
In this report, a motorcycle is defined as a powered, two-wheeled vehicle with an engine displacement that exceeds 50 cubic centimeters or a maximum design speed above 31 mph. Exemplars and definitions of the most common motorcycle types discussed in this report are provided.

Chopper:
A motorcycle that has been modified with an extended front fork assembly, extended upright handlebars, and a low seat to accommodate a more reclined riding position.



Conventional:
A general purpose on-road motorcycle with upright handlebars. These motorcycles usually have an upright riding position, and they are often referred to as standards or naked bikes.

Cruiser:
A large motorcycle with slightly pulled back handlebars, large fenders, and low seat height. These motorcycles usually have upright to slightly reclined riding positions with the rider's feet situated more forward.



Sport, race replica:
A motorcycle with drop handlebars, a small windscreen, and an aerodynamic fairing. These motorcycles usually have a forward crouch riding position and many are built on racing frames.

Executive Summary

Motorcyclists—motorcycle riders and their passengers—have the highest risk of fatal injury among all motor vehicle users. In 2016, 5,286 motorcyclists died in traffic crashes in the United States (NCSA 2018). Per mile traveled, motorcyclist fatalities occurred nearly 28 times more frequently than passenger vehicle occupant fatalities in traffic crashes (NCSA 2018). Like accidents across all modes of transportation, motorcycle crashes are complex events that can be influenced by multiple human, vehicle, and environmental factors. However, because motorcycles afford riders less protection, the likelihood of injuries and fatalities in a crash is much greater. In this safety report, the National Transportation Safety Board (NTSB) assesses select risk factors associated with the causes of motorcycle crashes in the United States and makes recommendations for improving motorcycle crash prevention.

The Federal Highway Administration (FHWA) provided the data analyzed in this report from its 2016 *Motorcycle Crash Causation Study* (*MCCS*). The *MCCS* represents the most recent data available for studying motorcycle crashes and risk factors in the United States since the US Department of Transportation published its comprehensive *Motorcycle Accident Cause Factors and Identification of Countermeasures* report in 1981. The NTSB analyzed the *MCCS* crashes involving a motorcycle with an engine displacement that exceeded 50 cubic centimeters or a maximum design speed above 31 mph, and at least one reported injury sustained by the motorcycle rider or passenger. All crashes occurred in Orange County, California, between 2011 and 2015. The NTSB's research goals were to (1) identify and assess factors that contribute to motorcycle crash risk, (2) compare these factors with previous research findings about motorcycle crash risk, and (3) evaluate the need for motorcycle safety improvements.

This safety report analyzed select risk factors associated with the causes of motorcycle crashes and evaluated strategies for crash prevention. The *MCCS* data were appropriate for identifying factors associated with an increase or decrease in motorcycle crash risk that warranted further evaluation. These factors were then examined as potential safety issue areas and compared to existing motorcycle safety research and publications to determine the need for safety improvements.

Previous NTSB safety recommendations to encourage universal motorcycle helmet use and to establish a per se blood alcohol concentration (BAC) limit of 0.05 grams per deciliter or lower for all drivers were not reiterated in this report. Nearly 100% of all motorcycle riders and passengers analyzed in the *MCCS* were wearing helmets, presumably a direct result of the universal helmet law in California. Although the use of a helmet is an important safety issue associated with the protection of motorcycle riders, injury mitigation (and therefore helmet use) was beyond this safety report's scope and stated focus on motorcycle crash causation and crash prevention. Concerning the role of alcohol, the BAC for the majority of the riders and passengers was either not tested or not available in the *MCCS*.

The NTSB identified the following motorcycle safety issues:

- **Inadequate integration of motorcycles in crash warning and prevention systems and with vehicle-to-vehicle and vehicle-to-infrastructure systems.** Multiple-vehicle crashes involving a motorcycle and another motor vehicle represented the majority of the crashes in the *MCCS*. In many of these crashes, the other vehicle driver reported not detecting the motorcycle or that a dangerous condition existed, and the motorcycle rider reported having insufficient time to react and complete a collision avoidance maneuver. Vehicle-based crash warning and prevention systems on passenger vehicles and connected technologies (vehicle-to-vehicle and vehicle-to-infrastructure) all have the potential to prevent crashes involving motorcycles by improving motorcycle conspicuity. However, these systems are not always being designed to detect or fully integrate motorcycles.

- **Need for enhanced braking and stability control systems on motorcycles.** The reduced stability on a motorcycle compared to four-wheeled vehicles can make braking, swerving, and other collision avoidance maneuvers more complicated. More than a third of the crashes analyzed involved a loss of control that contributed to crash causation. Running wide on curves and slide outs due to inappropriate braking were among the most common loss-of-control scenarios. More widespread availability of enhanced braking and stability control systems on motorcycles could improve safety by enhancing the effectiveness of braking, collision avoidance performance, and stability control for both novice and experienced riders.

- **Limitations of the most recent data collected on motorcyclist alcohol and other drug use and motorcycle crashes in the United States.** Although alcohol and other drug use is well established as a risk factor in motor vehicle collisions, more focused research is needed to understand the contribution of alcohol and other drug use as a risk factor in motorcycle crashes and whether specific countermeasures could reduce alcohol- and other drug-related motorcycle crashes. The *MCCS* attempted to collect the data needed to support such research; however, rider BAC and any indicator of the presence of drugs other than alcohol were either not tested or not available in many cases.

- **Need to evaluate the effectiveness of motorcycle rider licensing procedures.** Licensing procedures are intended to reduce crashes, injuries, and fatalities by requiring that riders have the basic knowledge and skills to ride a motorcycle safely. However, there is widespread variation in motorcycle rider licensing procedures across the United States. Despite efforts to ensure that all riders are licensed, the greater number of unlicensed riders involved in fatal crashes, when compared to unlicensed drivers of other motor vehicle types, has remained largely unchanged over the past decade. There has been limited independent research on unlicensed riders or the effectiveness of motorcycle rider licensing procedures, which makes it difficult to measure the impact these procedures are having on reducing motorcycle crashes, injuries, and fatalities.

As a result of this safety report, the NTSB makes recommendations to the National Highway Traffic Safety Administration, the FHWA, the Motorcycle Industry Council, the American Motorcyclist Association, and the Motorcycle Safety Foundation.

1 Introduction

Motorcyclists—motorcycle riders and their passengers—have the highest risk of fatal injury among all motor vehicle users.[1] In 2016, 5,286 motorcyclists died in traffic crashes in the United States (NCSA 2018).[2] Although motorcycles represented 3% of registered motor vehicles on the road in 2016, and less than 1% of all vehicle miles traveled (VMT), they accounted for 14% of all traffic fatalities (NCSA 2018; FHWA 2017).[3] Per mile traveled, motorcyclist fatalities occurred nearly 28 times more frequently than passenger vehicle occupant fatalities in traffic crashes (NCSA 2018). Like accidents across all modes of transportation, motorcycles crashes are complex events that can be influenced by multiple human, vehicle, and environmental factors. However, because motorcycles afford riders less protection, the likelihood of injuries and fatalities in a crash is much greater. The National Transportation Safety Board (NTSB) is concerned about factors that influence motorcycle crash risk and how these factors may be changing over time. In this report, the NTSB assesses select risk factors associated with the causes of motorcycle crashes in the United States and makes recommendations for improving motorcycle crash prevention.

1.1 Scope

This safety report analyzed potential risk factors associated with the causes of motorcycle crashes and evaluated strategies for crash prevention. The data analyzed were appropriate for identifying factors associated with an increase or decrease in motorcycle crash risk that warranted further evaluation. These factors were then examined as potential safety issue areas and compared to existing motorcycle safety research and publications to determine the need for safety improvements.

1.2 Goals

The goals of this research were to (1) identify and assess factors that contribute to motorcycle crash risk, (2) compare these factors with previous research findings about motorcycle crash risk, and (3) evaluate the need for motorcycle safety improvements. In particular, this report focused on motorcycle crashes resulting in injury or death.

The NTSB used existing data to achieve these goals. Although the NTSB did not collect the data analyzed in this report, the data are the most current of their kind and contribute to the understanding of motorcycle crash causation in the United States.

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[1] *Motorcyclist* is a general term used to refer to a motorcycle rider, a passenger on a motorcycle, or both. *Rider* refers to a person operating a motorcycle. *Passenger* refers to a person seated on but not operating a motorcycle.

[2] These data were compiled from the National Highway Traffic Safety Administration's (NHTSA) Fatality Analysis Reporting System (FARS). The 2016 data were updated and finalized by NHTSA in February 2018. These were the most current data available at the time of this report.

[3] NHTSA's definition of traffic fatalities includes bicyclists and pedestrians, as well as motorcyclists and other motor vehicle drivers and passengers.

1.3 In-Depth Motorcycle Crash Investigations

In-depth motorcycle crash investigations use highly trained teams to collect data from crash scenes, inspect the vehicles involved, and interview survivors and eyewitnesses. These teams often include motorcycle safety researchers and former police motorcycle officers and crash investigators. The crashes are reconstructed by integrating the vehicle and scene data with interview and injury data, police reports, and medical records, when available. In-depth crash investigations provide comprehensive information about the common characteristics of motorcycle crashes, but additional information is needed to appropriately assess crash risk.

The case-control methodology is commonly used in epidemiological research to compare cases of interest, such as people who experience a particular injury or disease, with a control group of individuals from a similar population who do not exhibit that injury or disease. The comparison of cases and controls can then be used to identify the unique characteristics that set the two groups apart.

When applied to the study of risk factors associated with motorcycle crashes, motorcycle crash cases are compared to motorcycles not involved in crashes that pass through the same geographic area near the time of the crash. The control group information is collected by stopping motorcyclists and asking them to voluntarily provide information similar to the details collected from the motorcycle crash cases. Such non-crash-involved controls serve as a comparative point of reference against which findings about those involved in motorcycle crashes can be assessed.

1.3.1 1981 Hurt Report

In 1981, the US Department of Transportation published one of the most comprehensive studies of motorcycle crash risk in the United States, *Motorcycle Accident Cause Factors and Identification of Countermeasures*. The study is commonly referred to as the "Hurt Report" after its lead author, Hugh H. Hurt (Hurt and others 1981). The study data were collected in Southern California within the city of Los Angeles. The data collection methods used in the Hurt Report became the foundation of an in-depth crash investigation technique and have since been formalized as the *Common International Methodology for On-Scene, In-Depth Accident Investigation* for the Organisation for Economic Co-operation and Development (OECD).[4] Until recently, the Hurt Report was one of the only studies of its kind available for analyzing motorcycle crashes and risk factors in the United States.[5]

[4] The OECD is an intergovernmental economic organization with 35 member countries. One of the organization's goals is to provide a platform for its members to share comparable data and statistics on a wide range of public policy issues. The OECD's *Motorcycles: Common International Methodology for On-Scene, In-Depth Accident Investigation* is based on research methods developed by Hugh H. Hurt and colleagues at the University of Southern California in the late 1970s. Hereafter in this report, the OECD's *Motorcycles: Common International Methodology for On-Scene, In-Depth Accident Investigation* will be referred to as the OECD methodology.

[5] To date, at least six other countries have applied this methodology to study motorcycle crash risk factors and develop policy and preventive measures for their respective motorcycling populations (Kasantikul 2001; ACEM 2009). The European *Motorcycle Accident In-Depth Study* (*MAIDS*), published by the Association des Constructeurs Européens de Motocycles in 2009, was conducted in Italy, Spain, Germany, Holland, and France between 1999 and 2001; the other study, conducted in Thailand, took place between 1998 and 2001.

The Hurt Report found that the most frequent type of injury-producing motorcycle crash involved a motor vehicle causing a collision by violating a motorcycle's right-of-way. The motorcyclist involved in the crash was typically inconspicuous in traffic; untrained and inexperienced at operating a motorcycle; operating without a safety helmet or a motorcycle license; and unskilled at braking, counter steering, and other collision avoidance actions (Hurt and others 1981).

1.3.2 2016 *Motorcycle Crash Causation Study*

In 2005, Congress recognized the need for updated information to better understand how motorcycle safety trends might be changing over time and authorized funds for the collection of a new motorcycle crash causation dataset using the OECD methodology.[6] The Federal Highway Administration (FHWA) oversaw the resulting data collection effort and final publication of the 2016 *Motorcycle Crash Causation Study* (*MCCS*). The *MCCS* data were collected in Orange County, California, and consist of 1,053 records (351 crashes and 702 controls), with more than 1,900 variables coded for each record (FHWA 2016).[7] The *MCCS* represents the most current data available for studying motorcycle crashes and risk factors.

Like the Hurt Report, the *MCCS* focused its study area in Southern California, which provided a year-round population of motorcycle riders. This additional exposure to risk has the potential to generate more motorcycle crashes for analysis, but not necessarily crashes that would be meaningfully different from motorcycle crashes elsewhere in the United States.[8] The environmental characteristics of Orange County, California, offered a range of road types (highway, arterial, non-arterial) and land use (urban, suburban, rural), and the *MCCS* had the support of local law enforcement and experienced motorcycle crash scene investigators (FHWA 2016).

Numerous motorcycle crash prevention and mitigation strategies have been implemented since 1981 to improve motorcycle safety, yet many of the same factors contribute to motorcycle crash risk today. An updated assessment of motorcycle crash risk factors is needed to understand

[6] Section 5511 of the *Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users*, Public Law 109-59, directed the Secretary of Transportation to provide grants to the Oklahoma Transportation Center "for the purpose of conducting a comprehensive, in-depth motorcycle crash causation study that employs the common international methodology for in-depth motorcycle accident investigation of the Organisation for Economic Co-operation and Development."

[7] (a) According to the FHWA, the 2016 *MCCS* investigated a total of 349 crash events; 2 of these crashes involved a motorcycle-to-motorcycle crash. Thus, a total of 351 crash cases were recorded during the study period from 2011 to 2015. (b) The *MCCS* collected two non-crash-involved controls for each crash case. These controls were selected from motorcycle traffic at or near the location where the crash cases occurred.

[8] With regard to weather and representativeness of study area, the Hurt Report argued that motorcycle crashes that occur in fair weather in the city of Los Angeles, California, are essentially the same as those that occur in fair weather in other locations in the United States. The report pointed out that motorcycles are not designed for all-weather use and most motorcycle crashes occur in favorable weather simply because of the more frequent use of motorcycles during favorable weather conditions. Further, the report found that all environmental factors, including weather, contributed to less than 5% of the motorcycle crashes studied, and in most cases, the weather at the crash scenes was clear and dry. As a result, the Hurt Report concluded that motorcycle crashes occurring in adverse weather conditions were only a small part of the total motorcycle crash problem (see Hurt and others 1981).

why motorcycle crashes continue to occur and to determine how to improve motorcycle crash prevention and save lives.

1.4 NTSB and Motorcycle Safety

For more than 50 years, the NTSB has been investigating highway accidents, determining their probable cause, and issuing recommendations to improve the safety of the traveling public. Although the NTSB does not typically investigate motorcycle crashes, it has addressed motorcycle safety via the following means.[9]

1.4.1 Motorcycle Safety Forum

In September 2006, the NTSB conducted a 2-day forum to examine issues specific to motorcycle safety, gather information about ongoing motorcycle safety research and initiatives, and discuss countermeasures to reduce the likelihood of motorcycle crashes and fatalities. The forum featured expert panelists in the areas of motorcycle safety trends and statistics; vehicle design; motorcyclist protective equipment, training, and licensing; public education and awareness; and motorcyclist impairment.[10] The forum provided the NTSB an opportunity to examine motorcycle safety in much greater detail than it could in any single crash investigation.

The forum highlighted many of the unique safety issues associated with motorcycling, such as the following:

- Maintaining control and stability is more complicated on motorcycles compared to four-wheeled vehicles.
- The size, power, and maneuverability of motorcycles influence how riders and other motor vehicle users detect and perceive each other, and how they interact in a mixed traffic environment.
- Even when operating in a safe and responsible manner, motorcycle riders and passengers are at greater risk than passenger vehicle occupants because they are not protected by an enclosed vehicle compartment with seat belts (thus leaving them more vulnerable to injury or death in the event of a crash).

[9] The NTSB conducts major highway accident investigations when the accident has a significant impact on public confidence or highway safety, involves an issue related to a current NTSB special investigation, or is determined by the NTSB to be catastrophic.

[10] See the NTSB Motorcycle Safety Forum summary.

1.4.2 Safety Recommendations

In September 2007, a year after the Motorcycle Safety Forum, the NTSB held a Board meeting to discuss recommendations that were developed as a result of the forum.[11] Subsequently, seven safety recommendations, H-07-34 through -40, were issued in October 2007.[12] These recommendations and the issues they address are discussed below.

A key issue raised by forum panelists was the need for more accurate motorcycle activity data, such as vehicle registrations and VMT, to better understand motorcycle crash and fatality trends. Such data are required to calculate reliable motorcycle crash, fatality, and injury rates, and in turn, to evaluate government funding, assess safety countermeasures, and develop legislation for improving motorcycle safety. The NTSB recommended that the FHWA develop guidelines for states to use to gather accurate motorcycle registration and VMT data (Safety Recommendation H-07-34).[13]

The US Department of Transportation's 2000 National Agenda for Motorcycle Safety (NAMS) and its recommendations were referenced several times during the forum as a guide for future motorcycle safety initiatives and for increasing motorcycle awareness (NHTSA 2000).[14] However, the NTSB found no objective criteria available for prioritizing the 82 NAMS recommendations, and there was no official process in place for tracking the status of each recommendation.

In 2007, the NTSB recommended that the National Highway Traffic Safety Administration (NHTSA) reprioritize the NAMS recommendations (Safety Recommendation H-07-35), and then implement an action plan to guide stakeholders in accomplishing those recommendations determined to be high priority (Safety Recommendation H-07-36).[15] Further, the NTSB recommended that the 50 states, the District of Columbia, and the US territories assist NHTSA by providing information on the effectiveness of their respective motorcycle safety efforts (Safety Recommendation H-07-37).[16] Since these 2007 NTSB recommendations were issued, the

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[11] See the NTSB Board Meeting Presentations—Public Meeting of September 11, 2007, Motorcycle Safety Recommendation Letters.

[12] These recommendations, and all NTSB recommendations referenced in this report, as well as relevant excerpts of associated correspondence exchanged to determine a recommendation status, are available via the NTSB Safety Recommendations Database. The database also provides a chart explaining all of the possible recommendation statuses. See also appendix A for a list of past NTSB recommendations referenced in this report.

[13] Because the FHWA updated its Traffic Monitoring Guide, which provides a comprehensive approach for all states to collect traffic data on all vehicle types, and uses its Traffic Monitoring Community of Practice Website as an ongoing forum to share best practices for collecting motorcycle travel data with states and data users, Safety Recommendation H-07-34 was classified "Closed—Acceptable Alternate Action" on September 11, 2009.

[14] NHTSA and the Motorcycle Safety Foundation co-sponsored the NAMS. A technical working group of experts and other stakeholders from professional associations, industry, and transportation safety contributed to the development of 82 NAMS recommendations aimed at improving motorcycle safety. A copy of the *National Agenda for Motorcycle Safety* (2000) is available through NHTSA's website or through the Motorcycle Safety Foundation. NHTSA's *Implementation Guide for the National Agenda for Motorcycle Safety* (2006) is also available via its website.

[15] Safety Recommendations H-07-35 and -36 are classified "Closed—Acceptable Action."

[16] (a) For 47 states, the District of Columbia, the Commonwealth of Puerto Rico, the US Virgin Islands, and the Commonwealth of Northern Mariana Islands, Safety Recommendation H-07-37 is classified "Open—Initial Response

American Association of State Highway and Transportation Officials has included motorcycle safety as an emphasis area within its Strategic Highway Safety Plan, and the NAMS recommendations have served as a resource and starting point for the development of *A Guide for Addressing Collisions Involving Motorcycles* (NCHRP 2008). NHTSA published its prioritization of the 82 NAMS recommendations in 2013, and it continues to include motorcycle safety as a chapter in its 8th edition of *Countermeasures that Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices* (NHTSA 2015).

The Motorcycle Safety Forum also provided the framework for safety recommendations focused on increasing helmet use among motorcycle riders and passengers. Head injury represents the leading cause of death and disability in motorcycle crashes nationwide (NTSB 2007). When a crash occurs, a motorcyclist's single greatest protection is the proper use of a safety helmet that complies with Federal Motor Vehicle Safety Standard (FMVSS) 218, *Motorcycle Helmets,* (NTSB 2007). These helmets are estimated to be 37% effective in preventing fatal injuries to motorcycle riders and 41% effective for motorcycle passengers (Deutermann 2004). At the time of the forum, however, less than a quarter of US states and territories required all motorcyclists to wear a helmet. Therefore, the NTSB recommended that state and territorial governments with partial or no helmet laws adopt a universal helmet law requiring all motorcycle riders and passengers (no matter what age) to use a FMVSS 218-compliant helmet when motorcycling (Safety Recommendations H-07-38 through -40).[17]

1.4.3 Most Wanted List

The NTSB's Most Wanted List highlights the most critical changes needed to improve transportation safety and save lives. Motorcycle safety has been specifically named on the list, and over the years, the list has also helped bring attention to emerging safety issues that are applicable to motorcycling, such as the importance of collision avoidance technologies, the safety benefits of personal protective equipment (such as helmets), and the dangers of fatigue as well as alcohol and other drug impairment.[18]

Received"; for 2 states, H-07-37 is classified "Closed—Acceptable Action"; for 1 other state H-07-37 is classified "Closed—No Longer Applicable"; and for 2 territories H-07-37 is classified "Closed—Reconsidered."

[17] Safety Recommendations H-07-38 through -40 are all currently classified "Open—Unacceptable Response."

[18] See the NTSB's Most Wanted List. In addition, the NTSB has encouraged motorcycle safety by issuing a safety alert and creating several Safety Compass blog posts on the topic. See the NTSB 2010 safety alert titled Motorcycle Deaths Remain High and the following 2011, 2012, 2014, 2016, and 2017 NTSB blog posts. The NTSB has also testified numerous times before state legislatures to advocate for improving motorcycle safety.

2 Methodology

To identify safety issues associated with motorcycle crash causation, the NTSB conducted a detailed analysis of the FHWA's *MCCS* data, analyzed motorcycle crash and activity data from national and state sources, and reviewed the existing scientific literature to evaluate safety mitigation options for the risk factors identified in the *MCCS* data analysis.

2.1 *MCCS* Data

The FHWA's 2016 *MCCS* used a matched case-control design to collect data about potential motorcycle crash risk factors.[19] The two basic types of case-control studies (matched and nonmatched) are distinguished by the method used to select the controls. A nonmatched case-control study selects controls without regard to the number of cases or the characteristics of the cases. In a matched case-control study, the controls are selected based on one or more characteristic of the cases (these characteristics are commonly referred to as the matching criteria). For example, the *MCCS* matched the locations of the controls to the locations of the crash cases.

The NTSB analyzed the *MCCS* data to identify safety issues associated with motorcycle crash causation. In the NTSB's analysis, cases were limited to *MCCS* crashes that involved a motorcycle with an engine displacement that exceeded 50 cubic centimeters (cc) or a maximum design speed above 31 mph.[20] At least one reported injury was sustained by the motorcycle rider or passenger in every crash, and all crashes occurred in Orange County, California, between 2011 and 2015.

2.1.1 Matching Criteria

For each crash-involved motorcycle in the *MCCS*, two control motorcycles were matched based on the crash scene location, travel direction, day of the week, and time of day.[21] This approach is commonly used in medical, epidemiological, and transportation safety research, and it facilitates comparing factors between an affected group, such as individuals involved in a crash (the cases), and an unaffected group of non-crash-involved individuals (the controls).

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[19] According to the FHWA, the primary focus of the *MCCS* was gathering more comprehensive data on motorcycle crashes to encourage and support future research on crash risk factors, injury severity, and the design of countermeasures for improving motorcycle safety. The *MCCS* final report and dataset are available on request at the FHWA's website.

[20] The *MCCS* data included a total of 351 crash cases and 702 controls that represented powered, two-wheeled vehicles from one of two main categories: L1 and L3. L1 refers to two-wheeled vehicles with an engine displacement *not exceeding* 50 cc and a maximum design speed *not exceeding* 31 mph. L3 refers to two-wheeled vehicles with an engine displacement *exceeding* 50 cc or with a maximum design speed *exceeding* 31 mph. These vehicle categories and definitions are consistent with those used by the OECD methodology (2001) and in the *MAIDS* report (2009). Based on engine displacement and design speed, motorcycles are considered to be L3 vehicles. L1 vehicles from the *MCCS* data were not included in the data analyzed for this report.

[21] With matched-pair case-control data, each crash case is paired to a control based on the matching of selected variables such as geographic location or time of day (Fleiss and others 2003).

The controls were recruited from the motorcycle traffic passing by the crash location from the same direction of travel, on the same day of the week, and near the time of day the crash occurred. The *MCCS* used roadside stops at a safe location at or near the crash location with signage indicating that volunteer motorcycle riders and passengers were being asked to participate in a motorcycle study, and that a $40 gas card would be provided to those volunteering to participate.

When analyzing the *MCCS* data, the NTSB further matched the cases and controls by motorcycle type when examining rider-related factors, and by rider age group when examining motorcycle-related factors. For many of the cases, it was only possible to match one of the two controls to the case. As a result, the analyses in this report use a case-control ratio of 1:1 (that is, each case-control pair consisted of one crash case matched to one control). After matching by motorcycle type and rider age group, the final datasets used in this report had 177 and 168 case-control pairs, respectively. There were more than 150 variables in common for analysis, such as rider and passenger demographics, training and licensing histories, previous traffic violations, and motorcycle characteristics (FHWA 2016). The following variables were selected and analyzed to identify factors that set the crash cases apart from the controls:

Rider Information

- Rider age
- Total years of on-road motorcycle experience
- Total number of months riding the crash/control motorcycle
- Motorcycle license (yes or no)[22]
- Total number of years with a motorcycle license
- Type of motorcycle rider training completed
- Number of moving traffic convictions in the previous 5 years (any vehicle type)
- Number of motorcycle crashes in the previous 5 years
- Number of hours of sleep in the past 24 hours
- Retroreflective items worn by rider (if any)[23]
- Registered owner of the motorcycle

[22] In California, where the *MCCS* data were collected, motorcycle riders that meet the requirements for a full motorcycle license may be issued a stand-alone motorcycle license or a motorcycle endorsement on their driver's license. Unless otherwise specified, the term "motorcycle license" in this report refers to a valid stand-alone motorcycle license or motorcycle endorsement.

[23] A *reflective* surface is one that provides a reflection, such as a mirror. A *retroreflective* surface, like a reflector on a motorcycle or the reflective tape on a motorcycle rider's garments, refers to a surface that returns light back to where it came from and nowhere else.

Motorcycle Information

- Engine displacement[24]
- Antilock braking system (ABS) brakes (yes or no)
- Tire tread depth
- Retroreflective parts, materials, or paint on the motorcycle
- Headlight and auxiliary lights (yes or no)

Trip and Activity Information

- Average number of miles ridden per year
- Motorcycle use (for recreation, transportation, or both)
- Trip duration (in minutes)

2.1.2 Statistical Analysis

The NTSB used conditional logistic regression analysis to examine the selected variables as potential factors contributing to motorcycle crash risk. Previous transportation safety research has used this statistical model, and it was appropriate for analyzing the *MCCS* data. Logistic regression analysis is used to determine if the presence of a particular factor increases or decreases the odds of a given outcome, such as motorcycle crash involvement.[25] Conditional logistic regression analysis is a modification of this model that is used when the case and control data are matched, and when working with smaller sample sizes. Similar approaches have been used in research involving other types of motor vehicles (Stein and Jones 1988; Teoh and others 2017).

Sample sizes were reported as the number of crash and control pairs, which varied depending on the risk factor being analyzed.[26] For example, rider age had 173 pairs available for analysis, whereas previous traffic convictions had 92 pairs. When the crash or its matched control was missing data, the pair was excluded from that particular analysis. All statistical analyses for this report were computed using SAS Enterprise Guide 7.1.[27]

Matched-pair odds ratio estimates were used to understand each factor's contribution to crash risk. Appendix B provides a detailed explanation of how these estimates were computed. Because the outcome of interest—motorcycle crashes—is relatively rare in the population, these estimates provided an approximation of the relative risk and were interpreted as such throughout the report. An estimate greater than 1.0 indicated that the factor being analyzed was

[24] *Engine displacement* refers to the internal volume of an engine. The measure of engine displacement is commonly given in cc.

[25] The *odds* are defined as the probability that an outcome is a case divided by the probability that it is a noncase.

[26] With matched-pair case-control data, only the discordant pairs contribute to the matched-pair odds ratio estimate. A concordant pair would include any pair where the crash case and its associated controls exhibit the factor being analyzed, and a discordant pair would be any pair where the crash case exhibits the factor and its controls do not (or vice versa). See Fleiss and others 2003 for more information on matched-pair case-control data and analysis.

[27] SAS Enterprise Guide 7.1 is a recent version of a software application that facilitates the importing, combining, and statistical analysis of data, such as that obtained by the *MCCS* and analyzed by the NTSB in this report.

overrepresented in the crash group compared to the control group. An estimate less than 1.0 indicated that the factor was *underrepresented*.

Statistical significance was reported for each estimate by including a 95% confidence interval (in parentheses after the estimates). A confidence interval is a range of values above and below an estimate and can be used to interpret the estimate's accuracy and precision.[28] The estimates with intervals that did not include 1.0 were considered significant and predictive in terms of changes in crash risk.[29] The factors associated with a significant increase or decrease in crash risk were investigated further to evaluate the need for motorcycle safety improvements.

2.1.3 Limitations

The *MCCS* sample size limited the ability to examine some potential crash risk factors by various subgroups of interest. As a result, some less influential risk factors may not have reached statistical significance. Further, the data were collected in Orange County, California, to target an area with high motorcycle ridership and a mix of urban, suburban, and rural settings; therefore, the data are not geographically representative of the entire United States. This limitation is similar to the Hurt Report, which collected data in the city of Los Angeles.

Other limitations common to case-control data included the potential for recall bias among the crash-involved riders and selection bias among the non-crash-involved controls.[30] In addition, the matching criteria in case-control data cannot be analyzed as potential risk factors, which precluded the analysis of certain roadway features and local or state traffic laws. Further, the control sample, because it was matched to the crashes, is not independently representative of all motorcycling activity in the area.[31]

[28] The *accuracy* is defined in terms of whether or not the confidence interval contains the true value; the *precision* refers to the width of the confidence interval.

[29] If the 95% confidence interval associated with an estimate did not include 1 (for example, if the interval was 0.25, 0.80 or 1.50, 4.53), that estimate was considered to be a statistically significant result. Conversely, if the 95% confidence interval associated with an estimate included 1.0 (for example, if the interval was 0.50, 1.50), that estimate was considered to be a result that was not statistically significant.

[30] (a) An example of *recall bias* is the crash-involved motorcyclist being more motivated to recall risk factors during on-scene or hospital interviews to help explain why the crash occurred. If the motorcyclist was at fault in the crash, the motorcyclist may have been hesitant to share certain details about the moments leading up to the crash. (b) The non-crash-involved controls that passed through the study area were volunteer participants; however, a potential candidate may have been less likely to pull over and provide an interview if they were unlicensed or had been drinking. This is an example of *selection bias*.

[31] Statistics about the crash sample can be calculated and used to make inferences about the larger crash picture; however, it was not possible to calculate the average age of the control sample and interpret that as the average age of the motorcycling population because the controls were matched to the crashes when the *MCCS* data were collected.

2.2 Other Data Sources

The NTSB also analyzed crash and activity data from other sources to understand national and state-level motorcycle safety trends. Annual motorcycle crash fatality data were derived from NHTSA's Fatality Analysis Reporting System (FARS).[32] To estimate fatality rates associated with motorcycle activity, FARS data were compared to motorcycle VMT data provided by the FHWA.

In addition, the NTSB used the California Highway Patrol's Statewide Integrated Traffic Records System (SWITRS) database to analyze police traffic accident reports detailing motorcycle crashes that occurred in Orange County between 2011 and 2015. The NTSB also used geographic analyses to compare the SWITRS data with *MCCS* crash case locations to better understand the *MCCS* crashes in context with local population data, traffic and crash density, infrastructure, and highway characteristics.

2.3 Literature Review

The NTSB reviewed the existing scientific literature to evaluate safety mitigation options for the risk factors identified in the *MCCS* data analysis. This review identified four broad safety issue areas associated with motorcycle crash causation and prevention. Section 4 of this report provides a discussion of the safety issue areas and associated recommendations aimed at reducing motorcycle crashes and improving safety.

[32] The FARS database is a census of fatal traffic crashes within the United States. The database represents crashes that occur on a public road and result in a death within 30 days of the crash.

3 Results

This section describes the *MCCS* crashes analyzed for this report and identifies crash risk factors for additional evaluation. Estimates of crash risk are organized by rider and motorcycle characteristics.

3.1 Crash Cases

Table 1 provides the distribution of crashes by matching criteria. The conventional, cruiser, and chopper motorcycle types were combined and represented more than half (54%) of the crash-involved and control motorcycles.[33] Sport, race replicas accounted for another 40%, and all other motorcycle types made up the remaining 6%.[34]

More than half (51%) of the crashes, and 50% of fatal crashes, took place on Fridays, Saturdays, and Sundays.[35] In addition, crashes occurred more often in an urban environment (65%) and on arterial roadways (79%). Figure 1 shows that crash frequencies were generally highest between 2 p.m. and 8 p.m. and lowest between 12:00 a.m. and 6 a.m. About 27% of crashes occurred at night and 66% in the daylight.[36]

[33] Conventional, cruiser, and chopper motorcycle types were combined during the analyses in this report because they share similar design characteristics. This approach has been used in other motorcycle research (see Teoh and Campbell 2010).

[34] The other motorcycle types included touring, sport touring, dual purpose, off-road, scooters, and step-throughs.

[35] That is, the crashes occurred between 12:00 a.m. on Friday and 11:59 p.m. on Sunday.

[36] The remaining crashes occurred at dawn (1%) and dusk (6%).

Table 1. Crash cases by matching criteria (motorcycle type, day of week, crash environment, type of roadway, and time of day).

Matching criteria	Crashes	
	Number	%
Motorcycle type		
Conventional, cruiser, chopper	96	54
Sport, race replica	71	40
Other	10	6
Day of week		
Monday	21	12
Tuesday	19	11
Wednesday	30	17
Thursday	17	9
Friday	29	16
Saturday	33	19
Sunday	28	16
Crash environment		
Urban	114	65
Rural	11	6
Suburban	52	29
Type of roadway		
Interstate, freeway	3	2
Principal arterial	76	43
Minor arterial, collector	65	36
Non-arterial	30	17
Other (driveway, alley)	3	2
Time of day		
2:00 a.m. - 5:59 a.m.	3	2
6:00 a.m. - 9:59 a.m.	27	15
10:00 a.m.-1:59 p.m.	31	18
2:00 p.m. - 5:59 p.m.	59	33
6:00 p.m. - 9:59 p.m.	49	28
10:00 p.m.-1:59 a.m.	8	4

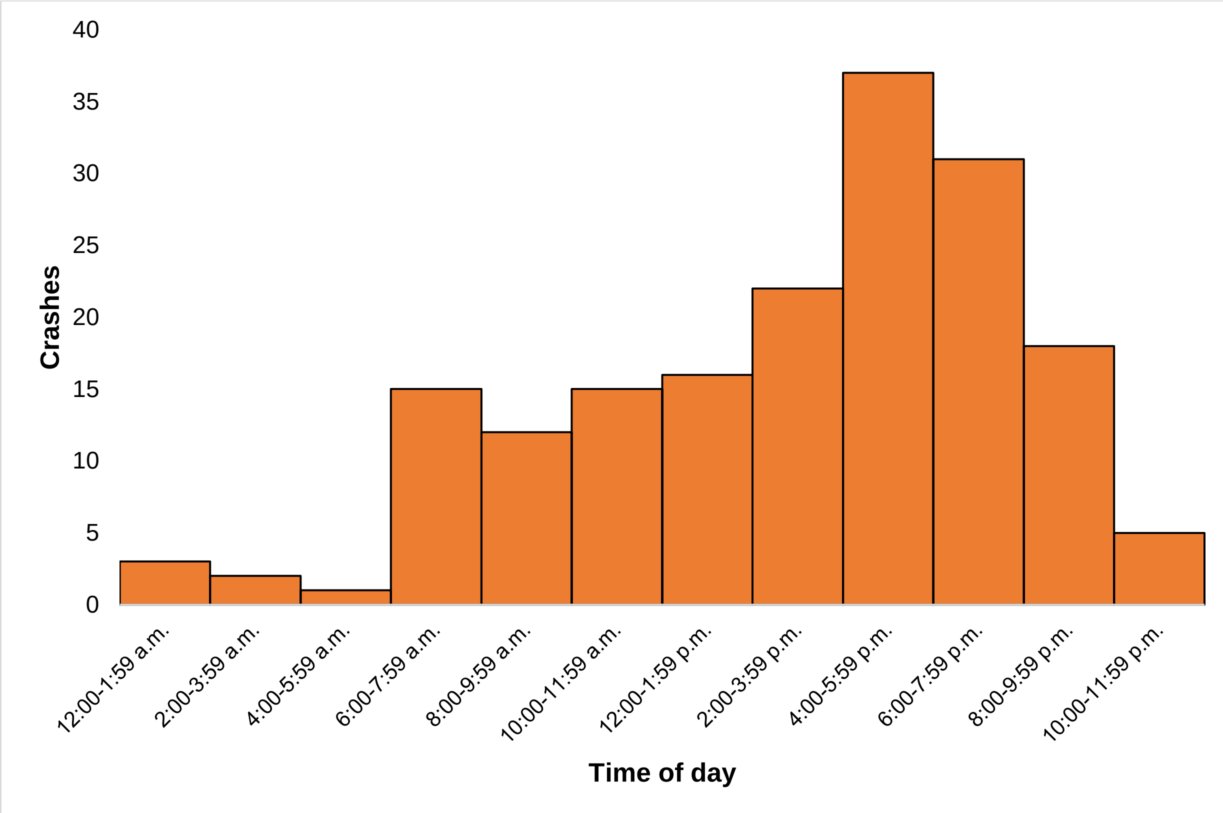

Figure 1. Number of crash cases by each 2-hour period of the day.

Figures 2 and 3 summarize additional environmental characteristics of the crash locations, such as the presence of an intersection and posted speed limits.

Most of the crashes (81%) involved another motor vehicle besides the crash-involved motorcycle, usually a passenger vehicle. The single-vehicle crashes (19%) involved only the motorcycle and its rider (and in some cases a passenger), and the collision was usually with a fixed roadside object after running off the roadway.

Of all the crashes analyzed, 20 (11%) were fatal (17 motorcycle riders and 3 passengers) and 157 (89%) involved nonfatal injuries. Although the single-vehicle crashes represented 19% of all crashes, these crashes accounted for 50% of all fatal crashes.

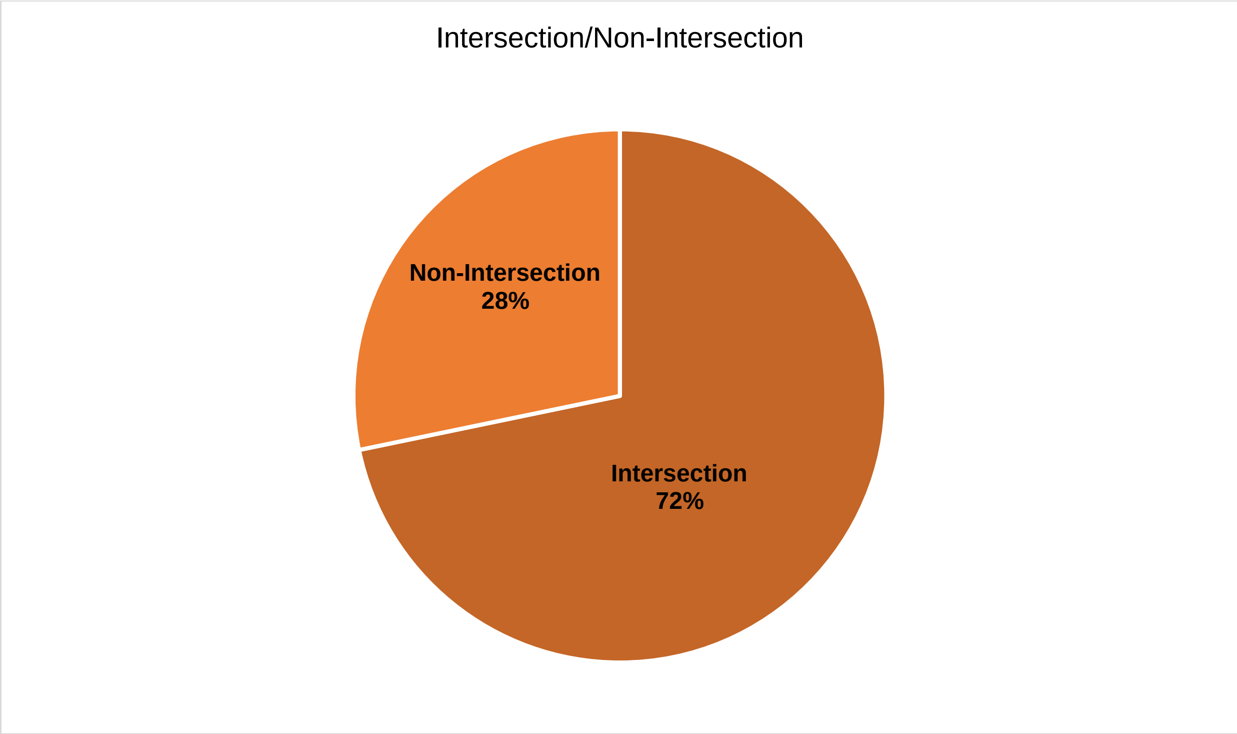

Figure 2. Crashes by intersection and non-intersection locations.

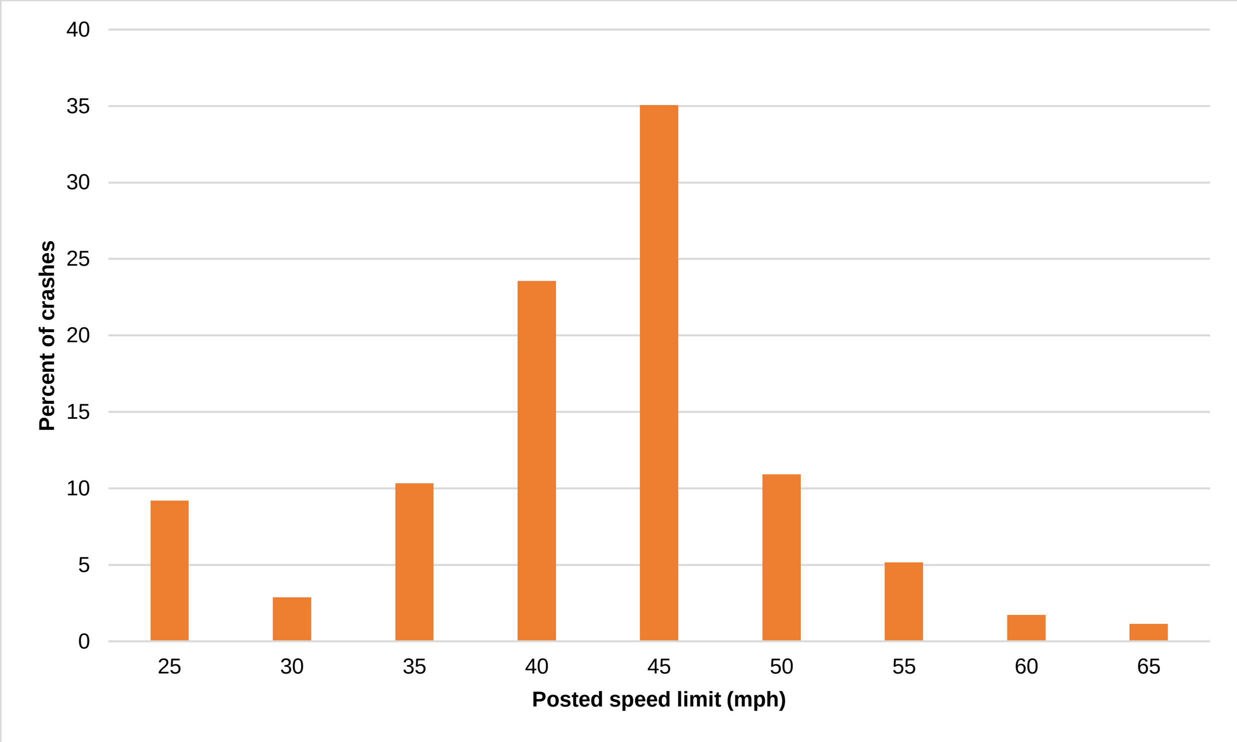

Figure 3. Distribution of crash location posted speed limits (mph).

A comparison of posted speed limit data and estimated travel speeds indicated that about 15% of the crashes analyzed (26 of 177) involved a motorcycle that was exceeding the posted speed limit by at least 10 mph. Table 2 provides the distribution of the crashes where the estimated travel speed of the rider before the crash was at least 1, 5, or 10 mph over the posted speed limit, and these data are subdivided further by multiple- and single-vehicle crash types and fatal and nonfatal outcomes. Single-vehicle and fatal crashes had the highest percentages of motorcycles that were traveling at least 10 mph over the posted speed limit (38% and 45%, respectively).

Table 2. Estimated motorcycle travel speeds not exceeding and exceeding the posted speed limit by crash type and crash severity.

Crashes	Estimated travel speed (mph)							
	At or below posted		Above posted (≥1)		Above posted (≥5)		Above posted (≥10)	
	Number	%	Number	%	Number	%	Number	%
Multiple-vehicle (n=143)	98	69%	45	31%	28	20%	13	9%
Single-vehicle (n=34)	16	47%	18	53%	16	47%	13	38%
Fatal (n=20)	6	30%	14	70%	12	60%	9	45%
Nonfatal (n=157)	108	69%	49	31%	32	20%	17	11%
All (n=177)	**114**	**64%**	**63**	**36%**	**44**	**25%**	**26**	**15%**

3.1.1 Primary Contributing Factors

Human error attributed to either the motorcycle rider or the other vehicle driver was the primary documented contributing factor to crash causation in about 94% of the crashes analyzed (166 of 177). Vehicle and environmental factors such as mechanical defects, maintenance problems, roadway design issues, traffic control failures, and adverse weather accounted for another 3%. The remaining crashes were associated with phantom vehicles (2%) and other circumstances (1%) that *MCCS* investigators classified as unknown or indeterminate.[37]

[37] A phantom vehicle case typically involved the motorcyclist reporting that the loss of control was associated with attempting to avoid an unexpected maneuver made by another vehicle or a different collision involving other vehicles on the roadway. In these cases, *MCCS* investigators typically had insufficient evidence to confirm or refute the motorcyclist's report.

Figure 4 shows the number of crashes attributed to human error and distributed by whether the motorcycle rider or the other vehicle driver was at fault. More than half of these crashes involved an error or failure on the part of the other vehicle driver and not the motorcycle rider.[38] Perception failures were most common among other vehicle drivers.[39] In many of these crashes, drivers reported that they failed to detect the motorcycle or to discern that a dangerous condition existed. The motorcycle riders failed to react more often than other vehicle drivers, resulting in either no attempt to avoid the dangerous condition or faulty collision avoidance. Motorcycle riders were also more frequently associated with comprehension failures compared to other vehicle drivers.

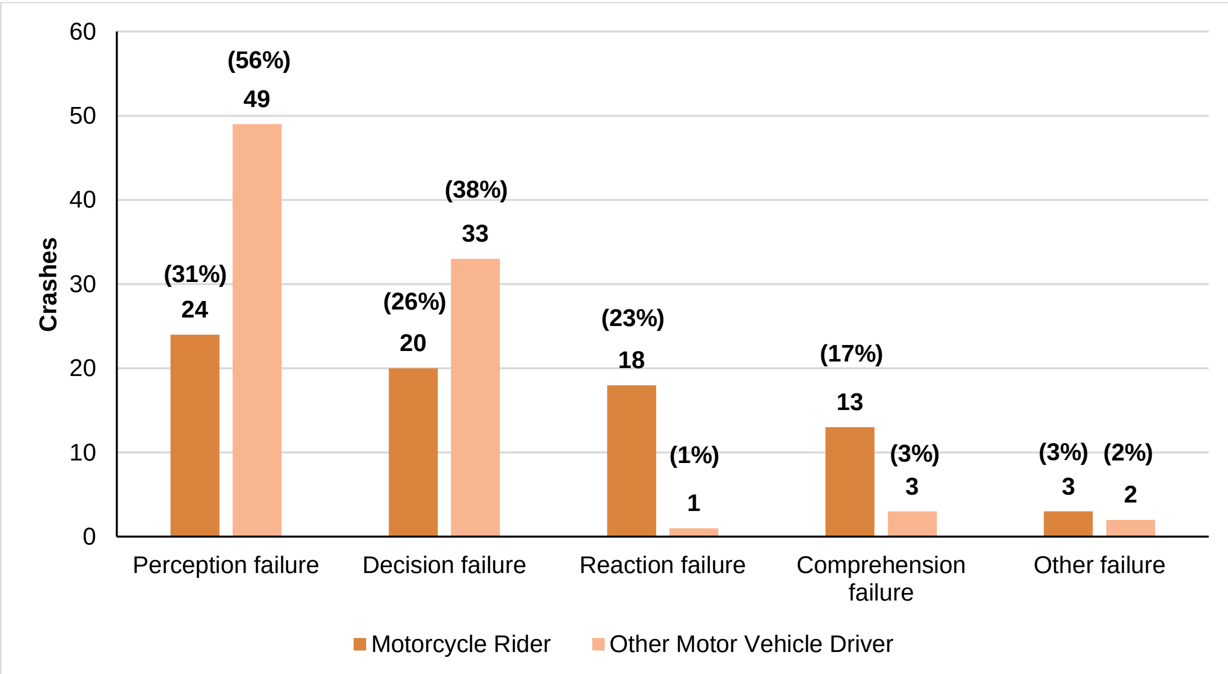

Figure 4. Crash cases attributed to human error by primary contributing factor.

[38] Other vehicle driver errors represented 88 of 166 crashes (53%) in which the primary contributing factor was a human error, compared to 78 of 166 (47%) crashes for motorcycle riders. When limited to multiple-vehicle crashes, about 64% (88 of 138) were attributed to an error or failure on the part of the other vehicle driver and not the motorcycle rider. *MCCS* investigators assigned a human, vehicle, or environmental factor as the *primary* crash contributing factor for each crash case. This factor was considered to have made the greatest overall contribution to crash causation. As a result, multiple and overlapping factors may have contributed to a crash case, but only one factor was assigned as the primary crash contributing factor.

[39] The OECD defines a *perception failure* as a situation where a motorcycle rider or other vehicle driver failed to detect that a dangerous condition existed based on the strategy being used to detect dangerous conditions. A *reaction failure* is defined as a situation where the failure to react to a dangerous condition resulted in either no collision avoidance attempt or faulty collision avoidance. A *decision failure* is defined as a situation where the rider or driver failed to make the correct decision to avoid a dangerous condition. A *comprehension failure* is defined as a situation where the rider or driver perceived (detected) the dangerous condition but failed to comprehend the danger associated with that condition.

3.1.2 Crash Configurations

Figure 5 provides a distribution of the crashes by crash scenario or configuration. The most frequent configurations involved a vehicle turning left in front of a motorcycle, or a motorcycle falling on the roadway while attempting a collision avoidance maneuver.[40] Motorcycles that ran off the roadway with no other vehicle involvement represented about 10% of the crashes but accounted for 35% of fatal crashes (7 of 20 fatal crashes). Sideswipe crashes, typically the result of drivers improperly checking for traffic in blind spot areas before changing lanes, represented the next most frequent crash configuration.

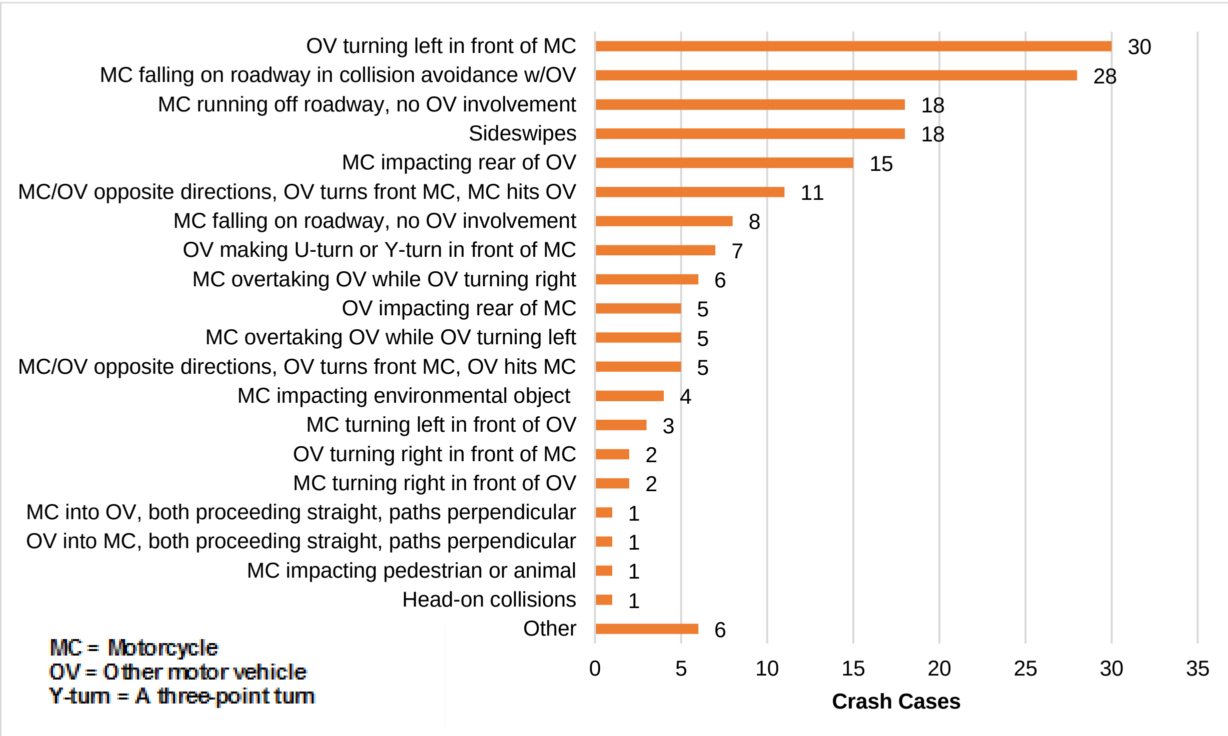

Figure 5. General description of crash configurations.

Because other vehicle drivers often failed to detect or anticipate the presence of a motorcycle, and many of these crashes involved turning scenarios, sideswipes, or motorcycle loss of control while attempting collision avoidance, the NTSB concludes that many high-risk traffic situations between motorcycles and other motor vehicles could be prevented if vehicle drivers were better able to detect and anticipate the presence of a motorcycle when entering or crossing a road, making a turn, or changing lanes.

[40] Figure 5 provides a basic overview of the crash configurations for discussion purposes. As such, the figure does not display all 24 crash configurations separately. For example, the two types of sideswipe crashes are grouped under one category labeled "Sideswipes." In addition, two crash configurations described by *MCCS* investigators as "other motorcycle accidents" and "other motorcycle/motor vehicle impacts" were grouped together as "Other."

3.1.3 Collision Avoidance Performance

Table 3 shows motorcycle rider collision avoidance performance for all crashes analyzed (single- and multiple-vehicle crashes). About a third of the crash-involved riders never attempted to perform collision avoidance. Among the majority of riders that attempted collision avoidance, they chose an appropriate evasive maneuver for the hazardous condition about two-thirds of the time (65%), but effectively carried out the chosen maneuver only about a quarter of the time (26%).

An example of choosing an appropriate maneuver but failing to properly execute the maneuver would be a motorcycle rider that detects a motor vehicle is about to turn left and potentially violate the rider's right-of-way. The rider recognizes that there is sufficient distance to slow down or even stop before reaching the other vehicle and decides to apply the brakes (an appropriate choice for the situation). However, the rider fails to appropriately brake, loses control of the motorcycle, and crashes.

Table 3. Assessment of motorcycle rider collision avoidance performance.

Choice of collision avoidance maneuver	Execution of collision avoidance maneuver		
	Inappropriate	Appropriate	Total
Inappropriate	30%	5%	**35%**
Appropriate	44%	21%	**65%**
Total	**74%**	**26%**	

Figure 6 illustrates the time from the precipitating crash event to crash impact as a cumulative percent distribution.[41] Based on *MCCS* investigator judgment, more than three-quarters of the crash-involved riders had 3 seconds or less to detect that a hazardous condition existed and attempt collision avoidance. After removing crashes that involved motorcycles that were exceeding the posted speed limit by at least 5 mph and at least 10 mph, the proportion of riders with 3 seconds or less remained about the same (see figure 7).

[41] According to the FHWA, the estimate of the number of seconds from the precipitating event to crash impact should be considered an evidence-based judgment made by the *MCCS* investigators at each crash scene and not a scientific measurement.

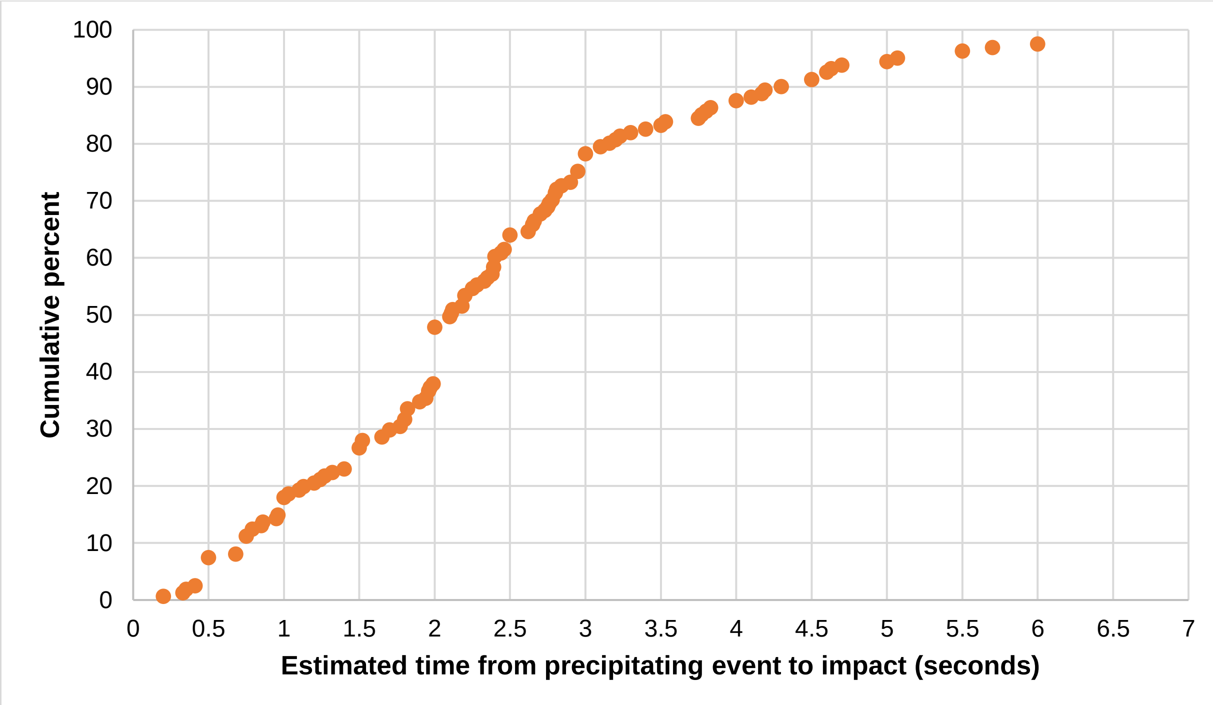

Figure 6. Cumulative percent distribution of time from precipitating event to impact.

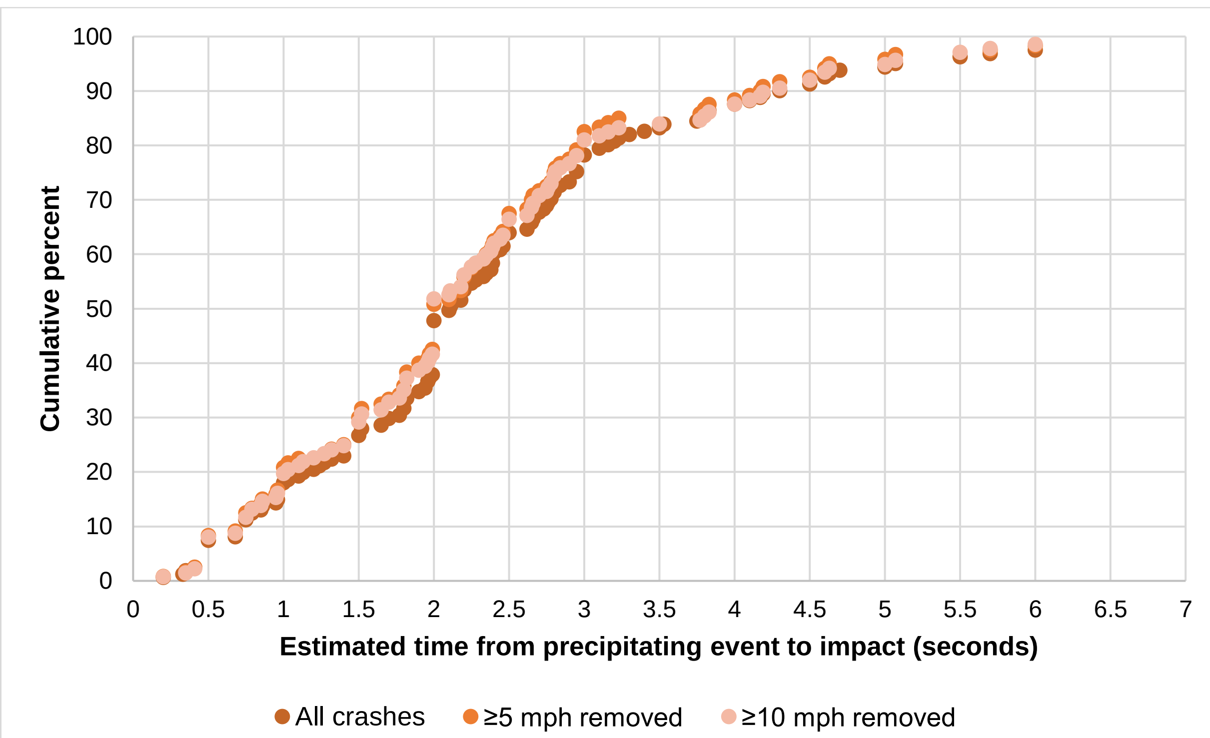

Figure 7. Estimated time from precipitating event to impact after removing motorcycles exceeding the speed limit by at least 5 mph and 10 mph.

About a third of the crash-involved riders made no collision avoidance attempt (65 of 177) before crash impact. Inadequate time to complete an attempted collision avoidance was reported by riders in about a quarter (26%) of the crashes analyzed (47 of 177). More than a third of the crashes analyzed (34%) involved a loss of control that contributed to crash causation (60 of 177). Among the most common scenarios were running wide on a curve (21 of 60) and slide outs associated with inappropriate braking (17 of 60).

These data suggest that in most crashes the riders needed to detect and recognize the precipitating event as a dangerous condition almost as soon as the event happened to have sufficient time to complete an evasive maneuver. However, comprehension and reaction failures were both overrepresented among riders compared to other motor vehicle drivers, suggesting that the danger associated with a precipitating event was often not immediately recognized or fully understood by the rider. Therefore, the NTSB concludes that motorcycle riders' collision avoidance performance could be improved by extending the range of hazard detection and providing riders with more information, enhanced awareness, and more time to react to crash risks.

3.1.4 Alcohol and Other Drug Use

Overall, the motorcycle rider's blood alcohol concentration (BAC) level was either not tested or unknown for 72% of the *MCCS* crashes and 60% of the controls. Further, the consumption of drugs other than alcohol in the 24 hours leading up to the crash was unknown in 32% of the crash-involved riders. As a result, determinations regarding whether rider alcohol or other drug involvement contributed to crash causation were based largely on *MCCS* investigator judgment. These determinations were available for 173 of the 177 crash-involved riders analyzed by the NTSB. Alcohol or other drug use by motorcycle riders was determined by *MCCS* investigators to have contributed to crash causation in 15% of all crashes analyzed (26 of 173), 35% of single-vehicle crashes (12 of 34), and 40% of fatal crashes (8 of 20). In comparison, *MCCS* investigators determined that other vehicle driver alcohol or other drug use contributed to crash causation in about 2% of the multiple-vehicle crashes (3 of 143) and 10% of fatal crashes (2 of 20).

3.1.5 License Information

Motorcycle rider license information was available for 110 of the 177 crashes analyzed. About 24% (26 of 110) of these riders did not have a valid motorcycle license. In multiple-vehicle crashes, about 21% of riders did not have a motorcycle license, compared to 7% of other vehicle drivers that did not have an automobile license. Nearly all crash-involved riders that did not have a motorcycle permit or license were the registered owner of their motorcycle.

3.2 Rider-Related Factors

3.2.1 Age and Experience

Analyses of potential motorcycle rider-related crash risk factors are presented in table 4. Relative to motorcycle riders over 50 years of age, younger riders (under 30) were about 4 times more likely to be involved in a crash.

The riders that reported having less than 2 years of total on-road motorcycle experience were also associated with increased crash risk, compared to those with 5 or more years of experience. A rider's familiarity with the motorcycle did not have a strong effect on risk in these data. However, in about 14% of the crashes involving a sport, race replica, it was the rider's first time operating the motorcycle.

3.2.2 Unlicensed Riders

The risk estimate for license status indicated that the crash-involved motorcycle riders were 8 times as likely to be unlicensed (that is, riding without a valid motorcycle license or endorsement). However, this result was attributed to problems with how the control riders were selected for the *MCCS*.[42]

3.2.3 Moving Traffic Violations

The relative crash risk for riders with traffic violation convictions for any motor vehicle type in the past 5 years was higher than for those riders without a conviction. Those riders that reported having one conviction were more than 2 times as likely to be involved in a crash as those riders that reported having no convictions. The crash risk increased for riders with two or more convictions.

[42] Participation in the *MCCS* was voluntary; therefore, unlicensed riders that passed through the study area may have been less likely to stop and participate as a control. This would have potentially biased the selection of controls toward licensed riders. There were a few unlicensed controls that participated in the *MCCS*. One control (<1%) reported having no driver's license and 36 controls (<5%) reported having no motorcycle license.

Table 4. Distribution of motorcycle rider characteristics and crash risk estimates (statistically significant findings are in bold).

Rider characteristics	N (pairs)	Crash/control motorcycles	Crash risk estimate (Matched-pair odds ratio)	95% confidence interval
Age				
<30	173	81/42	**4.49**	(2.36, 8.55)
30–50	173	59/65	**2.01**	(1.10, 3.69)
51+	173	33/66	1	--
Years of experience (all motorcycles)				
<2	99	18/8	**2.72**	(1.06, 6.98)
2–4	99	21/19	1.24	(0.58, 2.62)
5+	99	60/72	1	--
Motorcycle license				
Yes	109	26/5	1	--
No	109	83/104	**8.00**[a]	(2.41, 26.57)
Familiarity with motorcycle				
<6 months	100	25/25	1.01	(0.51, 2.00)
6–11 months	100	13/12	1.09	(0.49, 2.41)
12+ months	100	62/63	1	--
Moving traffic convictions (all vehicles)				
None	92	30/53	1	--
1	92	32/20	**2.38**	(1.19, 4.78)
2 or more	92	30/19	**2.77**	(1.24, 6.18)
Annual motorcycle mileage				
<7,000	90	39/45	0.96	(0.45, 2.04)
7,000–12,000	90	32/25	1.39	(0.59, 3.29)
12,001+	90	19/20	1	--
Hours of sleep in past 24				
<8	91	39/31	1.40	(0.79, 2.49)
8+	91	52/60	1	--

[a] See footnote 42.

3.3 Motorcycle-Related Factors

Table 5 presents analyses of potential motorcycle-related crash risk factors. For these analyses, the NTSB had to match the *MCCS* crash cases and controls by rider age group instead of by motorcycle type to facilitate the evaluation of headlight configuration, engine displacement, ABS technology, and other motorcycle characteristics as potential crash risk factors. After matching by rider age group, the final dataset consisted of 168 case-control pairs for analysis.

Table 5. Distribution of motorcycle characteristics and crash risk estimates (statistically significant findings are in bold).

Motorcycle characteristics[a]	N (pairs)	Crash/control motorcycles	Crash risk estimate (Matched-pair odds ratio)	95% confidence interval
Antilock braking system (all models)				
ABS-equipped	160	11/23	1	--
Not ABS-equipped	160	149/137	**2.09**	(1.02, 4.29)
Antilock braking system (2001–2015)				
ABS-equipped	106	8/19	1	--
Not ABS-equipped	106	98/87	**2.38**	(1.04, 5.43)
Headlight configuration				
Auxiliary lights	168	26/27	1	--
No auxiliary lights	168	142/141	1.05	(0.58, 1.91)
Engine displacement (cc)				
<1000	167	100/98	1.27	(0.73, 2.21)
1000–1400	167	33/27	1.52	(0.76, 3.03)
1401+	167	34/42	1	--
Retroreflective parts, materials, paints				
Present	167	119/129	1	--
Not present	167	48/38	1.44	(0.84, 2.44)
Retroreflective garments				
Present	94	22/20	1	--
Not present	94	72/74	0.88	(0.44, 1.77)

[a] Case-control pairs analyzed in this table are matched by rider age groups instead of motorcycle type.

3.3.1 ABS Technology

Non-ABS-equipped motorcycles had 2 times the crash risk relative to motorcycles that had this safety feature. The percentage of *MCCS* motorcycles that were equipped with ABS (11%) was consistent with that of all registered motorcycles with ABS as a standard or optional feature in the United States (12%) in 2015 (IIHS 2017a). The model years of the ABS-equipped motorcycles ranged from 1999 through 2015; however, most of the *MCCS* motorcycles equipped with ABS were model years 2001 through 2015. As a result, the NTSB further analyzed the effects of ABS on crash risk after limiting the data to those model years. The increased risk associated with non-ABS-equipped motorcycles continued to be present when the data were restricted to motorcycles from model years 2001 through 2015.

3.3.2 Conspicuity Enhancement

The presence of retroreflective parts, materials, or paint on motorcycles and retroreflective garments on riders was examined for a potential contribution to conspicuity.[43] These results indicated that the presence of such enhancements was not markedly different between the crash-involved and control riders and motorcycles. In addition, headlamp configuration and the presence of auxiliary lights was similar between the crash-involved motorcycles and the controls.

Previous studies, including the Hurt Report, have used engine displacement as a measure of motorcycle size (and therefore conspicuity). The *MCCS* data analyzed in this report indicated that engine displacement was not associated with a statistically significant increase in crash risk. Recent studies of motorcycle engine displacement and crash risk have reported inconsistent findings and have suggested that power-to-weight ratio may provide more useful insights about risk (Langley and others 2000; Haworth and Blackman 2013). The *MCCS* data included motorcycle weight but not horsepower (or other measures of vehicle power); as a result, the NTSB did not calculate the power-to-weight ratio and analyze it as a potential risk factor.

3.4 Crash Narratives and Other Information

Appendix C provides selected case study examples of the most frequent crash configurations discussed in this section. Appendix D includes a comparative review of the rider and crash characteristics in the 2016 *MCCS* and 1981 Hurt Report.

[43] *Conspicuity* refers to the quality of being easily seen or readily observed.

4 Safety Issues

The NTSB identified four motorcycle safety issue areas in this report: (1) crash warning and prevention, (2) braking and stability, (3) alcohol and other drug use, and (4) licensing procedures. This report analyzes issues associated with motorcycle crash causation and prevention; therefore, many well-established injury prevention issues, such as helmet use, are not included.

4.1 Crash Warning and Prevention

Multiple-vehicle crashes involving a motorcycle and at least one other motor vehicle represented more than three-quarters of the *MCCS* crashes analyzed in this report. Right-of-way violations were common, and a typical crash scenario involved a motorcycle hitting or being hit by a turning motor vehicle at an intersection, the entrance of an alley, or a driveway. Nearly all vehicle and other hazards were in front of the motorcycle before the crash, and few were to the sides or the rear of the motorcycle. The next most common scenario was a rider falling on the roadway while attempting to avoid colliding with another vehicle.

The NTSB found that other vehicle drivers were more likely to experience a perception failure than motorcycle riders. These scenarios often involved sight distance and conspicuity issues, such as the other vehicle driver failing to detect the motorcycle or to discern that a dangerous condition existed. For riders, the more important determinant of crash involvement was the amount of time available between the precipitating event and the moment of crash impact. Most riders had a few seconds or less to recognize that a dangerous condition existed, decide what to do, and react to the situation. This fundamental problem may explain why a third of the crash-involved riders analyzed in this report never attempted to perform collision avoidance, and it underscores the need to extend the motorcycle riders’ range of hazard detection to give them more time to respond to crash risks.

4.1.1 Motor Vehicle-Based Technologies

Previous research has demonstrated that vehicle-based crash warning and prevention systems on passenger vehicles have the potential to enhance motorcycle safety by improving motorcycle conspicuity. The passenger vehicle technologies most relevant to motorcycle crashes include collision warning systems, lane maintenance, and blind-spot assistance. In 2017, the Insurance Institute for Highway Safety (IIHS) published a study of crashes involving passenger vehicles and motorcycles between 2011 and 2015. The study focused on crashes relevant to forward collision warning and automatic emergency braking, lane maintenance, and blind-spot assistance. The IIHS estimated that more than 8,000 two-vehicle crashes involving motorcycles could be prevented or mitigated each year by equipping passenger vehicles with these technologies (IIHS 2017b; Teoh 2018). For this reason, the IIHS also concluded that crash warning and prevention systems should be refined to ensure that all road users, including motorcyclists, can be detected (IIHS 2017b; Teoh 2018).

Advances in crash warning and prevention systems for passenger vehicles provide both direct and indirect safety benefits to motorcycle riders. However, not all systems are designed to detect smaller, less conspicuous vehicles specifically (IIHS 2017b; Teoh 2018). Further, turning left and crossing vehicle traffic scenarios, which are among the most common types of crash scenarios involving motorcycles and other motor vehicles, continue to present a difficult performance challenge for crash warning and prevention systems (Carpenter and others 2011; Scanlon and others 2017). For example, after a 2016 collision between a Tesla Model S and a tractor-semitrailer truck, near Williston, Florida, NHTSA's Office of Defects Investigation surveyed manufacturers and suppliers of sensors and technology for automated vehicle systems and reported that none of such systems through model year 2016 were designed to address crossing path collisions (NTSB 2017a; NHTSA 2017a, 2018a). Some manufacturers of crash warning and prevention systems are beginning to address turning and crossing vehicle traffic scenarios, such as left-turn assist technology.[44]

Given that more than half (64%) of the multiple-vehicle crashes analyzed in this report were attributed to an error on the part of the other vehicle driver, and the most common type of error in these crashes was the driver's failure to perceive or detect that a crash risk existed with the motorcycle, the NTSB concludes that vehicle-based crash warning and prevention systems will be most effective at preventing collisions when they can reliably detect all vehicle types, including motorcycles. Therefore, the NTSB recommends that NHTSA incorporate motorcycles in the development of performance standards for passenger vehicle crash warning and prevention systems.

4.1.2 Connected Vehicles and Infrastructure

The NTSB found that about one-third of the crash-involved motorcycle riders, regardless of training or experience, never attempted to perform collision avoidance, suggesting that they may have needed more time to respond to emerging crash risks. Although many of them perceived that a hazard existed, they continued to travel straight, at a constant speed, and never attempted to brake or swerve. In 2018, the Texas A&M Transportation Institute (TTI) conducted an independent evaluation of the crash-involved riders documented in the *MCCS*. The purpose of the analysis was to identify possible infrastructure countermeasures for the FHWA. According to the TTI's analysis, about 70% of the crash-involved riders in the *MCCS* could have potentially benefited from vehicle-to-vehicle connected technology, and about 53% could have potentially benefited from vehicle-to-infrastructure connected technology, such as intersection-movement, right-of-way, and left-turn assistance (TTI 2018).

Vehicle-to-vehicle and vehicle-to-infrastructure connected technologies allow vehicles to communicate with one another or with road infrastructure to help warn drivers of risks and avoid crashes (Harding and others 2014; NHTSA 2016, 2017b). Connected technologies are designed to have a much greater range of detection compared to the sensors, cameras, lasers, and radar used in vehicle-based technologies, thus providing vehicle drivers with more time to detect and react to potential crash risks. Moreover, this increased functionality can work together with current onboard crash warning and prevention systems to optimize warnings and interventions (NTSB 2015). NHTSA has been collaborating with the automobile industry and supporting the

[44] According to one manufacturer of this technology, it is designed to assist motor vehicle drivers when making a left turn that involves crossing the other side of the roadway. The technology can issue a warning to the driver or automatically apply the brakes to avoid a collision with oncoming traffic (Bosch Mobility Solutions 2018a).

development of connected vehicle and infrastructure technologies for more than a decade (Harding and others 2014).[45]

In 2012, during its investigation of a collision between a school bus and a roll-off truck with a fully loaded dump container, at an intersection near Chesterfield, New Jersey, the NTSB found that connected vehicle technology could have provided an active warning to the school bus driver of the approaching truck and possibly prevented the crash. As a result, the NTSB recommended that NHTSA develop minimum performance standards for connected vehicle technology for all highway vehicles, and once developed, require the technology to be installed on all newly manufactured highway vehicles (Safety Recommendations H-13-30 and -31, NTSB 2013a).[46]

In 2014, the NTSB reviewed an advance notice of proposed rulemaking for FMVSS 150, *Vehicle-to-Vehicle (V2V) Communication Systems*, in which NHTSA proposed creating a minimum performance standard for connected vehicle communications devices and messages and requiring this capability on new passenger vehicles and light trucks (NTSB 2014). In its response, the NTSB cautioned that the potential for crashes similar to the one investigated in 2012 near Chesterfield, New Jersey, "would continue to exist unless the rulemaking is expanded to address *all* highway vehicles" (NTSB 2014).[47] In 2015, the NTSB published a special investigation report that examined the use of crash warning and prevention technologies and noted that beyond the immediate benefits of requiring new vehicles to be equipped with these safety features, the presence of these technologies in more vehicles would also support their future integration with connected vehicles (NTSB 2015).

In 2017, NHTSA published a notice of proposed rulemaking (NPRM) for FMVSS 150 and a series of requirements for manufacturers of passenger cars, multipurpose vehicles, and light trucks to install short-range radios to establish a means of communication between new models of these vehicles by 2023 (NHTSA 2017c). Although NHTSA's early testing of these systems included a few motorcycles among the vehicles, the proposed requirements in FMVSS 150 did not include motorcycles (NHTSA 2017c). The NTSB's response to the NPRM emphasized that "widespread use throughout the vehicle fleet—including all heavy vehicles and motorcycles—is required to capitalize on the full lifesaving benefits of V2V technology" (NTSB 2017b). Promoting and increasing the implementation of collision avoidance technologies, such as connected vehicles and infrastructure, across all transportation modes has remained on the NTSB's Most Wanted List since 2016.

[45] NHTSA's Intelligent Transportation Systems Joint Program Office is responsible for the development and operational testing of connected vehicle and infrastructure systems, as required by the *Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users*, Public Law 109-59. In Europe, the Association des Constructeurs Européens de Motocycles (or the European Association of Motorcycle Manufacturers) and the Federation of European Motorcyclists' Associations have promoted safety action plans, since 2004, that encourage the development of vehicle-to-vehicle connectivity, specifically for the purpose of reducing crashes involving motorcycles and other powered, two-wheeled vehicles (ACEM 2004; FEMA 2008).

[46] Safety Recommendations H-13-30 and -31 are currently classified "Open—Unacceptable Response."

[47] Emphasis present in the original comments from the NTSB Acting Chairman to NHTSA on October 16, 2014.

Because the development of performance standards for connected vehicles and infrastructure have been focused primarily on passenger vehicles, the NTSB concludes that the integration of motorcycles with connected vehicle-to-vehicle and vehicle-to-infrastructure systems has been limited compared to other vehicle types. Therefore, the NTSB recommends that NHTSA incorporate motorcycles in the development of performance standards for connected vehicle-to-vehicle systems. The NTSB further recommends that NHTSA and the FHWA work together to incorporate motorcycles in the development of performance standards for connected vehicle-to-infrastructure systems.

As passenger vehicles become more automated and connected, they will be navigating around and interacting with smaller, more vulnerable road users, such as motorcyclists. Similar to manufacturers of motor vehicle-based and connected crash warning and prevention systems, automated vehicle manufacturers will also need to specifically incorporate motorcycles in their development of highly automated and fully automated vehicle navigation systems.

4.2 Braking and Stability

The NTSB found that motorcycle riders attempted some form of collision avoidance before impact in nearly two-thirds of the *MCCS* crashes analyzed for this report. Although they often chose the best evasive maneuver for the situation, relatively few of them performed the maneuver successfully to avoid the crash. The reduced stability on a motorcycle compared to four-wheeled vehicles can make braking, swerving, and other evasive maneuvers more complicated. More than a third of the crashes analyzed involved a motorcycle loss of control that contributed to crash causation. Among the most common scenarios were running wide on a curve and departing the roadway or slide outs associated with inappropriate braking.[48] Similar findings from the Hurt Report prompted its authors to conclude that—

> Research is needed to investigate the potential improvement in collision avoidance performance by the use of interconnected and antilock or antiskid brake systems. Effective collision avoidance braking was a significant deficiency in these accident data with the typical accident-involved motorcycle rider skidding the rear tire but not using the front brake (Hurt and others 1981).

ABS is currently available on some motorcycles, and the NTSB found that non-ABS-equipped motorcycles were associated with increased crash risk relative to the ABS-equipped motorcycles analyzed in this report.

[48] A *low side slide out* results from a loss of traction and occurs when either the front or rear wheel of a motorcycle skids too far to one side or the other, and the motorcycle goes down on its side (the low side or side closest to the ground). This loss-of-control type is often associated with either too much braking, acceleration, or speed while cornering. A *high side slide out* results from a loss of traction by the rear wheel followed by a sudden recovery of traction, and the motorcycle flips violently. This loss-of-control type is often associated with over-correcting a rear wheel slide.

4.2.1 ABS Technology

ABS technology is designed to allow a rider to maximize braking force during an emergency and bring the motorcycle to a rapid, controlled stop without locking up either wheel, which also improves stability. Numerous studies have demonstrated that this technology can improve the stopping performance of both novice and experienced riders (Vavryn and Winkelbauer 2004; Green 2006; Rizzi and others 2009, 2015, 2016; Roll and others 2009; HLDI 2009, 2012, 2013, 2014; Trafikverket 2011; Teoh 2011; Teoh 2013). The IIHS and the Highway Loss Data Institute (HLDI) have conducted one of the most recent studies on the effectiveness of motorcycle ABS technology in the United States, estimating a 31% reduction in fatal crash rate per registered motorcycle (Teoh 2013). The IIHS and the HLDI have also cited studies in Europe that found ABS technology was particularly beneficial for multiple-vehicle crashes that involved another vehicle violating the right-of-way of a motorcycle (Gwehenberger and others 2006 cited in Teoh 2013).

Although braking technologies have advanced significantly on motorcycles since the Hurt Report recommended them in 1981, the implementation of these systems has been much slower than on passenger vehicles, which have been equipped with ABS as standard equipment on new vehicles since 2000.[49] According to the IIHS, in 2002, less than 1% of all on-road motorcycles registered in the United States were manufactured with ABS as a standard feature, and 1.4% had ABS as an optional feature. Despite lagging behind passenger vehicles, the technology has become increasingly more available over the past decade in the United States. By 2015, the proportions had increased to 5% and 12%, respectively (IIHS 2017a). Similar to the IIHS's 2015 data on US-registered motorcycles, the NTSB found that ABS-equipped motorcycles represented about 11% of the *MCCS* motorcycles analyzed in this report. In contrast, the European Union began the process of requiring ABS technology as standard equipment on all motorcycles with an engine displacement over 125 cc starting in 2016 and 2017 (OECD 2015).

ABS research provides evidence that this technology could reduce motorcycle crashes involving several of the crash scenarios discussed in this report. The riders on motorcycles that were not ABS-equipped had increased crash risk relative to those on ABS-equipped motorcycles. Further, riders involved in crashes often knew the appropriate evasive action to take but were unable to execute it successfully. As a result, the NTSB concludes that ABS technology would improve motorcycle safety by enhancing the effectiveness of rider evasive actions through improved braking performance and stability. Therefore, the NTSB recommends that NHTSA require all new motorcycles manufactured for on-road use in the United States be equipped with ABS technology.

[49] NHTSA FMVSS 135, *Light Vehicle Brake Systems*, established ABS safety standards for passenger cars manufactured on or after September 1, 2000. FMVSS 122, *Motorcycle Brake Systems*, does not currently require ABS on motorcycles.

4.2.2 Stability Control Systems

ABS technology provides maximum stopping capability when a motorcycle is in an upright position and all traction is available for braking. However, when a rider is negotiating a curve, part of the traction needed for braking is already being used for cornering. An imbalance between braking and cornering forces can cause the rider to lose stability and directional control of the motorcycle, resulting in the rider falling or running wide on the curve and off the roadway. Although single-vehicle motorcycle crashes represented less than a quarter of the crashes analyzed in this report, they accounted for half of all fatalities. These crashes were also more likely to be associated with a loss of control that involved a collision with a fixed roadside object. Motorcycles that ran off the roadway with no other vehicle involvement represented about one-tenth of the crashes analyzed in this report but accounted for more than a third of all fatalities.

Starting in 2007, BMW and Kawasaki were among the first manufacturers to use ABS technology combined with a basic traction control system on a motorcycle (Cardinale and others 2009). These systems were used to prevent rear wheel slippage during acceleration, which improved motorcycle stability. However, most of these systems were developed for high-performance racing motorcycles. As of 2018, a few motorcycle manufacturers (BMW, Ducati, and KTM, for example) offer some form of advanced stability control system on specific models, but this safety feature is not widely available on all retail, on-road motorcycles (Bayly and others 2006; Seiniger and others 2012).

Stability control systems on motorcycles are designed to link ABS technology to the lean angle of the motorcycle, offering riders the safety benefit of ABS during braking in a straight, upright position, or while cornering (Bosch Mobility Solutions 2018b; Cameron 2015). One example, Bosch's Motorcycle Stability Control system, relies on sensors to continuously monitor dynamic performance data (including torque, lean angle, acceleration, and rotational speed of the front and rear wheels) to detect high-risk situations. In addition, the system integrates ABS technology and calculates the limits of braking force to improve a rider's braking effectiveness and motorcycle stability even in curves (Bosch Mobility Solutions 2018b; Cameron 2015).

Stability control systems designed specifically for use on two-wheeled vehicles function differently than electronic stability control (ESC) systems on four-wheeled vehicles. In general, stability control systems on motorcycles require the rider to engage the brakes for the system to work, unlike the automatic nature of ESC on four-wheeled vehicles. According to NHTSA, the introduction of ESC systems on four-wheeled vehicles has proven effective at preventing single-vehicle loss-of-control crashes. In 2011, NHTSA analyzed FARS and National Automotive Sampling System Crashworthiness data from 1997 to 2009 to evaluate the crash prevention effectiveness of ESC systems (NHTSA 2011a). NHTSA's study showed that passenger vehicles equipped with an ESC system were about half as likely to be involved in single-vehicle crashes as similar vehicles without an ESC system. Moreover, there was a 58% decrease in the likelihood that a vehicle would be involved in a crash involving an impact with a roadside fixed object (NHTSA 2011a).[50] The IIHS conducted a study that used vehicle registration data to compare vehicle models before and after having an ESC system installed as a standard feature. The IIHS

[50] For additional NHTSA research on the effectiveness of ESC systems on four-wheeled vehicles, see NHTSA 2004, 2007, 2014a, and 2014b.

found a 49% decrease in single-vehicle crashes, a similar reduction to that found by NHTSA (Farmer 2010).

However, NHTSA has not addressed stability control system applications, standards, or requirements for motorcycles. This represents a missed opportunity to improve motorcycle safety, given that more research, development, and implementation of this technology has the potential to address one of the more severe motorcycle loss-of-control crash scenarios (that is, running wide on a curve, departing the roadway, and hitting a roadside fixed object). Although motorcycles that ran off the roadway with no other vehicle involvement represented a very small proportion of the crashes analyzed in this report, they accounted for more than a third of all fatal crashes. In addition, ABS and stability control systems on motorcycles may aid riders during collision avoidance and other evasive maneuvers in multiple-vehicle crashes.

The NTSB concludes that stability control systems on motorcycles could reduce single-vehicle crashes that involve loss of control and running wide on a curve and off the road, which would reduce the prevalence of motorcyclists killed or injured by impacts with roadside fixed objects. Therefore, the NTSB recommends that NHTSA conduct or sponsor research to evaluate the effectiveness of stability control systems for motorcycles. Further, the NTSB recommends that, based on the research recommended in Safety Recommendation H-18-33, NHTSA develop and publish performance standards for stability control systems on motorcycles, and require systems meeting those standards on all new motorcycles manufactured for on-road use in the United States. In the interim, to facilitate wider familiarization with the findings of this safety report, the NTSB also recommends that the Motorcycle Industry Council, the American Motorcyclist Association, and the Motorcycle Safety Foundation inform their members about the findings of this safety report, and promote the safety benefits of advanced motorcycle antilock braking and stability control technologies.

4.3 Alcohol and Other Drug Use

Alcohol is consistently identified as a major risk factor in all types of motor vehicle crashes in the United States. In 2016, a NHTSA study found that alcohol was the largest contributor to crash risk for all motor vehicle types and estimated that drivers with a BAC level at 0.08 grams per deciliter (g/dL) were more likely to be involved in a crash than drivers with no alcohol in their blood (Lacey and others 2016). Motorcycle riders involved in fatal crashes represented the highest percentage of alcohol-involved driving fatalities among all vehicle types in 2016. That year, there were 1,259 fatally injured motorcycle riders (25%) with BAC levels at or above 0.08 g/dL (NCSA 2018). However, given that fatally injured riders are more likely to be tested for alcohol compared to crash survivors, and the fact that motorcycle riders are much more likely to be fatally injured in the event of a crash (compared to drivers of enclosed vehicles), it is not possible to fully evaluate the relationship between rider alcohol use and motorcycle crash risk using only the fatality data from NHTSA's FARS.

Research on the safety impact of lowering BAC limits has continued to demonstrate reductions in alcohol-related crash fatalities. Most recently, in 2018, the National Academies of Sciences, Engineering, and Medicine published a comprehensive report, *Getting to Zero Alcohol-Impaired Driving Fatalities*, focused on alcohol-impaired driving as a complex, yet preventable public health problem (NAS 2018). Another study published by the University of

Chicago, in 2017, has shown that from 1982 to 2014, in the 50 states and the District of Columbia, lowering the BAC limit from 0.10 to 0.08 g/dL resulted in a 10.4% reduction in alcohol-related fatalities, with no change in alcohol consumption during the same period (Fell and Scherer 2017a, 2017b). International studies over the past two decades have also reported similar decreases (between 5% and 10%) in alcohol-related fatal and injury crashes when the BAC limit is lowered from 0.08 to 0.05 g/dL (Mann and others 2001; Fell and Voas 2006). Although researchers studying the effectiveness of BAC laws have suggested that the legal limit for motorcycle riders should be lower than for other motor vehicle drivers, there has been limited published research on whether alcohol or other drug use increases crash risk for motorcycle riders more so, or in unique ways, compared to passenger vehicle drivers.[51]

Progressively hazardous effects of alcohol when operating a motor vehicle are well documented, and there are several methods for evaluating alcohol impairment risk among passenger vehicle drivers that may be adapted to motorcycle riders (Voas and others 2007). For example, the National Institutes of Health's National Institute on Alcohol Abuse and Alcoholism has found that visual function, balance and coordination, steering, and the ability to respond to emergency situations can begin to decline in motor vehicle drivers at BAC levels between 0.02 and 0.05 g/dL (NIH/NIAAA 2001). These findings suggest that motorcycle riders, like other vehicle drivers, can experience an elevated crash risk before reaching a BAC of 0.08 g/dL. In addition, NHTSA has studied motorcycle rider performance at different BAC levels (0.00, 0.02, 0.05, and 0.08 g/dL) on a closed track and found that riders at the 0.05 g/dL level had slower reaction times, resulting in narrower margins of hazard avoidance (Creaser and others 2007, 2009). Further, in 2013, the NTSB recommended stronger laws, improved enforcement strategies, improvements to adjudication programs, and the accelerated development of detection technologies to reduce the number of crashes involving alcohol-impaired driving (NTSB 2013b).[52]

The NTSB remains concerned about alcohol and other drug use trends and the safety implications for all modes of transportation. NHTSA's 2013–2014 National Roadside Survey of Alcohol and Drug Use by Drivers has found a continuing trend of decreasing alcohol-involved driving, particularly for weekend nighttime drivers with a BAC level at or above 0.08 g/dL (Ramirez and others 2016). However, for motorcycle riders, the Governors Highway Safety Association (GHSA), using NHTSA FARS data, has noted that the percentage of motorcycle rider fatalities with higher BAC levels (at or above 0.08 g/dL) has increased between 2013 and 2016 (GHSA 2018).

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[51] Commercial motor vehicle drivers and drivers under age 21 are examples of groups with lower BAC limits.

[52] (a) According to the NTSB's report, *Reaching Zero: Actions to Eliminate Alcohol-Impaired Driving*, the proportion of fatalities associated with alcohol-impaired drivers has remained between 30% and 32% since about 1995. (b) As a result of that report, the NTSB recommended that the 50 states, the Commonwealth of Puerto Rico, and the District of Columbia establish a per se BAC limit of 0.05g/dL or lower for all drivers who are not already required to adhere to lower BAC limits (Safety Recommendation H-13-5). For 24 states, the District of Columbia, and the Commonwealth of Puerto Rico, Safety Recommendation H-13-5 is classified "Open—Initial Response Received"; for 2 states, H-13-5 is classified "Open—Acceptable Response"; for 2 states, H-13-5 is classified "Open—Unacceptable Response"; and for 22 states, H-13-5 is classified "Open—Await Response."

The decriminalization of marijuana for medicinal and recreational use in some states has prompted needed research on the relationship between tetrahydrocannabinol (THC) and crash risk for all types of motor vehicle crashes.[53] The 2013–2014 National Roadside Survey of Alcohol and Drug Use by Drivers found a 48% increase over its 2007 survey results for weekend nighttime drivers that tested positive for THC (Kelley-Baker and others 2017). In addition to marijuana, the 2013–2014 National Roadside Survey of Alcohol and Drug Use by Drivers results have also shown an overall increase in the prevalence of drug-positive driving (with no alcohol) between 2007 and 2013–2014. For similar drugs found in both surveys, total drug-positive driving increased from about 16% to 20% (Kelley-Baker and others 2017). The Centers for Disease Control and Prevention has recently estimated that the number of overdose deaths involving opioids was about 5 times higher in 2016 than in 1999 (Rudd and others 2016).

Despite these national drug trends, and a general increase in the use of over-the-counter medications, specific research on patterns of alcohol or other drug use among motorcycle riders, and rider perceptions of how different substances may influence their crash risk, have been largely absent compared to other motor vehicle drivers. The Transportation Research Board of the National Academies of Sciences, Engineering, and Medicine first identified motorcycle rider alcohol and other drug use patterns, and countermeasures to reduce or prevent such use while operating a motorcycle, as needed research areas for its Motorcycle and Moped Committee (ANF30) in 2007. In addition, NHTSA has prioritized the study of motorcyclist alcohol, drug, and medication use patterns as an urgent recommendation in the NAMS since June 2013 (NHTSA 2013).

The *MCCS* attempted to collect data on the relationship between alcohol and other drug use and motorcycle crash risk. Based on *MCCS* investigator judgment, rider alcohol or other drug involvement contributed to crash causation in nearly half of the crashes involving a fatality. However, the *MCCS* could not collect sufficient data to determine the unique risks that may be associated with alcohol and other drug use and motorcycle crashes.[54] In nearly three-quarters (72%) of the *MCCS* crashes, and in more than half of the controls (60%), the motorcycle rider's BAC level was either not tested or unknown. Moreover, the consumption of drugs other than alcohol in the 24 hours leading up to the crash was unknown in about a third (32%) of the crash cases.

[53] (a) THC is one of more than a hundred cannabinoids identified in marijuana; however, this specific cannabinoid is the principal psychoactive constituent of marijuana. As of 2018, a total of 30 states, the District of Columbia, and Guam have medical marijuana programs. Eight states and the District of Columbia have also decriminalized marijuana for recreational use. (b) *Recreational use* means taking a drug for its psychoactive effects rather than to treat an illness or disease. Over-the-counter, prescription, and illicit drugs as well as other substances may all be used "recreationally." For example, dextromethorphan (cough syrup), oxycodone, methamphetamine, amphetamine, heroin, and gasoline or other solvents are other substances commonly used for their psychoactive effects.

[54] The Hurt Report documented similar problems collecting data related to alcohol and other drug use for the crash and control motorcycle riders involved in that study.

The NTSB notes that the 2016 *MCCS* does not have enough data on alcohol and other drug use to allow for generalizations about motorcycle rider alcohol and other drug use patterns. Although alcohol and other drug use is well established as a risk factor in motor vehicle collisions, the NTSB concludes that more focused research is required to understand the contribution of alcohol and other drug use as a risk factor in motorcycle crashes and whether specific countermeasures could reduce alcohol- and other drug-related motorcycle crashes. NHTSA is responsible for reducing deaths, injuries, and economic losses resulting from motor vehicle crashes, and it routinely oversees research on driver behavior and traffic safety. Therefore, the NTSB recommends that NHTSA examine the influence of alcohol and other drug use on motorcycle rider crash risk compared to that of passenger vehicle drivers, and develop guidelines to assist states in implementing evidence-based strategies and countermeasures to more effectively address substance-impaired motorcycle rider crashes.

4.4 Licensing Procedures

MCCS riders under 30, and those in the early years of gaining on-road motorcycle experience, both had increased crash risk relative to older, more experienced riders. These results were consistent with comparable motorcycle case-control studies. The Hurt Report, for example, found that riders under 30 years of age (particularly those 16 to 24) and riders with less than 6 months of on-road experience were both overrepresented in the crash data (Hurt and others 1981). More recent case-control studies conducted in Australia and Europe have also found higher crash risk among riders between 18 and 25 years old, and decreased crash risk associated with riders that had more years of on-road motorcycle experience (Allen and others 2017; Haworth and others 1997; ACEM 2009). Similar trends are found among young and inexperienced passenger vehicle drivers (NHTSA 2008; NHTSA 2018b; Cassarino and Murphy 2018).

Licensing procedures are intended to reduce crashes, injuries, and fatalities by requiring that motor vehicle operators of all experience levels, and young or novice operators in particular, have the basic knowledge and skills to operate a vehicle safely. For passenger vehicle drivers, licensing procedures are relatively consistent across the United States. In addition, all 50 states and the District of Columbia have adopted some form of graduated driver licensing (GDL) for drivers between 15 and 18 to 21 years of age. GDL programs are primarily focused on giving teenage passenger vehicle drivers the opportunity to slowly develop their driving skills, experience, and maturity in lower-risk environments (Thor and Gabler 2010; McCartt and others 2010; Fell and others 2011; Shults and Williams 2016).[55] GDL programs have been shown to be effective and are estimated to reduce teenage crashes by 10% to 30% on average (IIHS 2018a).

All 50 states, the District of Columbia, and the Commonwealth of Puerto Rico have motorcycle rider licensing requirements that establish a minimum age for new motorcycle riders and the procedures they must follow to become fully licensed (MSF 2016). Each jurisdiction is legally responsible for licensing qualified motorcycle riders, regularly verifying that they are capable of riding safely, and keeping unqualified riders off public roads. However, in contrast to passenger vehicles, motorcycle licensing procedures and requirements vary greatly across the United States.

[55] The NTSB has a long history of recommending that states adopt and implement comprehensive GDL programs.

As of 2016, 47 states require entry-level motorcycle riders to pass a vision test, complete a rules-of-the-road knowledge exam, and hold a learner's permit to be eligible for a full license.[56] The minimum age requirements varied from 13 to 21 years (MSF 2016). All states, with the exception of Alabama and Florida, place restrictions on riders with a learner's permit, such as not riding with a passenger, mandatory helmet use, and riding limited to specific times of day and roadway types. Most states require a practical riding skills test; however, this requirement can often be waived upon completion of an approved motorcycle safety training course.[57]

In 7 states and the District of Columbia, a formal training course is mandatory for all new riders, regardless of age.[58] Of the 14 states that have tiered motorcycle licensing procedures, New Jersey and Utah require their riders to test on the motorcycle size they intend to ride. Moving up to larger, more powerful motorcycles requires additional testing. Finally, 11 states reported having a GDL program for motorcycle riders with elements similar to GDL programs used for teenage passenger vehicle drivers (MSF 2016; NHTSA 2009).

For motorcycle licensing procedures to be effective, riders must comply with them. In 2016, however, 1,972 motorcycle riders involved in fatal crashes (27%) were riding without a valid motorcycle license at the time of their crash (NCSA 2018).[59] In comparison, 13% of passenger vehicle drivers involved in fatal crashes that year were unlicensed (NCSA 2018). The NTSB similarly found that about a quarter (21%) of the *MCCS* motorcycle riders involved in the multiple-vehicle crashes analyzed in this report did not have a valid motorcycle license, compared to 7% of the other vehicle drivers involved in the same crashes. Furthermore, the majority of unlicensed *MCCS* riders analyzed were also associated with the under 30 age group.

Previous research has identified challenges to the effectiveness of licensing procedures for passenger vehicle drivers. These include drivers that refuse to participate or advance through the licensing procedures, and the failure of licensing procedures to effectively discriminate between adequate and inadequate skill levels among permit and license applicants (NCSA 2014; NCHRP 2003). Numerous studies have associated unlicensed passenger vehicle drivers with increased risk of serious and fatal injury, and with more high-risk behaviors like drinking, speeding, and not wearing a seatbelt (Elliott and others 2008; Fu and others 2012).

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[56] Alabama, Florida, Louisiana, and the District of Columbia do not issue motorcycle learner permits.

[57] In 46 states, this skills test requirement is waived if the rider completes a motorcycle safety training course or other approved form of rider education (regardless of the rider's age). This incentive is intended to motivate novice riders to complete training. In 2 states, the skills test waiver is only available to riders 18 years of age or older that complete training. Maine and the District of Columbia do not waive the skills test; Alabama does not require a learner's permit, a riding skills test, or rider education (a written exam is required, and the minimum age to take the exam is 14 for motorcycles with an engine displacement of 150 cc or less and 16 for motorcycles with an engine displacement greater than 150 cc).

[58] In 21 states, training is only required for riders under 16, 18, and 21 years of age, depending on the jurisdiction, and 22 states have no formal training requirement for obtaining a motorcycle license.

[59] NHTSA defines a *valid motorcycle rider license* as the rider having either a valid passenger vehicle license with a motorcycle endorsement, or a valid motorcycle-only license. Therefore, the term *unlicensed motorcycle rider* includes those riders using a passenger vehicle license that is not lawfully endorsed for motorcycle operation, or riders that do not have a valid motorcycle-only license.

There has been limited research, however, on unlicensed motorcycle riders and the effectiveness of current licensing procedures in the United States. One study, in 2004, examined the influence of state motorcycle licensing on crash rates and found that requiring motorcycle safety training and implementing learner permit restrictions were both associated with lower fatality rates (McGwin and others 2004). States that required a skills test for the permit, a longer permit holding period, and three or more restrictions on permit holders also had lower rider fatality rates (McGwin and others 2004; Daniello and others 2009).

More recently, in 2018, the GHSA has found that motorcycle learner permit procedures may be undermining the effectiveness of the licensing process in some jurisdictions. For example, in 17 states, there are no limits on the number of times a motorcycle rider can renew a learner's permit, and some renewals are valid for up to 4 years (MSF 2016). The GHSA has suggested that these types of gaps in licensing procedures may encourage some riders to continue renewing their permit indefinitely and never complete the riding skills test needed for the full license (GHSA 2018).

Following the NTSB's 2006 Motorcycle Safety Forum, NHTSA and the American Association of Motor Vehicle Administrators (AAMVA) conducted a nationwide survey of motorcycle licensing procedures to address the estimated 89% increase in the number of unlicensed riders involved in fatal crashes between 1998 and 2007 (NHTSA 2009). In addition, NHTSA and AAMVA published *Guidelines for Motorcycle Operator Licensing* in 2009. These guidelines updated AAMVA's *Motorcycle Operating Licensing System* (1997) and *Integrating Motorcycle Rider Education and Licensing* (1993) manuals and added an enhanced motorcycle licensing model for novice riders of all ages using GDL concepts adapted from GDL programs for passenger vehicle drivers (NHTSA 2009).[60] Despite these efforts, however, the number of unlicensed motorcycle riders involved in fatal crashes has remained largely unchanged between 2007 and 2016. Further, nearly all of the unlicensed *MCCS* riders analyzed in this report were also the registered owner of the motorcycle they were riding at the time of the crash.

Licensing procedures are intended to reduce crashes, injuries, and fatalities by requiring that novice and experienced riders have the same basic knowledge and skills to ride a motorcycle safely. Based on the findings in this report, and the fact that licensing procedures vary significantly between states, the NTSB concludes that motorcycle licensing procedures have not been adequately evaluated for safety and effectiveness, which makes it difficult to determine if current licensing procedures are achieving reductions in motorcycle crashes, injuries, and fatalities or encouraging unlicensed riders to become fully licensed. Therefore, the NTSB recommends that NHTSA evaluate the effectiveness of state motorcycle licensing procedures for reducing motorcycle crashes, injuries, and fatalities among novice and unlicensed riders; based on the results of that evaluation, update the *Guidelines for Motorcycle Operator Licensing* or other guidance as appropriate.

[60] NHTSA also conducted two reviews of motorcycle rider education and licensing programs and practices in 2005, prior to publishing its 2009 *Guidelines for Motorcycle Operator Licensing* (see NHTSA 2005a, 2005b).

5 Conclusions

5.1 Findings

1. Many high-risk traffic situations between motorcycles and other motor vehicles could be prevented if vehicle drivers were better able to detect and anticipate the presence of a motorcycle when entering or crossing a road, making a turn, or changing lanes.

2. Motorcycle riders' collision avoidance performance could be improved by extending the range of hazard detection and providing riders with more information, enhanced awareness, and more time to react to crash risks.

3. Vehicle-based crash warning and prevention systems will be most effective at preventing collisions when they can reliably detect all vehicle types, including motorcycles.

4. The integration of motorcycles with connected vehicle-to-vehicle and vehicle-to-infrastructure systems has been limited compared to other vehicle types.

5. Antilock braking system technology would improve motorcycle safety by enhancing the effectiveness of rider evasive actions through improved braking performance and stability.

6. Stability control systems on motorcycles could reduce single-vehicle crashes that involve loss of control and running wide on a curve and off the road, which would reduce the prevalence of motorcyclists killed or injured by impacts with roadside fixed objects.

7. More focused research is required to understand the contribution of alcohol and other drug use as a risk factor in motorcycle crashes and whether specific countermeasures could reduce alcohol- and other drug-related motorcycle crashes.

8. Motorcycle licensing procedures have not been adequately evaluated for safety and effectiveness, which makes it difficult to determine if current licensing procedures are achieving reductions in motorcycle crashes, injuries, and fatalities or encouraging unlicensed riders to become fully licensed.

6 Recommendations

As a result of this safety report, the National Transportation Safety Board makes the following safety recommendations:

To the National Highway Traffic Safety Administration:

> Incorporate motorcycles in the development of performance standards for passenger vehicle crash warning and prevention systems. (H-18-29)
>
> Incorporate motorcycles in the development of performance standards for connected vehicle-to-vehicle systems. (H-18-30)
>
> Work with the Federal Highway Administration to incorporate motorcycles in the development of performance standards for connected vehicle-to-infrastructure systems. (H-18-31)
>
> Require all new motorcycles manufactured for on-road use in the United States be equipped with antilock braking system technology. (H-18-32)
>
> Conduct or sponsor research to evaluate the effectiveness of stability control systems for motorcycles. (H-18-33)
>
> Based on the research recommended in Safety Recommendation H-18-33, develop and publish performance standards for stability control systems on motorcycles, and require systems meeting those standards on all new motorcycles manufactured for on-road use in the United States. (H-18-34)
>
> Examine the influence of alcohol and other drug use on motorcycle rider crash risk compared to that of passenger vehicle drivers, and develop guidelines to assist states in implementing evidence-based strategies and countermeasures to more effectively address substance-impaired motorcycle rider crashes. (H-18-35)
>
> Evaluate the effectiveness of state motorcycle licensing procedures for reducing motorcycle crashes, injuries, and fatalities among novice and unlicensed riders; based on the results of that evaluation, update the *Guidelines for Motorcycle Operator Licensing* or other guidance as appropriate. (H-18-36)

To the Federal Highway Administration:

> Work with the National Highway Traffic Safety Administration to incorporate motorcycles in the development of performance standards for connected vehicle-to-infrastructure systems. (H-18-37)

To the Motorcycle Industry Council, the American Motorcyclist Association, and the Motorcycle Safety Foundation:

> Inform your members about the findings of this safety report, and promote the safety benefits of advanced motorcycle antilock braking and stability control technologies. (H-18-38)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

ROBERT L. SUMWALT, III Chairman	**EARL F. WEENER** Member
BRUCE LANDSBERG Vice Chairman	**T. BELLA DINH-ZARR** Member
	JENNIFER HOMENDY Member

Adopted: September 11, 2018

Vice Chairman Bruce Landsberg filed the following concurring statement on September 14, 2018, and was joined by Chairman Sumwalt and Member Weener.

Member T. Bella Dinh-Zarr filed the following concurring statement on September 18, 2018, and was joined by Chairman Sumwalt, Vice Chairman Landsberg, and Members Weener and Homendy.

Board Member Statements

Vice Chairman Bruce Landsberg
Concurring Statement – Motorcycle Study

I concur with the findings of the report but would like to suggest additional study on the efficacy of enhanced conspicuity for motorcycles.

While antilock braking and enhanced stability can save thousands of lives in the years ahead, their lifesaving benefits are limited only to the riders of newly manufactured motorcycles leaving the vast majority of current riders unaffected.

It was also noted that the reaction times by riders to an emergency event averaged only a few seconds, which in many cases is insufficient to avoid a crash. Greater motorcycle conspicuity, however, has the potential to offer safety enhancements to all riders, including the many who will continue to own and operate bikes that are not equipped with the aforementioned advanced technological systems.

With brighter and more noticeable running lights, drivers of other vehicles will be much more likely to see motorcycles, reducing the number of crashes in which the lack of visibility is a contributing factor. Although the 2016 Motorcycle Crash Causation Study did not find that running lights were particularly effective, there is continuing innovation with new products using LEDS, color, and random flashing sequences that may offer safety benefits to today’s riders.

In order to provide riders with a greater range of options to lower their chances of being in a lack-of-conspicuity type of crash, there should be a comprehensive evaluation of running light configurations. This evaluation should then be used to create a consensus on standards.

If clear benefits can be established, these devices should be made available to riders of both new and existing motorcycles. Relatively low acquisition costs and reduced installation complexity could make this highly attractive to manufacturers, riders and their insurance companies.

In summary, reducing the risk of vehicle encroachment and lack-of-visibility types of crashes will provide all riders, including those operating motorcycles without the advanced technology, with a greater margin of safety.

Safety Report: Select Risk Factors Associated with Causes of Motorcycle Crashes (DCA18SS001)

Board Member T. Bella Dinh-Zarr, Concurring:

I appreciate the careful thought that went into this safety report and I concur with its findings. But, it is important to add a note of caution. Sometimes, in our efforts to be highly precise and focused on a study topic, such as crash causation, we inadvertently minimize the easiest and most straightforward solution that can save lives and prevent injuries. In the case of deaths and injuries resulting from motorcycle crashes, that straightforward solution is a requirement that all riders properly wear a helmet that meets federal safety standards. Helmet use is not the only topic we should highlight when we discuss motorcycle safety, but it certainly is an essential one. Helmets for motorcycles are like seatbelts for cars – they are the most important tools we have to prevent large numbers of deaths and injuries in a crash.

This report is about crash *causation* and it is useful because it analyzes the current evidence and provides safety recommendations to prevent motorcycle crashes from occurring. It identifies gaps in our knowledge related to important crash prevention measures such as stability control, motorcycle licensing systems and the role of alcohol and other drugs in motorcycle crashes. It drives home the important point that safety equipment such as ABS should be standard equipment on motorcycles and that safety should not be an optional luxury feature. Likewise, helmets should be considered standard equipment for every motorcycle rider.

This isn't such a farfetched concept.

In the early 1970's, 47 States and the District of Columbia had universal helmet laws. Currently, however, the majority of states do not require all riders to wear helmets that meet Federal safety standards, even though the evidence that helmet laws increase helmet use, prevent traumatic brain injuries, and save lives, has only increased in recent decades. What happened? Federal sanctions on states without adequate helmet laws were repealed in 1976 and states began repealing helmet laws. States today continue to debate helmet laws, not for their lifesaving potential or even their economic benefit (the evidence is solid on both), but for their political feasibility.

In September 2006, NTSB held a public forum to gather information about ongoing motorcycle safety research and initiatives, as well as safety countermeasures that may reduce the likelihood of motorcycle accidents and fatalities. The forum covered a variety of motorcycle safety issues including trends and safety statistics, vehicle design, rider protective equipment, training and licensing, public education and awareness, and rider impairment. Participants in the forum included representatives from Government agencies, motorcycle manufacturers, motorcyclist associations, state motorcycle rights organizations, law enforcement, and insurance companies. Researchers and trauma physicians also participated on the panels. As a result, in 2007, the NTSB recommended that all U.S. States and Territories adopt universal motorcycle helmet use requirements. NTSB reviewed an extensive body of motorcycle research published over the last 40 years. The data clearly show that head injury is a leading cause of death in motorcycle accidents and helmet use is the most effective countermeasure for preventing serious head injuries and fatalities when riders are involved in a crash.

Although this report focuses specifically on the causes of crashes, rather than on the causes of injury overall, we should not shy away from emphasizing, again and again, the one solution that can work today to save motorcyclists' lives (and spare their families and communities the emotional and economic burden of preventable deaths and injuries). As a nation and as a society, we are sometimes wise enough to realize that some requirements are needed because they benefit everyone in the community. As we work on implementing the safety recommendations in this report which will help prevent motorcycle crashes from occurring in the first place, let's be wise enough to realize that requiring motorcycle riders to wear helmets will prevent deaths and injuries when a motorcycle crash *does* occur.

Appendixes

Appendix A: Past NTSB Recommendations Referenced in This Report

All NTSB recommendations referenced in this report are listed in table A-1. These recommendations, and relevant excerpts of associated correspondence exchanged to determine their status, are available via the NTSB Safety Recommendations Database. The database also provides a chart explaining all of the possible recommendation statuses.

Table A-1. Past NTSB recommendations referenced in this report.

Rec #	Recipient	Recommendation	Status (as of August 2018)
H-07-34	Federal Highway Administration	Following the 2007 Motorcycle Travel Symposium, develop guidelines for the states to use to gather accurate motorcycle registrations and motorcycle vehicle miles traveled data. The guidelines should include information on the various methods to collect registrations and vehicle miles traveled data and how these methods can be put into practice.	Closed—Acceptable Alternate Action
H-07-35	National Highway Traffic Safety Administration	Reprioritize the National Agenda for Motorcycle Safety recommendations based on objective criteria, including known safety outcomes.	Closed—Acceptable Action
H-07-36	National Highway Traffic Safety Administration	Following completion of the reprioritization of the National Agenda for Motorcycle Safety requested in Safety Recommendation H-07-35, implement an action plan for states and others, such as federal agencies, manufacturers, insurance organizations, and advocacy groups, to carry out those recommendations that are determined to be of high priority.	Closed—Acceptable Action
H-07-37	To the 50 states and the District of Columbia	Provide information to the National Highway Traffic Safety Administration (NHTSA) on the effectiveness of your motorcycle safety efforts to assist NHTSA with its effort to reprioritize the National Agenda for Motorcycle Safety recommendations.	Open—Response Received
H-07-38	To the three states with no motorcycle helmet laws	Require that all persons shall wear a Department of Transportation Federal Motor Vehicle Safety Standard 218-compliant motorcycle helmet while riding (operating), or as a passenger on any motorcycle.	Open—Unacceptable Response

Rec #	Recipient	Recommendation	Status (as of August 2018)
H-07-39	To the 27 states and 1 territory with partial motorcycle helmet laws	Amend current laws to require that all persons shall wear a Department of Transportation Federal Motor Vehicle Safety Standard 218-compliant motorcycle helmet while riding (operating), or as a passenger on any motorcycle.	Open—Unacceptable Response
H-07-40	To the 8 states, the District of Columbia, and the 4 territories with universal motorcycle helmet laws/regulations not specifically requiring FMVSS 218-compliant helmets	Amend current laws to specify that all persons shall wear a Department of Transportation Federal Motor Vehicle Safety Standard 218-compliant motorcycle helmet while riding (operating), or as a passenger on any motorcycle.	Open—Unacceptable Response
H-13-05	To the 50 US states, the District of Columbia, and the Commonwealth of Puerto Rico	Establish a per se blood alcohol concentration (BAC) limit of 0.05 or lower for all drivers who are not already required to adhere to lower BAC limits.	Open—Await Response
H-13-30	To the National Highway Traffic Safety Administration	Develop minimum performance standards for connected vehicle technology for all highway vehicles.	Open—Unacceptable Response
H-13-31	To the National Highway Traffic Safety Administration	Once minimum performance standards for connected vehicle technology are developed, require this technology to be installed on all newly manufactured highway vehicles.	Open—Unacceptable Response

Appendix B: Calculation of Matched-Pair Odds Ratio Estimates

In this report, motorcycle crash risk factors were analyzed and interpreted using matched-pair odds ratio estimates. Each crash and control pair was assessed based on the presence of a given factor for the crash-involved motorcycle and its matched control motorcycle. The discordant pairs (that is, when one member of the pair had the factor and the other did not) provided the basis for the estimates of risk. The following illustration and formula explain how the estimates were computed:

		Control motorcycle	
		Factor present	**Factor not present**
Crash motorcycle	**Factor present**	a	b
	Factor not present	c	d

The a, b, c, and d in the above illustration represented the number of matched pairs with or without the factor being analyzed. The odds ratio (OR) estimate was then computed as follows:

OR = b/c

95% confidence interval is $e^{\log(OR)\pm 1.96 se[\log(OR)]}$

se[log(OR)] = $\sqrt{\frac{1}{b}+\frac{1}{c}}$

Appendix C: *MCCS* Crash Case Narratives

MCCS crash case narratives from selected cases are included here to provide more in-depth case studies related to many of the safety issues addressed in this report.

Case Number: 0087

Crash Type: Single vehicle

Crash Configuration: Motorcycle running off roadway; no other vehicle involvement.

Environmental Characteristics: The crash occurred in April 2012 at 11:36 p.m. in Southern California. The weather conditions were clear, and the winds were calm. The temperature was about 53˚F. The roadway was an asphalt material, and it appeared dry, new, and in good condition. The area was illuminated by overhead street lights that were on at the time of the crash. The surrounding area consisted of a high density, single-family residential gated community. The roadways in the community were two-way roadways with no markings. Parking was allowed on one side of the street. The speed limit was 25 mph.

Description of Crash: A 2012 Yamaha FZ 6R (600 cc) sport, race replica motorcycle, operated by a 20-year-old male; he had just purchased the motorcycle earlier in the day. He had gone to a friend's house to show off the motorcycle. The motorcycle rider was facing east, and he was stopped, talking with friends. He then rapidly accelerated, raising the front tire off the ground, and lost control of the motorcycle. The tire marks indicated that the motorcycle made a wide turn to the right, crossed the non-marked centerline, and struck a curb with the left front of the front tire. The rider was dragging at least one foot. The motorcycle mounted the curb and continued in an easterly direction across a driveway, paralleling a car garage door. The motorcycle and rider contacted the garage door. The rider brushed against the garage door with his jacket and helmet, leaving color transfer. The rider then impacted the garage door frame support (head first) causing fatal injuries; he was pronounced dead at the scene by paramedics. The motorcycle rider showed no signs of impairment, and the autopsy revealed no alcohol or other drugs in his system.

Crash Causation: Human error; a reaction failure on the part of the Yamaha FZ 6R motorcycle rider.

Case Number: 0140

Crash Type: Single vehicle

Crash Configuration: Motorcycle falling on roadway; no other vehicle involvement.

Environmental Characteristics: The crash occurred in September 2012 at 10:45 p.m. in Southern California. The weather conditions were clear, and the winds were calm. The temperature was about 69˚F. The roadway was asphalt, dry, and travel worn. The crash occurred on an east-west, uphill right curve on a six-lane principal city street in a residential area of single-family homes. Traffic was controlled by upright and overhanging traffic signals. The posted speed limit was 45 mph.

Description of Crash: A 2004 Honda CBR 600RR (599 cc) sport, race replica motorcycle, operated by a 27-year-old male, was traveling eastbound and stopped in the second lane waiting for the traffic signal to turn green. The motorcycle rider reported that he felt an epileptic seizure coming on. Witnesses observed him riding erratically before he stopped at the signal. After pulling away from the intersection, the rider veered left and struck a raised center median, at which point he was ejected from the motorcycle. The rider was transported to a local hospital where he was treated for his injuries and released. The rider had an epileptic seizure and sustained abrasions from his left shoulder to just above his wrist and minor abrasions to his left knee. The rider had taken antiseizure drugs prior to the crash and had smoked marijuana in the previous 24 hours.

Crash Causation: Human error; a decision failure on the part of the Honda CBR 600RR motorcycle rider. Additional factors included drug involvement (the rider was smoking marijuana while taking carbamazepine to control his seizures) and the unsafe act of continuing to ride the motorcycle after experiencing the onset of an epileptic seizure.

Case Number: 0261

Crash Type: Multiple vehicle

Crash Configuration: Motorcycle falling on roadway during collision avoidance with another vehicle.

Environmental Characteristics: The crash occurred in September 2013 at 7:44 p.m. in Southern California. The weather conditions were partly cloudy, with light winds from the south-southwest. The temperature was about 67˚F. The roadway was an asphalt composition, and it appeared worn and polished with a few repair areas, but otherwise in good condition. The traffic conditions were moderate. Both sides of the roadway had commercial businesses. There were no permanent visual obstructions, and the posted speed limit was 40 mph.

Description of Crash: A 2012 Royal Enfield Bullet Classic 500 (499 cc) motorcycle, operated by a 21-year-old female, was traveling eastbound with the flow of traffic about 40 mph, when a 2005 Chevrolet Trailblazer SUV made a lane change into the motorcycle's lane of travel and cut off the motorcycle. When the SUV driver suddenly made the lane change, the motorcycle rider attempted collision avoidance, over braked, locked up the rear wheel, and experienced a low side slide out on the right side. There was no contact between the motorcycle and the SUV. The 42-year-old female driver of the SUV said that she put on her turn signal and made a lane change and never saw the motorcycle or rider. A witness stated that the SUV made a quick lane change without proper clearance and cut off the motorcycle. The motorcycle rider said that the SUV driver did not signal the lane change. The motorcycle rider was taken to a local hospital where she was admitted for 4 days.

Crash Causation: Human error; a perception failure on part of the Chevrolet Trailblazer SUV driver.

Case Number: 0309

Crash Type: Multiple vehicle

Crash Configuration: Passenger vehicle impacting rear of motorcycle.

Environmental Characteristics: The crash occurred in February 2014 at 6:34 p.m. in Southern California. The weather conditions were clear with a light breeze from the south-southeast. The temperature was about 59˚F. The roadway was made of an asphalt composition, and it appeared worn and polished but otherwise in good condition. The roadway was a non-freeway minor arterial, with two through lanes in each direction and divided by solid double yellow lines. The crash occurred at an at-grade, four-way intersection with no signal controls or dedicated left turn lanes. Single-family residences were on both sides of the roadway. Visibility was clear and unrestricted from the crest of the roadway to the crash site. On-street parking was allowed, and the posted speed limit was 40 mph. The area was lit with overhead street lights that were illuminated at the time of the crash. Traffic conditions were light.

Description of Crash: A 2005 Honda CBR 600 RR (599 cc) sport, race replica motorcycle, operated by a 25-year-old male, was stopped (with the left turn signal on) and waiting to make a left turn at an uncontrolled intersection with no left turn lane. The motorcycle was rear-ended by a 2002 Honda CR-V passenger car operated by a 33-year-old male. There were no permanent visual obstructions that were considered to be contributory to the crash. The motorcycle rider stated that he was waiting for traffic to clear in the southbound direction so that he could make a left turn when he was hit from behind. He stated that the impact fully ejected him forward off his motorcycle. The car driver stated that he was traveling northbound about 30 mph and was conversing with his passenger over electronic directions to get home. He stated that he was not paying attention to traffic around him and collided with an unknown vehicle in front of him. When he looked forward, he saw the motorcycle and had no idea where it came from. The left front of the car impacted the rear of the motorcycle. The motorcycle was pushed forward about 31 feet before going down on its left side. The car left about 26 feet of right front locked-wheel skid (about 9 feet of this skid was pre-impact). There was about 11 feet of locked-wheel skid associated with the car’s left front tire, which started post-impact. The car was not equipped with ABS brakes. The motorcycle rider’s helmet remained in place and went to the hospital with the rider. The rider sustained moderate upper extremity injuries.

Crash Causation: Human error; a perception failure on the part of the Honda CR-V driver.

Case Number: 0488

Crash Type: Multiple vehicle

Crash Configuration: Other vehicle turning left in front of a motorcycle; motorcycle proceeding in either direction perpendicular to the path of the other vehicle.

Environmental Characteristics: The crash occurred in August 2015 at 6:52 p.m. in Southern California. The weather conditions were clear, with light winds from the west. The temperature was about 70˚F. The asphalt roadway surface was dry and noted to be in good condition, and there was light traffic. The crash occurred at a T intersection in a residential area bordered by apartments on the north side, and single-family homes on the south. The eastbound roadway was divided by a raised center median planted with shrubs and trees. The speed limit in the area was 45 mph.

Description of Crash: A 2006 Yamaha FZ6 (599 cc) motorcycle, operated by a 16-year-old male, was traveling eastbound approaching the T intersection about 45 mph. A 1993 Honda Civic LX, operated by a 20-year-old male, was westbound in the left turn lane at the intersection. The car entered the intersection, crossing the eastbound lanes traveling about 17 mph, and was struck in the right front wheel/fender area by the motorcycle. The motorcycle struck the car after braking hard and leaving an about 137-foot dry pavement skid. The rider of the motorcycle was ejected over the hood of the car and onto the roadway. The car driver failed to perceive the approaching motorcycle before entering the intersection. The motorcycle's speed was higher than what was safe for the situation, and his evasive maneuver was not properly executed. The motorcycle rider sustained the following injuries according to the police report: a fractured knee, bilateral leg abrasions, and abrasions to the right foot.

Crash Causation: Human error; a perception failure on the part of the Honda Civic LX driver.

Appendix D: *MCCS* Risk Factors and the Hurt Report

As part of the exploratory research and data analysis phase of this report, the NTSB conducted a side-by-side review of the 351 crash cases from the 2016 *MCCS* and the 900 crash cases studied in the 1981 Hurt Report focusing on data related to motorcycle riders, motorcycles, and general crash characteristics. This appendix provides a detailed summary of that review.

Rider age and inexperience accounted for much of the crash risk in both the *MCCS* and the Hurt Report. As shown in figure D-1, riders under 30 and over 50 years of age were overrepresented in the crashes studied in the Hurt Report. For the *MCCS*, riders under 30 were overrepresented in crashes, while the 30 to 50 group and the over 50 group were both underrepresented. The median age of the *MCCS* riders involved in crashes was older than those of the Hurt Report by almost 7 years.

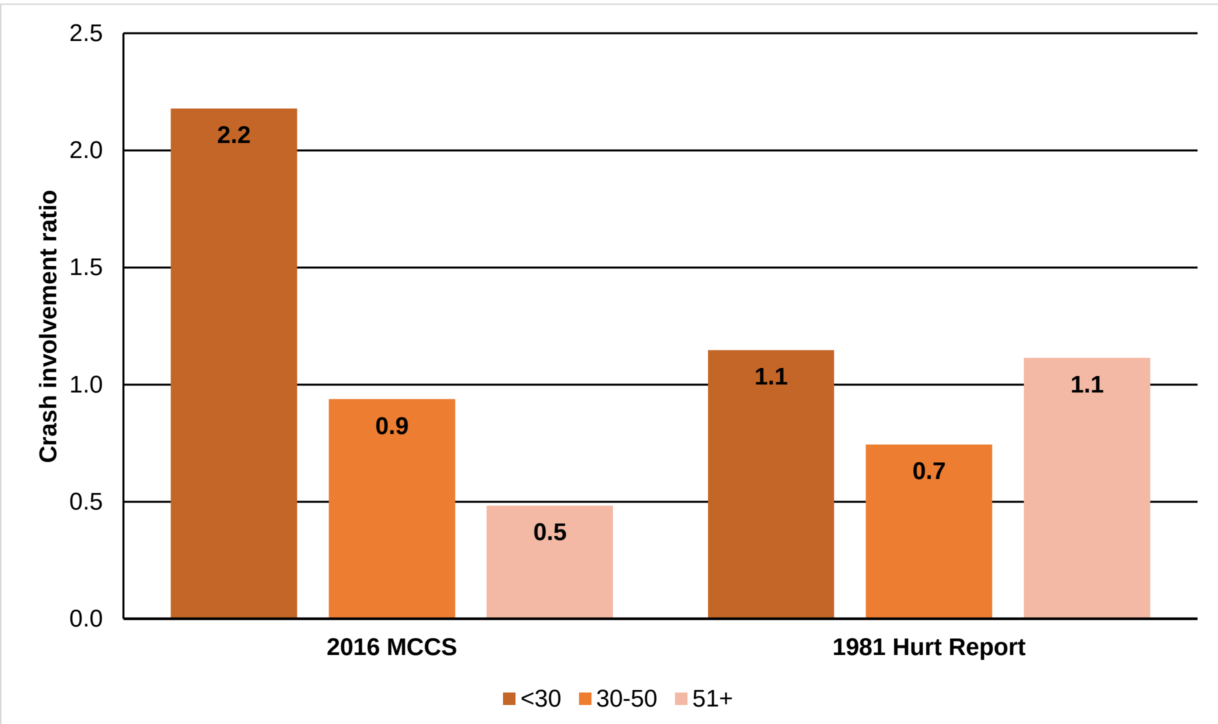

Figure D-1. Crash involvement by rider age groups for the *MCCS* and the Hurt Report.

More than half of the crash-involved riders in the Hurt Report had 6 months or less of familiarity on the motorcycle they were riding at the time of the crash. In comparison, about one-third of the *MCCS* riders had less than 6 months experience on the crash-involved motorcycle, and about one-quarter had less than 2 years of total on-road motorcycle experience. Trips were more likely to be shorter and not far from the trip's origin for crash-involved riders in both the Hurt Report and the *MCCS*. Transportation appeared to be the dominant use pattern for riders in both studies. The mobility benefits of motorcycles appear to be continuing to make them an attractive option for daily commuting. This may be the case more so for urban areas where there is often increased roadway congestion and more parking restrictions.

Motorcycle types, such as the sport, race replica, could not be compared between the *MCCS* and the Hurt Report. In general, about one-quarter of the *MCCS* riders on sport, race replica motorcycles had only been operating the crash-involved motorcycle for 2 months or less, and for many of them it was their first time ever operating the motorcycle. There did not appear to be an equivalent motorcycle type in the Hurt Report for comparison with the sport, race replicas in the *MCCS*.

The *MCCS* and the Hurt Report had similar crash type distributions. In both studies, the majority of the motorcycle crashes involved a collision with another motor vehicle, and about a quarter were single-vehicle crashes involving a motorcycle striking the roadway or some roadside fixed object. The *MCCS* crashes were distributed more on Saturdays and Sundays compared to those studied in the Hurt Report. Almost half of the fatal crashes in the Hurt Report involved alcohol. The *MCCS* data on alcohol and other drug use did not support a comparison with the Hurt Report. Riders with a record of previous moving traffic violation convictions were overrepresented in both the Hurt Report and the *MCCS*.

Rider and motorcycle conspicuity were critical factors in the multiple-vehicle crashes in both studies. The Hurt Report found that the use of high-visibility yellow, orange, or bright red jackets reduced crash involvement. These garments were also present among the *MCCS* riders; however, there did not appear to be as significant a difference between the crash and control groups compared to the Hurt Report. In addition, most of the *MCCS* motorcycles had headlights that were illuminated both day and night, unlike the motorcycles studied in the Hurt Report. Daytime running headlights have become a standard feature on motorcycles today, largely due to the findings of the Hurt Report.

For the multiple-vehicle crashes studied in the Hurt Report, the driver of the other motor vehicle violated the motorcycle's right-of-way and caused the accident in about two-thirds of those crashes. The other vehicle driver's failure to detect and recognize the motorcycle in the traffic environment were among the leading causes of these crashes. The *MCCS* multiple-vehicle crashes attributed to human error were divided more evenly between the other vehicle driver and the motorcycle rider. However, perception failures, in which the other vehicle driver failed to detect a dangerous condition or the motorcycle rider, remained the most common primary contributing factor in crashes, overall. The precrash median travel speed of crash-involved riders in the *MCCS* exceeded that of the riders in the Hurt Report.

The most frequent crash configuration in the Hurt Report involved a motorcycle proceeding straight and another vehicle making a left turn across the path of the motorcycle. This was also the most frequent crash configuration in the *MCCS*. Intersections were the most likely place for crashes in both studies and non-intersections were the most likely place for fatalities. Many of the Hurt Report riders exhibited significant collision avoidance problems. A frequently documented problem involved a slide out and fall onto the roadway due to inappropriate braking. In single-vehicle crashes, motorcycle rider error was more likely to involve running wide on a curve due to speed or under cornering. The Hurt Report also noted that riders lacked effective swerving and counter steering abilities. Many of these general crash characteristics, and the collision avoidance performance difficulties, were similar to the findings in the *MCCS* data.

Nearly a quarter of the crash-involved riders in both studies did not have a valid motorcycle license at the time of their crash. Participation in formal motorcycle safety training, however, was markedly different between the *MCCS* and the Hurt Report. Most of the riders in the Hurt Report were self-taught or learned how to ride a motorcycle from family or friends. In the *MCCS* data, very few riders were self-taught or taught by family or friends, and the majority had completed at least one motorcycle safety course. This is likely due to an increase in the availability of formal motorcycle safety training courses for riders in 2011 to 2015, compared to the late 1970s.

As shown in table D-1, about 34% of *MCCS* riders had formal motorcycle safety training, compared to about 7% of those studied in the Hurt Report. Informal types of training were associated more with riders in the Hurt Report. For example, nearly half (44%) were self-taught, and another third (38%) reported learning from a family member or a friend.

Table D-1. Types of motorcycle training reported by riders in the *MCCS* and the Hurt Report.

Training type	2016 *MCCS*		1981 Hurt Report	
	Number	%	Number	%
Formal training course	119	33.9	61	6.8
Self-taught	56	16.0	400	44.4
Family, friends	12	3.4	343	38.2
Other	2	0.6	4	0.4
Unknown	162	46.1	92	10.2
Total	**351**	**100.0**	**900**	**100.0**

About two-thirds of crash-involved riders in the *MCCS* attempted to take evasive action before the crash, but only a small proportion of them were able to execute the maneuver successfully. No evasive action was taken by nearly a third of the riders in the *MCCS* and the Hurt Report (see tables D-2 and D-3). Among riders that attempted an evasive action, there were no significant performance differences between riders with formal training and those with informal training. Although the most frequently cited evasive action in both studies was braking, the proportion of *MCCS* riders that chose to use the brakes (54%) was greater compared to riders from the Hurt Report (36%).

Table D-2. Evasive action by motorcycle rider training based on 2016 *MCCS* data.

Evasive action	No formal training		Formal training		Total	
	n	%	n	%	n	%
No action taken	16	25.0	28	23.8	101	31.5
Braking	38	59.4	71	60.2	174	54.2
Swerving	4	6.2	17	14.4	34	10.6
Accelerating	1	1.6	1	0.8	2	0.6
Lay down and slide	--	--	--	--	1	0.3
All other	5	7.8	1	0.8	9	2.8
Total	**64**	**100**	**118**	**100**	**321**	**100**

Table D-3. Evasive action by motorcycle rider training based on 1981 Hurt Report data.

Evasive action	No formal training		Formal training		Total	
	n	%	n	%	n	%
No action taken	226	30.8	21	34.4	283	31.9
Braking	276	37.7	22	36.1	322	36.3
Swerving	59	8.0	6	9.8	74	8.4
Accelerating	7	1.0	--	--	8	0.9
Lay down and slide	6	0.8	1	1.6	8	0.9
All other	159	21.7	11	18.1	191	21.6
Total	**733**	**100**	**61**	**100**	**886**	**100**

The evasive actions taken by the crash-involved riders from both studies were compared to examine whether their action was the proper choice for the situation and whether the chosen action was properly executed. Table D-4 presents these data for riders that attempted to take evasive action before their crash. In both studies, the riders most often chose an appropriate evasive action for the situation but failed to execute it effectively.

For the *MCCS* riders, about 67% of riders with formal training and 60% without formal training chose an appropriate evasive action for the situation. About 28% of *MCCS* riders with formal training and 32% without formal training were able to properly carry out the evasive action they chose. Finally, 24% of the *MCCS* riders with formal training chose an appropriate evasive action for the situation *and* properly carried out that action to completion. This was a slightly higher percentage compared to the *MCCS* riders without training (about 21%). The Hurt Report riders (with or without training) had lower percentages of success choosing and carrying out an appropriate evasive action for the situation compared to the *MCCS*.

Table D-4. Collision avoidance performance for riders in the *MCCS* and the Hurt Report.

Choice	Execution							
	2016 *MCCS*				1981 Hurt Report			
	No formal training (n=43)		Formal training (n=79)		No formal training (n=485)		Formal training (n=38)	
	Improper	Proper	Improper	Proper	Improper	Proper	Improper	Proper
Improper	27.9%	11.6%	29.1%	3.8%	26.8%	18.6%	28.9%	18.4%
Proper	39.5%	20.9%	43.0%	24.1%	49.9%	4.7%	47.4%	5.3%

Table D-5 compares loss-of-control type for riders with informal and formal training from the *MCCS* and the Hurt Report. More than half of the riders in both studies that chose and executed an evasive action before crash impact managed to perform the action without losing control of the motorcycle. The *MCCS* riders with formal training were somewhat more likely than those without formal training to maintain control. The Hurt Report riders without formal training were slightly more likely to maintain control of the motorcycle than those with training.

In both studies, the most common loss of control reported by riders attempting an evasive action was a braking-related slide out, which accounted for about 50% of these cases in the *MCCS* and 66% in the Hurt Report. Although the *MCCS* riders chose to use the brakes more than riders in the Hurt Report (54% compared to 36%; see tables D-2 and D-3), they were involved in slide outs less often (50% compared to 66%; see table D-5).

The median time from the precipitating event to crash impact was 2.1 seconds in the *MCCS* data and 1.9 seconds in the Hurt Report.[61] Figure D-2 overlays the data from the two studies and shows that about 75% of the *MCCS* riders had 3 seconds or less from precipitating event to crash impact, compared to more than 90% of those from the Hurt Report. About 10% of *MCCS* riders had more than 4 seconds available compared to less than 1% of riders from the Hurt Report.

In general, the cumulative percent distributions for both studies indicated a short amount of time available for evasive action in most crashes. At an initial travel speed of 45 mph (the most common posted speed limit in the *MCCS*), the rider traveled more than 65 feet in the first second that it took the rider to detect and recognize the crash risk, decide what evasive action to take, and provide the first input to the motorcycle's controls.

[61] The number of seconds between the event that precipitated the crash and crash impact was estimated (based on rider interview data and investigator judgment after crash scene reconstruction) for each crash in the *MCCS* and the Hurt Report.

Table D-5. Loss-of-control type by rider training in the *MCCS* and the Hurt Report.

Loss of control	2016 *MCCS*				1981 Hurt Report			
	No formal training		Formal training		No formal training		Formal training	
	n	%	n	%	n	%	n	%
No loss of control	35	51.5	79	66.9	305	60.2	22	55.0
Capsized or fell over	2	2.9	6	5.2	13	2.6	1	2.5
Braking slide out—low side	15	22.1	13	11.0	138	27.1	12	30.0
Braking slide out—high side	6	8.8	10	8.5	9	1.8	3	7.5
Wide on turn, ran off road	2	2.9	1	0.8	38	7.5	1	2.5
Other	8	11.8	9	7.6	4	0.8	1	2.5
Total	**68**	**100**	**118**	**100**	**507**	**100**	**40**	**100**

Any delay in the rider's detection or reaction increases the distance required for a safe stop and may exhaust all reasonable opportunity for a successful evasive maneuver. Many of the riders in the *MCCS* and the Hurt Report never attempted a maneuver between the precipitating event and crash impact. As shown in figure D-2, it is reasonable to suggest that inadequate time available was a factor in at least a quarter of the crashes.

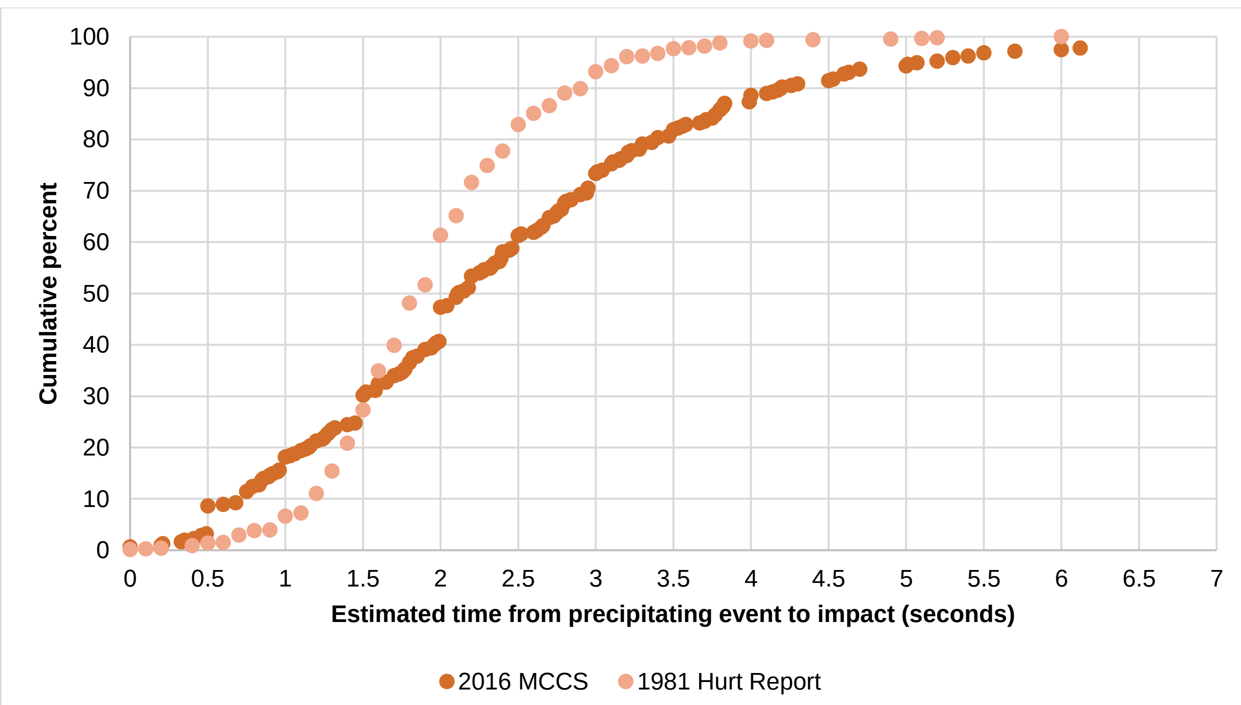

Figure D-2. Estimated time from precipitating event to impact for crash-involved riders in the *MCCS* and the Hurt Report.

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