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Pre-Crash Scenario Characteristics of Motorcycle Crashes for Crash Avoidance Research

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16. Abstract

This report defines the motorcycle crash problem based on national crash statistics using the Fatality Analysis Reporting System (FARS) and General Estimates System (GES) crash databases. Motorcycles include two- and three-wheeled motorcycles, mopeds, off-road motorcycles, mini-bikes, motor scooters, and pocket motorcycles. Crashes included in this study (from the FARS and GES databases) were those having at least one motorcycle involved in the critical event of the crash. This report identifies and prioritizes pre-crash scenarios based on annual harm measures. In addition, this report characterizes the priority pre-crash scenarios by vehicle role and statistical descriptions, and depicts these scenarios in terms of general kinematic equations. Pre-crash scenarios are defined and grouped based on similar motorcycle-vehicle dynamics for all crashes, and are prioritized based on fatal crash frequency, police-reported crash frequency, and comprehensive costs. Priority pre-crash scenarios include control loss, road departure, left turn across path, lane change, opposite direction, rear-end, and crossing paths crashes. The priority pre-crash scenarios are also characterized in terms of environmental conditions, vehicle role, road geometry, and other contributing factors; and are depicted in terms of the time-to-collision kinematic equations that describe the aspects of each priority pre-crash scenario. These depictions help to provide a basis to identify the information needs required for motorcycle crash avoidance applications.

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motorcycle, vehicle-to-motorcycle, pre-crash scenario, crash avoidance/mitigation systems, police-reported crashes, Fatality Analysis Reporting System, FARS, General Estimates System, GES, crash characteristics, vehicle-based communication	Document is available to the public from the National Technical Information Service, www.ntis.gov.

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List of Acronyms

AIS	Abbreviated Injury Scale
FARS	Fatality Analysis Reporting System
GES	General Estimates System
HV	heavy vehicle
LTAP/LD	left turn across path/lateral direction
LTAP/OD	left turn across path/opposite direction
LTIP	left turn into path
LV	light vehicle
LVA	lead vehicle accelerating
LVD	lead vehicle decelerating
LVM	lead vehicle moving
LVS	lead vehicle stopped
MAIDS	Motorcycle In-Depth Study
MAIS	Maximum Abbreviated Injury Scale
MC	motorcycle
MCCS	Motorcycle Crash Causation Study
RTAP	right turn across path
RTIP	right turn into path
SCP	straight crossing paths
TTC	time-to-collision
V2M	vehicle-to-motorcycle

List of Kinematic Parameters

$\boldsymbol{a_{LV}}$ acceleration of the light vehicle
$\boldsymbol{h}$ a sub-portion of an equation
$\boldsymbol{l_{LV}}$ length of the light vehicle
$\boldsymbol{l_{MC}}$ length of the motorcycle
$\boldsymbol{LV}$ light vehicle
$\boldsymbol{MC}$ motorcycle
$\boldsymbol{R_{lat}}$ latitudinal range
$\boldsymbol{R_{long}}$ longitudinal range
$\boldsymbol{r_{turn}}$ turning radius of the turning vehicle
$\boldsymbol{t_{clear}}$ time for a vehicle to clear the collision zone
$\boldsymbol{t_{reach}}$ time for a vehicle to reach the collision zone
$\boldsymbol{TTC}$ time to collision
$\boldsymbol{v_{LV}}$ speed of the light vehicle
$\boldsymbol{v_{MC}}$ speed of the motorcycle
$\boldsymbol{w_{LV}}$ width of the light vehicle
$\boldsymbol{w_{MC}}$ width of the motorcycle
$\boldsymbol{\alpha}$ degrees turned around circle at a given moment
$\boldsymbol{\theta}$ average change in heading

Executive Summary

This report quantifies the problem of motorcycle crashes and describes their characteristics to help identify intervention opportunities for crash avoidance applications. Each crash includes at least one motorcycle involved in the critical event of the crash (i.e., the circumstance that made the crash imminent). The definition of motorcycles encompasses two- and three-wheeled motorcycles, mopeds, off-road motorcycles, mini-bikes, motor scooters, and pocket motorcycles. The analysis approach consists of the following steps:

1. Define the motorcycle crash problem based on national crash statistics using available data from the Fatality Analysis Reporting System (FARS) and National Automotive Sampling System General Estimates System (GES) crash databases from 2011 to 2015.
2. Identify and prioritize pre-crash scenarios based on annual frequency of all crashes, fatal crashes, and comprehensive costs.
3. Characterize the priority pre-crash scenarios by vehicle role and provide related crash elements and statistical descriptions.
4. Express the kinematic relationships of the motorcycle and vehicle involved to depict the priority pre-crash scenarios in terms of general equations.

There are 4,649 fatal crashes involving motorcycles in the critical events of the crashes from the yearly average of the 2011-2015 FARS crash data. Based on 2011-2015 GES statistics, there are about 101,000 police-reported motorcycle crashes annually. The analysis of pre-crash scenarios reveals 11 priority scenarios based on the ranking of their national harm in terms of the annual frequency of fatal crashes, frequency of all crashes, and comprehensive costs. These 11 priority scenarios represent 3,779 (81 percent) fatal crashes, estimated 71,000 (70 percent) all crashes, and 79 percent of the comprehensive costs of motorcycle crashes annually.

There are 3 pre-crash scenarios that dominate motorcycle crashes based on their highest ranking in fatal crashes, all crashes, and comprehensive costs. Two of these scenarios are single-vehicle crashes including “control loss/no vehicle action” and “road edge departure/no maneuver” scenarios. These 2 pre-crash scenarios account for 37 percent of fatal crashes, 24 percent of all crashes, and 33 percent of the comprehensive costs. The third prominent pre-crash scenario is the “left turn across path, opposite direction” (LTAP/OD) scenario that involves a collision between a motorcycle and another vehicle. The LTAP/OD scenario accounts for 13 percent of fatal crashes, 9 percent of all crashes, and 12 percent of the comprehensive costs.

In addition to the three prominent pre-crash scenarios mentioned above, this report identifies 8 two-vehicle pre-crash scenarios that are amenable to vehicle-based and connected motorcycle-vehicle crash avoidance applications. Tables ES1 and ES2 list the 11 priority scenarios and provide their relative frequency in terms of fatal crashes (FARS) and all crashes (GES), respectively. In rear-end crash scenarios, the majority of fatal crashes (over 75 percent) involve motorcycles striking other vehicles. Also, very high percentages of fatal crashes occur when motorcyclists are drifting into vehicles going in the opposite direction, as opposed to other vehicles drifting into the motorcycles. These crashes happen more often on curved roads than on straight roads.

Finally, the statistical description and kinematic depiction of the most common motorcycle pre-crash scenarios provide the foundation for the research and development of effective crash countermeasure applications.

Table ES1. Priority Pre-Crash Scenarios for Fatal Motorcycle Crashes

Group	Priority Pre-Crash Scenario	FARS %*
Single-Vehicle Crashes		
Road Departure	Road Edge Depature/No Maneuver	24%
Control Loss	Control Loss/No Vehicle Action	13%
Two-Vehicle Crashes		
Left Turn Across Path, Opposite Direction	Left Turn Across Path, Opposite Direction	13%
Lateral Crossing Paths	Straight Crossing Paths	13%
	Left Turn Across Path, Lateral Direction	
Rear End	Lead Vehicle Stopped	8%
	Lead Vehicle Decelerating	
	Lead Vehicle Moving	
Lane Change	Changing Lanes, Same Direction	5%
	Turning, Same Direction	
Opposite Direction	Opposite Direction, No Maneuver	6%
	Total	81%

* *Percent of the total crashes involving a motorcycle in the critical event of the crash. Data from average of 2011-2015 Fatality Analysis Reporting System (FARS) crash data.*

Table ES2. Priority Pre-Crash Scenarios for All Motorcycle Crashes

Group	Priority Pre-Crash Scenario	GES %*
Two-Vehicle Crashes		
Rear End	Lead Vehicle Stopped	15%
	Lead Vehicle Decelerating	
	Lead Vehicle Moving	
Lateral Crossing Paths	Straight Crossing Paths	10%
	Left Turn Across Path, Lateral Direction	
Left Turn Across Path, Opposite Direction	Left Turn Across Path, Opposite Direction	9%
Lane Change	Changing Lanes, Same Direction	9%
	Turning, Same Direction	
Opposite Direction	Opposite Direction, No Maneuver	3%
Single-Vehicle Crashes		
Control Loss	Control Loss/No Vehicle Action	14%
Road Departure	Road Edge Depature/No Maneuver	10%
	Total	70%

* *Percent of the total crashes involving a motorcycle in the critical event of the crash. Data from average of 2011-2015 General Estimates System (GES) crash data.*

1 Introduction

This report defines the motorcycle crash problem based on national crash databases, as a basis for motorcycle crash avoidance research. It is important for government agencies, motorcycle manufacturers, and application developers to understand motorcycle crash dynamics in order to help prevent crashes and mitigate injuries through appropriate crash countermeasures. In addition, this crash problem definition is critical for the estimation of potential safety benefits for motorcycle crash countermeasure systems. The definition and understanding of the target crash population are the foundational steps in motorcycle crash avoidance research.

In 2015 there were over 6 million traffic crashes nationwide, resulting in 35,092 fatalities according to the National Highway Traffic Safety Administration (NCSA, 2015). Of these crashes there were 4,976 motorcyclists killed and estimated 88,000 more injured. Figure 1 provides the overall number of fatalities of all crashes and the number of fatalities involving motorcycle crashes over a 10-year period. During this period the number of total fatalities declined while the number of motorcyclist fatalities remained relatively constant, forcing the ratio of “motorcycle fatalities” to “all roadway fatalities” to rise. Although motorcycle fatalities remain a concern, current data and trends show that the number of registered motorcycles in the Nation has continued to increase while maintaining a high level of motorcycle miles traveled over the past 10 years as seen in Table 1. Table 1 shows the number of registered motorcycles and the motorcycle-miles traveled over this same period (Office of Highway Information, 2017, 2018). Figure 2 shows the motorcycle fatalities normalized by the number of registered motorcycles and by the number of motorcycle-miles traveled. The data show a decrease in motorcyclists fatality rates from 2005 to 2007, but the rates have fluctuated only slightly after that time, without a noteworthy decrease.

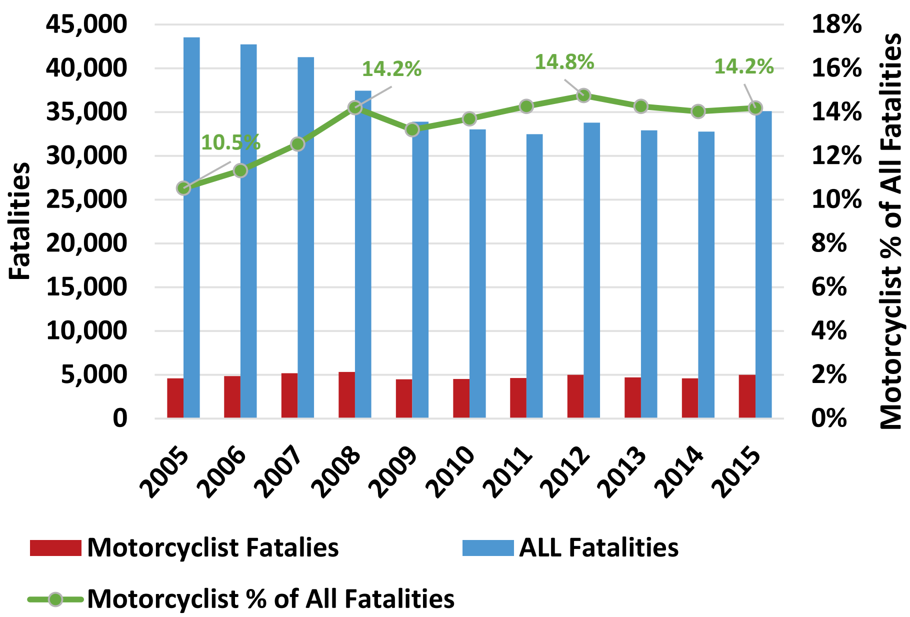

Figure 1. Statistical Trends of U.S. Motor Vehicle and Motorcycle Fatalities

Table 1. Statistics of Registered Motorcycles and Motorcycle Miles Traveled[1]

Year		
2005	6,227,146	10,454
2006	6,678,958	12,049
2007	7,138,476	21,396
2008	7,752,926	20,811
2009	7,929,724	20,822
2010	8,009,503	18,513
2011	8,437,502	18,542
2012	8,454,939	21,385
2013	8,404,687	20,366
2014	8,417,718	19,970
2015	8,600,936	19,606

*Includes private, commercial, and publicly owned motorcycles (publicly owned motorcycles may not be accurately represented since many States do not record such data.)

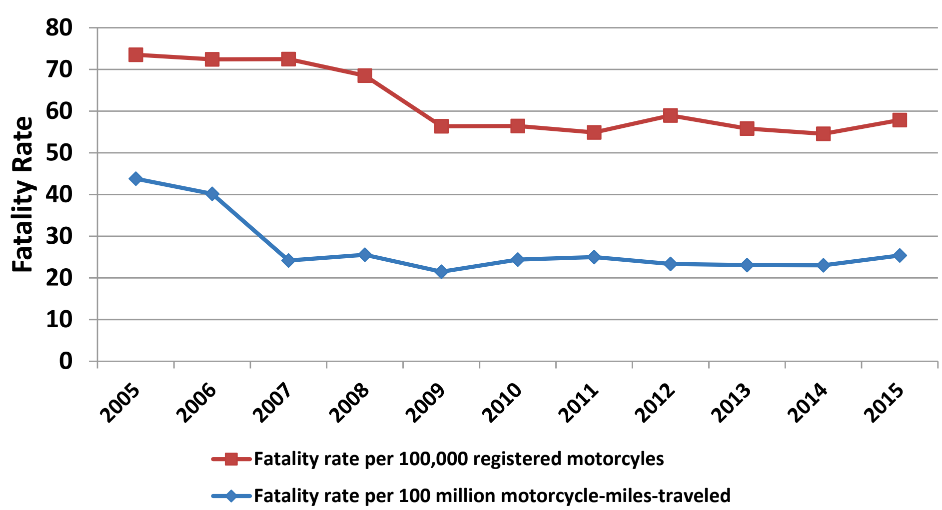

Figure 2. Motorcyclist Fatality Rates by Registered Motorcycles and Motorcycle-Miles Traveled

1 From Federal Highway Administration's "Highway Statistics Series" publications.

An initial analysis was conducted to determine the collision partner of the motorcycle (MC), if any, in the critical event of each fatal and police-reported crash. Motorcycles are the sole vehicles involved in the critical pre-crash events for 49 percent of the motorcycle fatal crashes as shown in Figure 3. These crashes typically involve motorcycles departing the road or losing control. Light vehicles (LVs) are involved with motorcycles in 44 percent of the critical pre-crash events of fatal crashes, while heavy vehicles (HVs) are involved with motorcycles in 4 percent of the crashes. The remaining body types, which amount to under 3 percent, include involvement with another motorcycle or an unknown/other vehicle involved in the pre-crash event. Similar data is presented in Figure 4 for the body types of vehicles involved in the critical pre-crash event in all motorcycle crashes.

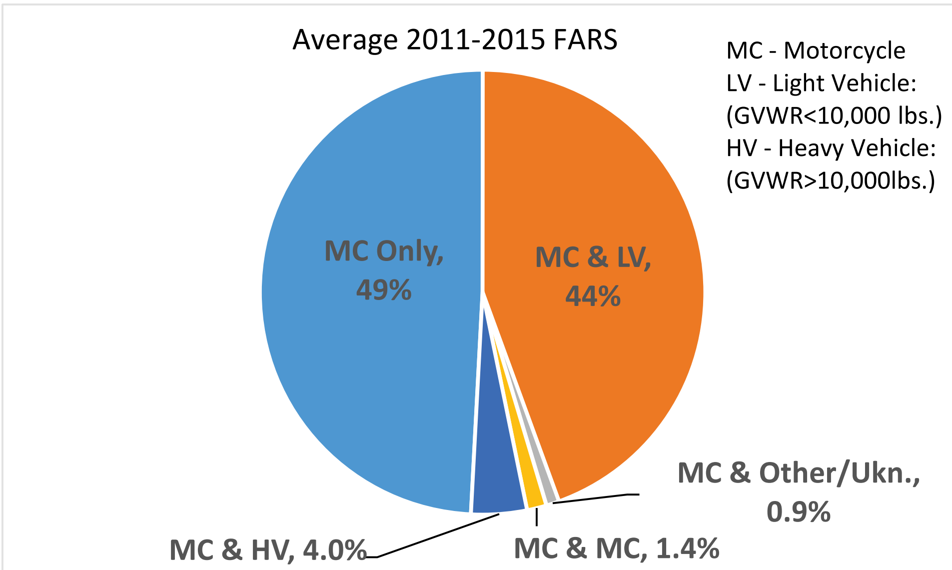

Figure 3. Vehicle Body Types Involved in the Critical Pre-Crash Event of Motorcycle Fatal Crashes

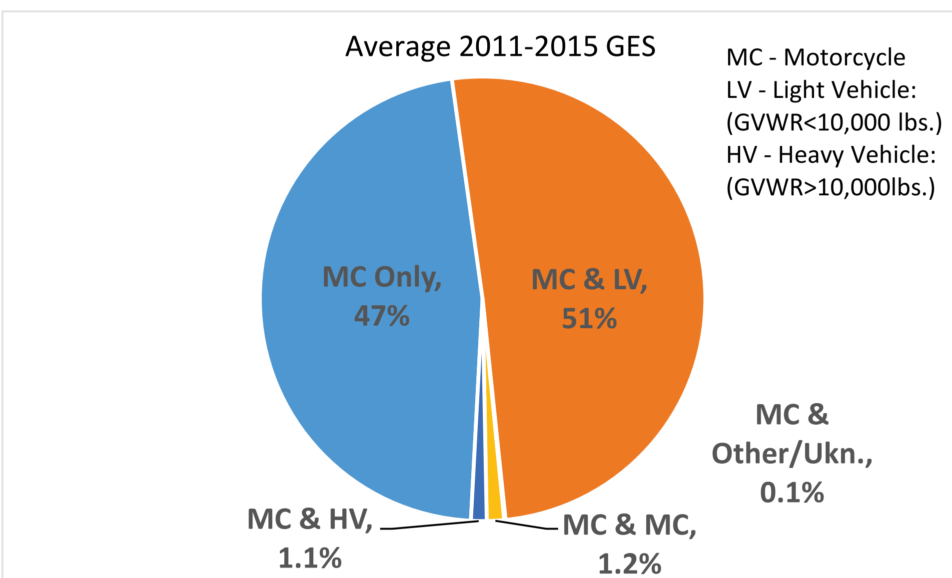

Figure 4. Vehicle Body Types Involved in the Critical Pre-Crash Event of All Motorcycle Crashes

The definition of the motorcycle crash problem yields information that researchers and developers can use to create crash avoidance and mitigation applications. The knowledge of the crash types, their frequency of occurrence, and their severity helps prioritize crash avoidance research and assess the effectiveness of crash type-specific safety applications. Moreover, the analysis of the motorcycle crash problem in terms of crash dynamics, characteristics, and conditions enables the development of effective crash avoidance technologies that could help prevent and reduce the severity of many motorcycle crashes.

1.1 Previous Motorcycle Research

Two in-depth reports relating to previous research on motorcycle crashes and related causes are described below in Sections 1.1.1 and 1.1.2. A recent study is presented in Section 1.1.3.

1.1.1 Motorcycle Crash Cause Factors and Identification of Countermeasures

A comprehensive report, the Hurt report, on motorcycle crashes was published in 1981 that analyzed motorcycle data from crashes and police reports to identify causal factors, evaluate the motorcycle safety equipment, and provide countermeasures to reduce or mitigate injury in the crashes (Hurt et al., 1981). A specialized research team conducted examinations of over 900 motorcycle crashes occurring in Los Angeles in 1976 and 1977. Numerous data elements were recorded for each crash to determine causal factors of the crash. For the same time period, over 3,600 police reports of crashes occurring in the same areas as the motorcycle crashes were reviewed for comparison. The researchers collected exposure data at crash sites related to where the motorcycle crashes occurred to closely simulate the crash conditions and locations. Additional exposure data related to equipment, rider experience, and the riding ability of the motorcyclists who were not involved in crashes at these specific sites were collected and analyzed. Comparisons of the actual crash data and the exposure data were used to identify the causal factors of the crashes and circumstances that might have contributed to the avoidance of crashes.

The type of crash that was observed most frequently was intersection crashes, particularly the left turn across path scenario, and usually involved motorcycles that were not seen by other drivers. The lack of driving ability and driving experience of motorcyclists also contributed to crashes. Findings also reported that daytime headlights were present on more of the motorcycles that were not involved in crashes. Other findings were reported related to the crash environment and other driver-, vehicle- and crash-related areas. Many changes are observed from the motorcycles included in this study to the motorcycles present on the road today (e.g., requirement of daytime running lights, improvement and availability of safety or vehicle equipment). Because of this and the fact that the Hurt study included only crashes occurring in California, the results may not compare to those presented in this study.

1.1.2 Motorcycle Accident In-Depth Study

The *Motorcycle Accident In-Depth Study (MAIDS)* was similar to the Hurt report in that its findings were based on motorcycle crashes and exposure data (ACEM, 2009). Researchers collected data on motorcycle crashes that occurred at sites in France, Germany, Italy, the Netherlands, and Spain. On-site, in-depth data of 921 motorcycle crashes was collected in 1999 and 2000 to determine the causal factors of these crashes. Exposure data were also collected in the same areas as the crashes to provide comparisons of characteristics. This involved researching vehicles in similar circumstances to the crashes, but the vehicles were not involved in crashes.

It was determined that human error, specifically due to the motorcyclist not being properly seen by the other driver, was a contributing factor to motorcycle crashes. Other factors present, such as alcohol use or unlicensed drivers, resulted in higher risks of crashes in comparison to the control group. Other conclusions were drawn relating to various crash, driver, and vehicle characteristics. Newer versions of the MAIDS report containing updated analysis have been done.[2] The latest update was in April 2009, which presented data and analysis separately for motorcycles and mopeds.

1.1.3 Motorcycle Crash Causation Study

A recent study by the Federal Highway Administration called the Motorcycle Crash Causation Study (MCCS) collected on-scene, investigative data on 351 motorcycle crashes in Orange County, California, from 2011 to 2016 (FHWA, n.d.). This effort was a comprehensive study aimed at determining crash causation factors and developing countermeasures to reduce the fatalities and injuries associated with motorcycle crashes. The study similarly included extensive police report reviews and interviews of motorcyclists for case control purposes. The data collection portion of the project was finished and a final report is pending. Preliminary results showed that 77 percent of motorcycle crashes had multiple vehicles involved and 48 percent of those crashes involved a turn by one of the vehicles. Of the crashes reported as single-vehicle crashes, 41 percent involved a road departure scenario. Related to the environment, 34 percent of the crashes were on a curve and 17 percent of the crashes occurred at driveways. Many factors related to age, rider experience, protective and safety equipment, motorcycle equipment, and other factors were recorded and can be reviewed in the future to aid in the analysis and help determine causal factors. Since this MCCS data collection was conducted in the same area as the data collection in the Hurt report, it allows for a comparison of the motorcycle crashes over time.

1.2 Approach

The scope of the work in this analysis relies on the following approach:

1. Define the motorcycle crash problem based on national crash statistics using the FARS and GES database variables (NCSA, 2016a, 2016b, 2016c).
2. Prioritize pre-crash scenarios based on annual frequency, fatalities, and comprehensive costs.
3. Select a group of pre-crash scenarios having the highest priority ranking
4. Characterize each of the selected scenarios by motorcycle and vehicle roles and provide related crash elements and statistical descriptions.
5. Express the kinematic relationship of the motorcycles and vehicles to depict the priority pre-crash scenarios in terms of general equations.

Five years of motorcycle crash data are categorized using a pre-crash typology consisting of pre-crash scenarios based on the critical pre-crash event (Najm et al., 2007)[3] The motorcycle crashes are categorized according to 36 dynamically distinct pre-crash scenarios, and the highest priority scenarios are selected for detailed analysis. The scenarios are based on vehicle movements and dynamics, and other pre-crash information. More information on the pre-crash scenarios is described later in Section 2. Motorcycle data is obtained from the FARS and GES crash databases. These are described in more detail in Section 1.3. The analysis examines all police-reported crashes involving a motorcycle in the critical event of the crash. Motorcycles include two- and three- wheeled motorcycles, mopeds, off-road motorcycles, mini-bikes, motor scooters, and pocket motorcycles. Statistical descriptions for each of the 11 pre-crash scenario groupings (e.g., environmental conditions, driver characteristics, injuries, costs) are also defined.

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[2] http://www.maids-study.eu/

[3] The circumstance that made the crash imminent

1.3 Data Sources and Limitations

Two databases, FARS and GES, are used to statically describe the motorcycle crash problem and related crash characteristics. Note the terms FARS and GES are used synonymously for "fatal crashes" and "all crashes," respectively, throughout the remainder of the report.

1.3.1 Data Sources

The FARS data is a complete census of all national crashes where each crash involves a fatal injury resulting from an in-transport motor vehicle (e.g., not parked). The fatality must have been suffered by at least one occupant of the vehicle or one nonoccupant, and must have happened as a result of the crash. Additionally, the fatality must have occurred within 30 days of the crash. A preliminary version of the FARS database, called the "annual file," is released every year when available. Subsequently, any additions and changes made to the data, particularly regarding alcohol test results and fatalities, are added and the data is released into a final version. The data in this report represents the final FARS datasets for the years 2011 to 2014. For 2015, the annual data is used.

Unlike the actual count in the FARS data, the GES crash database estimates the national crash population for each year. The data is based on a probability sample of about 50,000 police-reported crash cases that include all vehicle types and injury levels. [4] Since the GES data come directly from police reports, unreported crashes are not represented in the GES database. The GES data is projected to an estimated national level based on a weighting factor associated with each crash. The actual total number of crashes occurring on a national level might differ from the estimated values in the GES. This is because, unlike FARS, the data is based on a probability sample of police-reported crashes rather than a census of all crashes. The FARS and GES data both contain information on fatal crashes, but since GES is collected from police reports and weighted based on a probability sample, the GES fatal crash counts may differ from the FARS crash counts.

Both databases are structurally similar and contain information on environmental conditions, physical settings, and other contributing factors and circumstances. They differ since FARS is a complete census of all fatal crashes and GES is a nationally representative sampling of police-reported crashes involving any injury or at least major property damage.[5] Each database contains fatal injury information, but since FARS contains an actual fatality count, it is preferred for examining fatalities. This report uses data from 2011 to 2015 since the two databases have variables that are most compatible since 2011.[6]

1.3.2 Data Limitations

The GES data include sampling errors since it is a nationally representative data set estimated from samples of crashes (NCSA. 2016b). There also exist gaps in the data where there is no information because it is either unknown or unavailable. The database uses information taken directly from police reports. Any crashes that are unreported to law enforcement are not included in the statistics presented. The data include limitations of the police-reported data such as:

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[4] In 2013 this number was reduced to approximately 35,000 due to NHTSA budget restrictions.

[5] Crashes involving minor property damage are typically unreported. Unreported crashes are less likely to require towing and occupants involved in these crashes are less likely to require hospitalization or emergency services.

[6] For more information on the FARS and GES standardization refer to Appendix F in the National Automotive Sampling System General Estimates System Analytical User's Manual (NCSA, 2016b).

- Police reports may contain incomplete data;
- Police reports may have under-reporting of important facts, and are subject to the interpretation of the law enforcement officers or coders; and
- Many non-severe crashes are not reported to the police.

Also, the analysis in this study is independent of motorcycle body type and results could vary if analysis of the different vehicles were examined (e.g., people may drive differently on various motorcycle types and braking capabilities are different depending on the size of the vehicle).

Note that both FARS and GES contain values for fatalities. FARS represents an actual count and GES is an estimated value. The actual fatality values from FARS are used to replace the estimated values in GES when determining costs, so that there is not double-counting of fatalities.

2 Motorcycle Pre-Crash Scenarios

A pre-crash scenario typology is used to classify the total motorcycle crashes into a set of 36 pre-crash scenarios based on the motorcycle and vehicle dynamics and movements, location, and other characteristics of the crash (Najm et al., 2007). Appendix A has individual descriptions of the 36 pre-crash scenarios used in the typology shown in a prioritized order. The order of the pre-crash scenarios does not necessarily mean that a pre-crash scenario has more importance over another pre-crash scenario or that it has a higher priority for crash avoidance technology. Pre-crash scenarios involving a vehicle control loss are at the top of the list since these situations could lead to road departure, rear-end collision, opposite direction crash, etc. Each motorcycle crash is represented by only one pre-crash scenario (i.e., if a crash is categorized as a vehicle failure scenario, it is not classified again in a lower-ordered scenario like rear-end).

The pre-crash scenarios are defined by examining the critical event and the pre-crash circumstances that made the crash happen. The three key variables from the FARS and GES databases that are used to define the scenarios and their descriptions are listed below.

1. Critical event – The circumstance that made the crash imminent.
2. Pre-event movement – The action of the vehicle right before the critical event.
3. Crash type – The crash type defined by the first harmful event and pre-crash circumstances.

The pre-crash scenario definitions are enhanced based on a few other variables, such as the initial contact point on the vehicle or whether the vehicle was involved in a rollover or a hit-and-run. The sequence of events of the crash and other information (i.e., whether a second vehicle is involved) are also helpful in some scenario definitions. A motorcycle is defined using the body-type variable from FARS and GES and it includes two- and three- wheeled motorcycles, mopeds (motorized bicycles), off-road two-wheeled motorcycles, mini-bikes, motor scooters, pocket motorcycles (“pocket bikes”), and unknown motored-cycle body types.

2.1 Motorcycle Target Crashes

The FARS and GES data described in Section 1.3 are used to assess the motorcycle crash frequencies in the United States. All crashes that include an in-transport motorcycle involved in the critical event of the crash are shown in Table 2. These crashes account for an annual average of 4,649 fatal crashes and approximately 101,000 police-reported crashes for the years 2011 through 2015. This portion of crashes, which represents 99 percent of the total crashes involving a motorcycle, is the crash population used to categorize and characterize the motorcycle pre-crash scenarios presented in this report. A motorcycle crash that does not involve a motorcycle in the critical event represent a small percentage (1percent). This kind of crash includes a motorcycle involved in a later event of the crash and is not included in this report since it is difficult to assess how the crash avoidance technology could address these unique and sometimes complex situations.

Table 2. National Motorcycle Crashes

Motorcycle Crashes	Yearly Average (2011-2015)			
	Fatal Crashes		All Crashes	
Motorcycle Involved in the Critical Crash Event*	4,649	99%	101,476	99%
Motorcycle not Involved in the Critical Crash Event	47	1%	776	1%
Total Motorcycle Crashes	4,696	100%	102,252	100%

* *The event that made the crash occur.*

The distribution of motorcycle body types involved in all police-reported motorcycle crashes is shown in Figure 5. Two-wheeled motorcycles comprise the majority of these body types at 88 percent. These statistics only include motorcycles that are in-transport vehicles and they represent an annual average of the 2011 to 2015 data years.

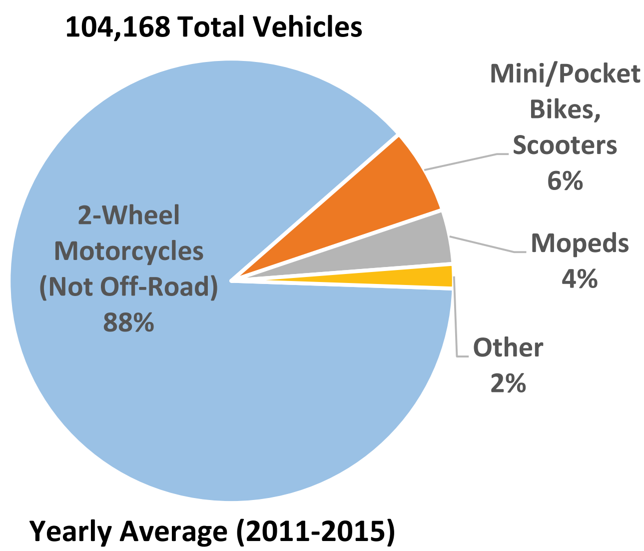


Figure 5. Distribution of Motorcycle Body Types Involved in All Police-Reported Crashes

Notes: *1. Data does not include a parked motorcycle involved in a crash.*
2. The category of "Other" includes off-road motorcycles (two-wheeled), three-wheeled motorcycles/mopeds (not all-terrain vehicles), and unknown motored-cycle types.
3. All-terrain vehicles are not included.

2.2 Priority Motorcycle Pre-Crash Scenarios

The set of 4,649 motorcycle fatal crashes and approximately 101,000 police-reported motorcycle crashes from Table 2 are separated into the distinct pre-crash scenario categories as shown in Table 3. Note that there are 41 categories listed in Table 3 since this table lists separately the sub-categories of the pre-crash scenario “other.” The sub-categories are shown below.

- Rollover
- Hit-and-run
- Other – Sideswipe
- Other – Turn into path
- Other – Turn across path

Table 3 is used to determine the priority pre-crash scenarios for potential motorcycle crash avoidance applications. It provides the rank of each pre-crash scenario according to all crashes, fatal crashes, and comprehensive costs.[7] Three pre-crash scenarios are the highest-ranked in all three measures. In order of the greatest number of crashes involving a motorcycle in the critical event, these are “control loss/no vehicle action,” “road edge departure/no maneuver,” and “left turn across path - opposite direction (LTAP/OD).” Of these 3 pre-crash scenarios, there are 2 single-vehicle pre-crash scenarios, control loss and road edge departure, which account for 24 percent of the total crashes, 37 percent of the fatal crashes, and 34 percent of the comprehensive costs.

Even though the focus of this report is on the priority pre-crash scenarios involving two-vehicle crashes, which are amenable to crash avoidance applications based on vehicle-to-motorcycle (V2M) communication technology, the characteristics of these two priority single-vehicle pre-crash scenarios are still included in Section 3.2. It should be noted that V2M and vehicle-based crash avoidance technology could potentially address these motorcycle crashes by alerting the other driver to the presence of the motorcycle, or vice versa, in situations of diminished lighting or instances where the vehicles are not visible (i.e., hills, obstructions, curves). The technology could also help to alert the other driver when a motorcycle is driving recklessly (e.g., speeding, driving between lanes) by providing timely information/actions to prevent a crash. In addition, connected vehicle-to-infrastructure technology may also help reduce motorcycle crashes by alerting motorcyclists to potential crash conditions (e.g., grooved pavement, debris or sand on the road, and curved roadways) in which a motorcycle’s handling is more complex than other vehicles that have more stability on four wheels. The infrastructure could also alert other vehicles to recognize motorcycles at intersections, or alert a motorcycle to a vehicle that intends to turn across its intended path.

The selection process for the priority pre-crash scenarios applicable to V2M technology included the highest-ranking pre-crash scenarios by crash frequency involving two vehicles. There are 9 V2M priority pre-crash scenarios involving two vehicles, as shown in Table 3, which all rank the highest in total crashes, fatal crashes, and comprehensive costs. The remaining scenarios that are not included as priority scenarios, either are made up of low percentages, are not adequately defined because of missing information, or may not be addressed by V2M technology. These were not chosen for further analysis and detailed depiction to keep the focus on those scenarios with higher percentages of crashes and costs.

[7] Comprehensive costs are based on 2010 economics and include all costs associated with medical and emergency services, lost productivity, insurance, workplace losses, legal issues, travel delays, and property damages. Intangible costs associated with lost quality of life or physical pain are also included. Details to determine the comprehensive costs can be found in Appendix B.

Table 3. Priority Pre-Crash Scenario Frequencies Ranked by All Crashes

Priority Scenarios	Motorcycle Pre-Crash Scenario	All Crashes			Fatal Crashes			Comprehensive Costs		
		Rank	Total	%	Rank	Total	%	Rank	Total	%
Single Veh. Priority	Control Loss/No Vehicle Action	1	14,181	14%	3	590	13%	2	$ 8,646,744,425	14%
	Road Edge Dep./No Maneuver	2	10,008	10%	1	1,125	24%	1	$ 12,658,964,913	20%
Multi-Vehicle Priority	Left Turn Across Path-Opposite Dir.	3	9,120	9%	2	610	13%	3	$ 7,925,033,543	12%
	Rear-End/Lead Vehicle Stopped	4	7,703	8%	8	108	2%	8	$ 2,063,557,281	3%
	Straight Crossing Paths	5	5,971	6%	4	416	9%	4	$ 5,337,429,684	8%
	Changing Lanes/Same Direction	6	5,095	5%	11	106	2%	11	$ 1,767,353,516	3%
	Rear-End/Lead Vehicle Decel.	7	5,080	5%	16	65	1%	14	$ 1,537,384,791	2%
	Evasive Maneuver/No Maneuver	8	4,803	4.7%	14	91	2%	10	$ 1,770,776,816	3%
Multi-Vehicle	Left Turn Across Path-Lateral Dir.	9	4,538	4%	7	174	4%	6	$ 2,733,839,655	4%
	Turning/Same Direction	10	4,411	4%	10	106	2%	9	$ 1,830,858,811	3%
	Control Loss/Vehicle Action	11	4,184	4%	13	92	2%	12	$ 1,674,320,036	3%
	Animal/No Maneuver	12	3,324	3%	9	108	2%	13	$ 1,574,344,614	2%
	Rollover	13	3,111	3%	12	98	2%	15	$ 1,520,984,544	2%
Multi-Vehicle Priority	Rear-End/Lead Vehicle Moving	14	2,581	3%	6	213	5%	7	$ 2,523,788,279	4%
	Opposite Direction/No Maneuver	15	2,574	3%	5	265	6%	5	$ 3,168,734,715	5%
	Drifting/Same Direction	16	1,923	1.9%	18	43	0.9%	18	$ 700,663,247	1.1%
	Road Edge Departure/Maneuver	17	1,483	1.5%	15	70	1.5%	16	$ 933,789,567	1.5%
	Vehicle Failure	18	1,429	1.4%	21	32	0.7%	19	$ 588,597,616	0.9%
	Noncollision - No Impact	19	1,067	1.1%	17	59	1.3%	17	$ 776,629,196	1.2%
	Right Turn Into Path	20	1,058	1.0%	24	24	0.5%	22	$ 426,246,565	0.7%
	Left Turn Into Path	21	941	0.9%	27	19	0.4%	26	$ 350,802,240	0.5%
	Backing into Vehicle	22	873	0.9%	29	8	0.2%	29	$ 149,528,905	0.2%
	Evasive Maneuver/Maneuver	23	816	0.8%	28	14	0.3%	28	$ 213,547,401	0.3%
	Object/No Maneuver	24	816	0.8%	26	21	0.5%	25	$ 375,487,836	0.6%
	Parking/Same Direction	25	636	0.6%	25	22	0.5%	27	$ 324,014,986	0.5%
	Rear-End/Striking Maneuver	26	628	0.6%	23	30	0.6%	24	$ 379,495,747	0.6%
	Pedestrian/No Maneuver	27	530	0.5%	22	30	0.6%	21	$ 450,725,727	0.7%
	Other	28	475	0.5%	20	37	0.8%	23	$ 412,079,290	0.6%
	Right Turn Across Path	29	383	0.4%	30	6	0.1%	31	$ 111,572,390	0.2%
	Cyclist/No Maneuver	30	363	0.4%	30	6	0.1%	30	$ 134,879,260	0.2%
	Object/Maneuver	31	307	0.3%	34	3	0.1%	33	$ 39,477,234	0.1%
	Hit and Run	32	285	0.3%	38	2	0.0%	36	$ 31,730,300	0.0%
	Opposite Direction/Maneuver	33	247	0.2%	19	41	0.9%	20	$ 477,657,908	0.7%
	Other - Turn Across Path	34	130	0.1%	36	2	0.0%	37	$ 31,436,233	0.0%
	Rear-End/Lead Vehicle Accelerating	35	109	0.1%	32	6	0.1%	32	$ 62,419,674	0.1%
	Animal/Maneuver	36	101	0.1%	35	2	0.0%	38	$ 31,130,664	0.0%
	Cyclist/Maneuver	37	79	0.1%	39	1	0.0%	35	$ 35,056,611	0.1%
	Other - Turn Into Path	38	78	0.1%	33	3	0.1%	34	$ 39,061,474	0.1%
	Pedestrian/Maneuver	39	32	0.0%	37	2	0.0%	39	$ 23,902,098	0.0%
	Road Edge Departure/Backing	40	6	0.0%	40	0	0.0%	40	$ 2,712,784	0.0%
	Other - Sideswipe	41	-	0.0%	40	0	0.0%	41	$ 1,829,200	0.0%
	Total		101,476	100%		4,649	100%		$ 63,838,589,773	100%

Based on average of 2011-2015 FARS and GES data for crashes involving an in-tranport motorcycle in the critical event of a crash.

Table 4 shows the nine priority pre-crash scenarios combined into similar groups according to the vehicle dynamics and crash types. The groups align with the vehicle technology that might potentially address the crashes involved. There are five groups:

1. Left Turn Across Path/ Opposite Direction
2. Lateral Crossing Paths
3. Rear End
4. Lane Change
5. Opposite Direction

Together, these groups account for 46 percent of all crashes, 44 percent of fatal crashes, and 45 percent of comprehensive costs. When combined with the two single-vehicle priority pre-crash scenarios, these percentages increase to 70 percent of all crashes, 81 percent of fatal crashes, and 79 percent of comprehensive costs. The focus of the remainder of the report is on the 11 priority pre-crash scenarios shown in Table 4. Individual characteristics and depictions are described for each priority pre-crash scenario. The characteristics are shown in Section 3 and the scenario depictions are shown in Section 4.

Table 4. V2M Priority Pre-Crash Scenarios

Scenario Group	Motorcycle Pre-Crash Scenario	All Crashes	%	Fatal Crashes	%	Comprehensive Costs	%
Single-Vehicle Priority Scenarios							
Control Loss	Control Loss/No Vehicle Action	14,181	14%	590	13%	$ 8,646,744,425	14%
Road Departure	Road Edge Dep./No Maneuver	10,008	10%	1,125	24%	$ 12,658,964,913	20%
	Total Single-Vehicle Priority Scenarios	24,189	24%	1,716	37%	$ 21,305,709,337	33%
Multiple-Vehicle Priority Scenarios							
LTAP/OD	Left Turn Across Path-Opposite Dir.	9,120	9%	610	13%	$ 7,925,033,543	12%
	Total LTAP/OD	9,120	9%	610	13%	$ 7,925,033,543	12%
Lateral Crossing Paths	Straight Crossing Paths	5,971	6%	416	9%	$ 5,337,429,684	8%
	Left Turn Across Path-Lateral Dir.	4,538	4%	174	4%	$ 2,733,839,655	4%
	Total Lateral Crossing Paths	10,509	10%	590	13%	$ 8,071,269,339	13%
Rear End	Rear-End/Lead Vehicle Stopped	7,703	8%	108	2%	$ 2,063,557,281	3%
	Rear-End/Lead Vehicle Decel.	5,080	5%	65	1%	$ 1,537,384,791	2%
	Rear-End/Lead Vehicle Moving	2,581	3%	213	5%	$ 2,523,788,279	4%
	Total Rear End	15,364	15%	386	8%	$ 6,124,730,351	10%
Lane Change	Changing Lanes/Same Direction	5,095	5%	106	2%	$ 1,767,353,516	3%
	Turning/Same Direction	4,411	4%	106	2%	$ 1,830,858,811	3%
	Total Lane Change	9,505	9%	213	5%	$ 3,598,212,327	6%
Opposite Direction	Opposite Direction/No Maneuver	2,574	3%	265	6%	$ 3,168,734,715	5%
	Total Opposite Direction	2,574	3%	265	6%	$ 3,168,734,715	5%
Scenario Focus	***Total Single-Vehicle Priority Scenarios***	24,189	24%	1,716	37%	$ 21,305,709,337	33%
Scenario Focus	***Total Multi-Vehicle Priority Scenarios***	47,072	46%	2,063	44%	$ 28,887,980,274	45%
Scenario Focus	***All Priority***	71,261	70%	3,779	81%	$ 50,193,689,611	79%
	Remaining Scenarios	30,215	30%	871	19%	$ 13,644,900,162	21%
	All Scenarios	101,476	100%	4,649	100%	$ 63,838,589,773	100%

Notes:

1. Based on average of 2011-2015 FARS and GES data for crashes involving an in-tranport motorcycle in the critical event of a crash.

2. Some totals may appear incorrect due to rounding.

3 Characteristics of Priority Motorcycle Pre-Crash Scenarios

A characterization of the crash circumstances and contributing factors of the 11 priority motorcycle pre-crash scenarios is done based on the 2011 to 2015 FARS and GES data. Crash characteristics are determined for all crashes where a motorcycle was involved in the critical event of the crash. These 11 pre-crash scenarios represent a total of 3,779 fatal crashes (81 percent of all motorcycle fatal crashes) and 71,261 overall crashes (70 percent of all motorcycle crashes).

The pre-crash scenarios are characterized using several variables that describe the environmental conditions, road geometry, location, and other contributing factors. The characteristics associated with these categories are listed in Table 5. Characteristics are obtained for each of the two-vehicle and single-vehicle priority pre-crash scenarios listed in Table 6.

Table 5. Pre-Crash Scenario Crash Characteristics

Category	Characteristic
Driving Environment	Atmospheric Conditions
	Lighting
	Roadway Surface Conditions
Roadway Geometry	Roadway Alignment
	Roadway Grade
Crash Location	Driveway Access
Driver Contributing Factors	Vision Obscured
	Driver Distraction
	Driver Impairment
	Driver Drinking
	Speeding Related

Table 6. Priority Pre-Crash Scenarios

Pre-Crash Scenario
Two-Vehicle Crashes
Left Turn Across Path, Opposite Direction
Left Turn Across Path, Lateral Direction
Straight Crossing Paths
Lead Vehicle Stopped
Lead Vehicle Decelerating
Lead Vehicle Moving
Opposite Direction, No Maneuver
Turning, Same Direction
Changing Lanes, Same Direction
Single-Vehicle Crashes
Control Loss/No Vehicle Action
Road Edge Depature/No Maneuver

3.1 Two-Vehicle Crashes - Priority Pre-Crash Scenario Characteristics

Nine of the priority pre-crash scenarios shown in Table 6 primarily involve two vehicles in the critical pre-crash event. Various statistics related to the driving environment, vehicle characteristics, and driver factors for these scenarios are shown in Figure 6 through Figure 14 for each vehicle according to the role of the motorcycle or the other vehicle (i.e., whether the vehicle is driving straight, turning left, striking a vehicle ahead in the lane). Note that driver-related statistics are provided individually for each driver. Definitions of the individual characteristics are presented in Appendix C.

3.1.1 Left Turn Across Path/Opposite Direction

In the LTAP/OD pre-crash scenario involving a motorcycle, there were 610 fatal crashes and slightly more than 9,100 police-reported crashes annually. According to the statistics shown in Figure 6, 95 percent of the fatal and 92 percent of all LTAP/OD crashes happen while motorcycles are traveling straight and other vehicles are turning left. Some key observations of the crashes are summarized below in terms of the vehicle role (turning or driving straight).

<u>Motorcyclist turning left and other vehicle driving straight:</u>

- Motorcyclists are reported as driver drinking in 24 percent of the fatal crashes, while drivers of other vehicles are reported as driver drinking in 6 percent of the fatal crashes.
- Nearly half of all the crashes happen in non-daylight conditions.

<u>Motorcyclist driving straight and other vehicle turning:</u>

- In 22 percent of fatal crashes, motorcyclist speed is a contributing factor. Speed is only a factor in 1 percent of the fatal crashes for the other vehicles.
- Motorcyclists are reported as drinking in 15 percent of the fatal crashes. The drivers of other vehicles are reported as drinking in 8 percent of the fatal crashes.
- The drivers of other vehicles are distracted in 8 percent of fatal crashes and in 11 percent of all crashes. In contrast, motorcyclists are distracted in only 1 percent of these crashes.
- About 39 percent of fatal crashes and 33 percent of all crashes happen during non-daylight conditions.

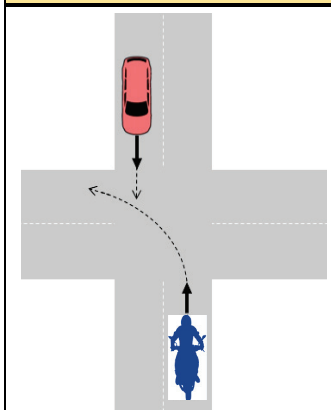
Additional observations are also presented below:

- Driver drinking is reported more frequently for motorcyclists than for drivers of the other vehicles, regardless of vehicle roles (turning or driving straight) in fatal crashes.
- Vision obstruction, distraction, or impairment are more likely associated with the drivers of the turning vehicles as compared to the vehicles driving straight, independent of body type for all crashes and fatal crashes.
- About 16 to 25 percent of the crashes occur near driveway access.[8]

[8] The portion of the traffic way at the end of a driveway. The vehicle was not on a traffic way but was entering/leaving one prior to its critical pre-crash event.

Left Turn Across Path/Opposite Direction Crashes Average 2011-2015	Total FARS	Total GES
	610	9,120

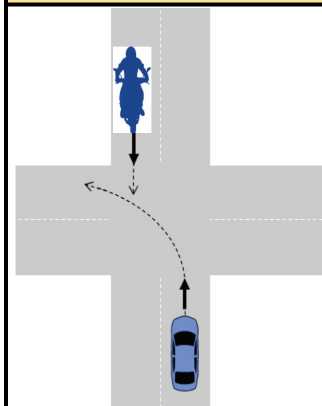
Motorcycle Turning Left



Crash Characteristics	FARS	GES
Crashes	28	765
% of Total	5%	8%
Clear Weather	96%	99%
Non-Daylight	37%	47%
Motorcyclist Fatality	96%	3%

	Motorcycle Turning Left		Other Vehicle Driving Straight	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	95%	99%	95%	99%
Not Level	10%	11%	11%	9%
Curve	5%	0%	5%	1%
Driveway Access	16%	22%	16%	22%
Known Vision Obstruction	4%	8%	2%	1%
Known Distraction	6%	2%	2%	1%
Impaired	11%	1%	7%	0%
Driver Drinking	24%	2%	6%	2%
Speed Related	1%	1%	5%	0%
Body Type*= Light Vehicle	-	-	89%	99%

Other Vehicle Turning Left



Crash Characteristics	FARS	GES
Crashes	582	8,355
% of Total	95%	92%
Clear Weather	97%	98%
Non-Daylight	39%	33%
Motorcyclist Fatality	100%	5%

	Other Vehicle Turning Left		Motorcycle Driving Straight	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	96%	95%	97%	95%
Not Level	16%	10%	17%	10%
Curve	4%	4%	4%	4%
Driveway Access	24%	25%	24%	25%
Known Vision Obstruction	6%	10%	3%	2%
Known Distraction	8%	11%	1%	1%
Impaired	8%	1%	6%	2%
Driver Drinking	8%	2%	15%	3%
Speed Related	1%	2%	22%	6%
Body Type = Light Vehicle	94%	98%	-	-

Characteristics exclude unknowns.

**Other body types not shown are medium, heavy, bus, other, and unknown.*

Figure 6. Statistical Characteristics of Left Turn Across Path/Opposite Direction Crashes

3.1.2 Left Turn Across Path/Lateral Direction

In the left turn across path/lateral direction (LTAP/LD) pre-crash scenario involving a motorcycle, there were 164 fatal crashes and over 4,000 police-reported crashes annually. According to the statistics shown in Figure 7, 94 percent of the fatal and 90 percent of all LTAP/LD crashes happen while motorcycles are traveling straight and other vehicles are turning left. Some key observations of the crashes are summarized below in terms of the vehicle role (turning or driving straight).

<u>Motorcyclist turning left and other vehicle driving straight:</u>

- Motorcyclists are reported as drinking in 18 percent of the fatal crashes, and for the drivers of the other vehicles in 8 percent of the fatal crashes.
- The roads are not level for motorcyclists in 27 percent of fatal crashes and for the other vehicles in 41 percent of fatal crashes. In about 32 percent of all crashes, the roads are not level for both vehicles.

<u>Motorcyclist driving straight and other vehicle turning:</u>

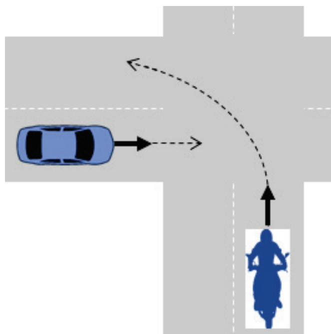
- In 27 percent of fatal crashes, motorcyclist speed is a contributing factor.
- Motorcyclists are reported as driver drinking in 17 percent of fatal crashes. On the other hand, the drivers of the other vehicles are reported as drinking in 6 percent of fatal crashes.
- Drivers of the other vehicles are distracted in 9 percent of both fatal and all crashes. In contrast, motorcyclists are distracted under 2 percent for these same crashes.
- About 37 percent of fatal crashes and 25 percent of all crashes happen during non-daylight conditions.

Additional observations are also presented below:

- Motorcyclists are reported as driver drinking more frequently in fatal crashes than drivers of the other vehicles, regardless of vehicle roles (turning or driving straight).
- Vision obstruction, distraction, or impairment are more likely associated with the drivers of turning vehicles as compared to the vehicles driving straight, independent of body type for all crashes and fatal crashes.
- About 22 to 34 percent of crashes occur near driveway access.
- The roadway surface conditions for turning vehicles are more likely to be wet/slippery as compared to vehicles driving straight, independent of body type for all crashes and fatal crashes.

Left Turn Across Path/Lateral Direction Crashes Average 2011-2015	Total FARS	Total GES
	174	4,538

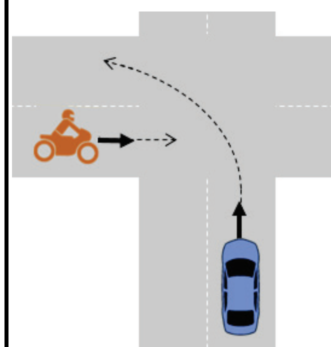
Motorcycle Turning Left



Crash Characteristics	FARS	GES
Crashes	10	448
% of Total	6%	10%
Clear Weather	96%	98%
Non-Daylight	16%	18%
Motorcyclist Fatality	98%	1%

	Motorcycle Turning Left		Other Vehicle Driving Straight	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	82%	79%	94%	95%
Not Level	27%	31%	41%	32%
Curve	2%	0%	8%	0%
Driveway Access	29%	22%	29%	22%
Known Vision Obstruction	4%	10%	2%	0%
Known Distraction	6%	0%	4%	0%
Impaired	16%	1%	8%	0%
Driver Drinking	18%	11%	8%	0%
Speed Related	2%	1%	2%	0%
Body Type*= Light Vehicle	-	-	88%	93%

Other Vehicle Turning Left



Crash Characteristics	FARS	GES
Crashes	164	4,090
% of Total	94%	90%
Clear Weather	96%	98%
Non-Daylight	37%	25%
Motorcyclist Fatality	99%	1%

	Other Vehicle Turning Left		Motorcycle Driving Straight	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	83%	68%	95%	96%
Not Level	12%	8%	16%	10%
Curve	4%	3%	5%	7%
Driveway Access	27%	34%	27%	34%
Known Vision Obstruction	10%	12%	4%	3%
Known Distraction	9%	9%	1%	2%
Impaired	6%	0%	9%	2%
Driver Drinking	6%	2%	17%	4%
Speed Related	0%	0%	27%	3%
Body Type = Light Vehicle	92%	99%	-	-

Characteristics exclude unknowns.

**Other body types not shown are medium, heavy, bus, other, and unknown.*

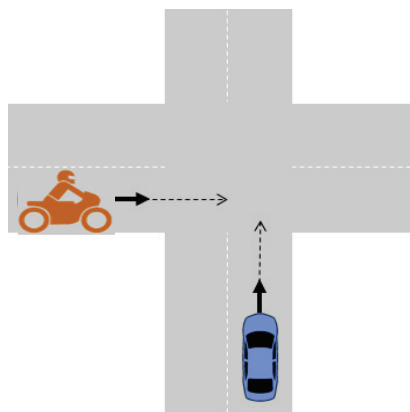
Figure 7. Statistical Characteristics of Left Turn Across Path/Lateral Direction Crashes

3.1.3 Straight Crossing Paths

In the straight crossing paths (SCP) pre-crash scenario involving a motorcycle, there were 416 fatal crashes and almost 6,000 police-reported crashes annually. The direction of the individual vehicles, or whether the vehicles were struck or striking, is not easily distinguished in this pre-crash scenario due to the unavailability of key data. Some key observations related to the statistics shown in Figure 8 for the crashes are summarized below in terms of the motorcycles or other vehicles:

- Motorcyclist speed is a contributing factor in 22 percent of fatal crashes as compared to 2 percent for the other vehicle.
- Motorcyclists are reported as driver drinking in 19 percent of fatal crashes as compared to 5 percent for the drivers of the other vehicles.
- Vision obstruction or distraction is more likely associated with drivers of other vehicles as compared to motorcyclists for all crashes and fatal crashes.
- About 33 percent of fatal crashes and 24 percent of all crashes happen during non-daylight conditions.

Straight Crossing Paths Crashes
Average 2011-2015



Crash Characteristics	FARS	GES
Crashes	416	5,971
Clear Weather	97%	96%
Non-Daylight	33%	24%
Motorcyclist Fatality	99%	4%

	Motorcycle Driving Straight		Other Vehicle Driving Straight	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	95%	93%	92%	91%
Not Level	15%	5%	13%	6%
Curve	4%	2%	2%	2%
Driveway Access	11%	11%	11%	12%
Known Vision Obstruction	3%	2%	6%	4%
Known Distraction	3%	3%	6%	11%
Impaired	8%	2%	5%	1%
Driver Drinking	19%	3%	5%	2%
Speed Related	22%	5%	2%	2%
Body Type*= Light Vehicle	-	-	92%	98%

Characteristics exclude unknowns.

**Other body types not shown are medium, heavy, bus, other, and unknown.*

Figure 8. Statistical Characteristics of Straight Crossing Paths Crashes

3.1.4 Lead Vehicle Stopped

In the lead vehicle stopped (LVS) pre-crash scenario involving a motorcycle, there were 108 fatal crashes and about 7,700 police-reported crashes annually. According to LVS crash statistics shown in Figure 9, motorcycles are the striking vehicles in 76 percent of fatal crashes and 58 percent of all crashes. Some key observations of the LVS crashes are summarized below in terms of motorcyclists striking stopped vehicles or motorcyclists struck by other vehicles while stopped:

<u>Motorcyclist striking a stopped vehicle:</u>

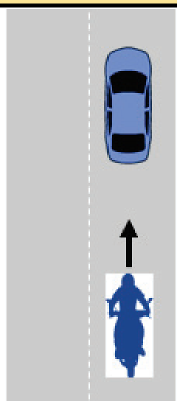
- Crashes happen in non-daylight conditions for 35 percent of the fatal crashes.
- Motorcyclists are distracted in 21 percent of fatal crashes and 26 percent of all crashes.
- Motorcyclists are reported as driver drinking in 25 percent of fatal crashes.
- Speed is a contributing factor in 43 percent of fatal crashes and 20 percent of all crashes.

Motorcyclist struck by another vehicle while stopped:

- Crashes happen in non-daylight conditions for 55 percent of fatal crashes.
- Roads are not level in 21 percent of fatal crashes and 10 percent of all crashes.
- Drivers of the other vehicles are distracted in 37 percent of fatal crashes and 36 percent of all crashes.
- Motorcyclists are reported as driver drinking in 17 percent of fatal crashes.
- Speed is a contributing factor for the other vehicles in 31 percent of fatal crashes and 24 percent of all crashes.

Lead Vehicle Stopped Crashes Average 2011-2015	Total FARS	Total GES
	108	7,703

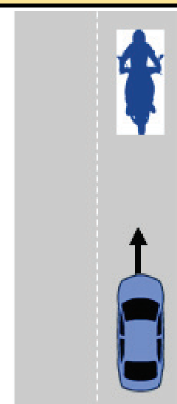
Motorcycle is Striking Vehicle



Crash Characteristics	FARS	GES
Crashes	82	4,475
% of Total	76%	58%
Clear Weather	99%	97%
Non-Daylight	35%	16%
Motorcyclist Fatality	99%	1%

	Motorcycle is Striking		Other Vehicle Stopped	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	98%	93%	97%	94%
Not Level	22%	16%	18%	14%
Curve	7%	3%	6%	2%
Driveway Access	7%	5%	9%	7%
Known Vision Obstruction	3%	2%	1%	0%
Known Distraction	21%	26%	1%	1%
Impaired	11%	3%	2%	0%
Driver Drinking	25%	4%	2%	0%
Speed Related	43%	20%	0%	0%
Body Type*= Light Vehicle	-	-	90%	96%

Motorcycle is Struck



Crash Characteristics	FARS	GES
Crashes	26	####
% of Total	24%	42%
Clear Weather	97%	96%
Non-Daylight	55%	34%
Motorcyclist Fatality	95%	1%

	Other Vehicle Striking		Motorcycle is Stopped	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	97%	94%	97%	94%
Not Level	21%	10%	21%	10%
Curve	2%	6%	2%	6%
Driveway Access	7%	2%	7%	2%
Known Vision Obstruction	2%	2%	0%	0%
Known Distraction	37%	36%	2%	1%
Impaired	26%	4%	5%	0%
Driver Drinking	23%	3%	17%	3%
Speed Related	31%	24%	1%	0%
Body Type = Light Vehicle	93%	97%	-	-

Characteristics exclude unknowns.

**Other body types not shown are medium, heavy, bus, other, and unknown.*

Figure 9. Statistical Characteristics of Lead Vehicle Stopped Crashes

3.1.5 Lead Vehicle Decelerating

In the lead vehicle decelerating (LVD) pre-crash scenario involving a motorcycle, there were 65 fatal crashes and about 5,000 police-reported crashes annually. According to the LVD crash statistics shown in Figure 10, 76 percent of the fatal and 73 percent of all crashes happen when motorcycles are the striking vehicles. Some key observations of the crashes are summarized below in terms of the vehicle role (i.e., striking or decelerating vehicle).

<u>In a striking vehicle (motorcycle or other vehicle)</u>:

- Speed is a contributing factor in slightly more fatal crashes for motorcyclists at 39 percent as compared to the other vehicles at 36 percent. In all crashes, speed is a contributing factor more for motorcyclists at 20 percent than for the other vehicles at 17 percent.
- Motorcyclists are reported as driver drinking in 21 percent of fatal crashes, compared to 10 percent for drivers of the other vehicles.
- Other vehicle drivers are distracted more often at 39 percent for fatal crashes and 22 percent for all crashes, compared to motorcyclists (21 percent and 14 percent of fatal and all crashes respectively).
- Non-daylight conditions are reported in 34 percent of fatal crashes and 36 percent of all crashes when other vehicles are the striking vehicles.
- More fatal crashes happen on curves when the other vehicles are the striking vehicles.

<u>In a decelerating vehicle</u>:

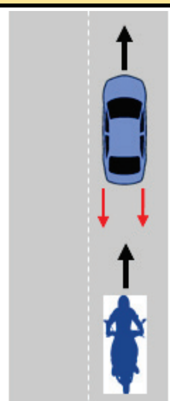
- Motorcyclists are reported as driver drinking in 12 percent of fatal crashes when they are decelerating.

Additional observations are also presented below:

- Roads are not level in 21 percent of fatal crashes and 16 percent of all crashes.

Lead Vehicle Decelerating Crashes Average 2011-2015	Total FARS	Total GES
	65	5,080

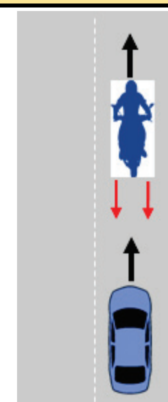
Motorcycle is Striking Vehicle



Crash Characteristics	FARS	GES
Crashes	49	3,686
% of Total	76%	73%
Clear Weather	98%	99%
Non-Daylight	22%	16%
Motorcyclist Fatality	96%	2%

	Motorcycle is Striking		Other Vehicle Decelerating	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	98%	97%	99%	99%
Not Level	21%	16%	19%	14%
Curve	5%	7%	5%	8%
Driveway Access	8%	12%	10%	19%
Known Vision Obstruction	1%	1%	0%	0%
Known Distraction	21%	14%	1%	1%
Impaired	11%	2%	4%	0%
Driver Drinking	21%	2%	4%	1%
Speed Related	39%	20%	3%	0%
Body Type*= Light Vehicle	-	-	71%	86%

Motorcycle is Struck



Crash Characteristics	FARS	GES
Crashes	15	1,394
% of Total	24%	27%
Clear Weather	95%	100%
Non-Daylight	34%	36%
Motorcyclist Fatality	100%	7%

	Other Vehicle Striking		Motorcycle is Decelerating	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	0%	0%	94%	95%
Not Level	22%	16%	22%	16%
Curve	10%	6%	10%	6%
Driveway Access	12%	7%	12%	7%
Known Vision Obstruction	5%	1%	1%	0%
Known Distraction	39%	22%	1%	0%
Impaired	14%	3%	4%	0%
Driver Drinking	10%	7%	12%	6%
Speed Related	36%	17%	1%	0%
Body Type = Light Vehicle	0%	0%	-	-

Characteristics exclude unknowns.

**Other body types not shown are medium, heavy, bus, other, and unknown.*

Figure 10. Statistical Characteristics of Lead Vehicle Decelerating Crashes

3.1.6 Lead Vehicle Moving

In the lead vehicle moving (LVM) pre-crash scenario involving motorcycles, there were 213 fatal crashes and about 2,500 police-reported crashes annually. According to LVM crash statistics shown in Figure 11, 63 percent of fatal crashes and 59 percent of all crashes happen when motorcycles are the striking vehicles. Some key observations of the crashes are summarized below in terms of the vehicle role (i.e., striking or struck-moving vehicle).

<u>In a striking vehicle (motorcycle or other vehicle)</u>:

- Motorcyclists are speeding in 59 percent of fatal crashes as compared to speeding by the other vehicles in 38 percent of fatal crashes. Conversely, speed is a contributing factor by motorcyclists in 21 percent of all crashes as compared to the other vehicles speeding in 28 percent of all crashes.
- Motorcyclists are reported as driver drinking in 46 percent of fatal crashes, compared to 24 percent of fatal crashes drivers of the other vehicles.
- Drivers of the other vehicles are distracted in 21 percent of fatal crashes and 15 percent of all crashes, as opposed to motorcyclists being distracted in 11 percent of fatal crashes and 14 percent of all crashes.
- Motorcyclists are impaired in 23 percent of fatal crashes, while drivers of the other vehicles are impaired in 26 percent of fatal crashes.
- Non-daylight conditions are reported in 73 percent of fatal crashes and 49 percent of all crashes when the other vehicles are the striking vehicle. When motorcyclists are striking other vehicles, 59 percent of fatal crashes and 40 percent of all crashes happen under non-daylight conditions.

<u>In a struck vehicle:</u>

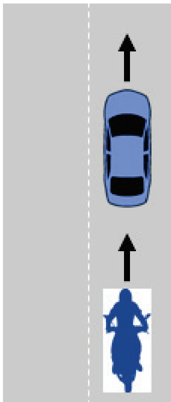
- Motorcyclists are reported as driver drinking in 19 percent of fatal crashes when struck.

Additional observations are also presented below.

- Roads are not level in about 20 percent of fatal crashes and 9 percent of all crashes when motorcycles are the striking vehicle, and in about 23 percent of fatal crashes and 8 percent of all crashes when the other vehicles are striking motorcyclists.

Lead Vehicle Moving Crashes Average 2011-2015	Total FARS	Total GES
	213	2,581

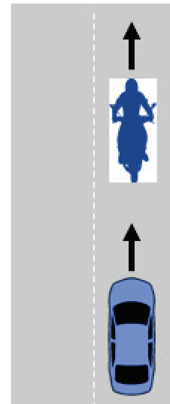
Motorcycle is Striking Vehicle



Crash Characteristics	FARS	GES
Crashes	134	1,531
% of Total	63%	59%
Clear Weather	97%	94%
Non-Daylight	59%	40%
Motorcyclist Fatality	97%	2%

	Motorcycle is Striking		Other Vehicle Moving	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	96%	88%	96%	87%
Not Level	20%	9%	20%	8%
Curve	7%	12%	6%	11%
Driveway Access	2%	2%	2%	2%
Known Vision Obstruction	2%	1%	1%	0%
Known Distraction	11%	14%	2%	0%
Impaired	23%	8%	4%	3%
Driver Drinking	46%	8%	5%	3%
Speed Related	59%	21%	0%	0%
Body Type*= Light Vehicle	-	-	71%	87%

Motorcycle is Struck



Crash Characteristics	FARS	GES
Crashes	79	1,050
% of Total	37%	41%
Clear Weather	93%	97%
Non-Daylight	73%	49%
Motorcyclist Fatality	99%	4%

	Other Vehicle Striking		Motorcycle is Moving	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	91%	96%	90%	96%
Not Level	23%	8%	23%	8%
Curve	2%	2%	2%	2%
Driveway Access	1%	0%	1%	0%
Known Vision Obstruction	4%	0%	2%	0%
Known Distraction	21%	15%	1%	0%
Impaired	26%	9%	5%	1%
Driver Drinking	24%	9%	19%	1%
Speed Related	38%	28%	1%	0%
Body Type = Light Vehicle	90%	100%	-	-

Characteristics exclude unknowns.

**Other body types not shown are medium, heavy, bus, other, and unknown.*

Figure 11. Statistical Characteristics of Lead Vehicle Moving Crashes

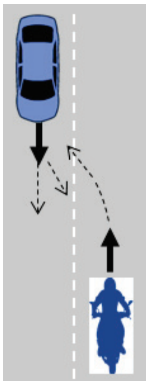
3.1.7 Opposite Direction, No Maneuver

In the opposite direction, no maneuver pre-crash scenario involving a motorcycle, there were 265 fatal crashes and slightly over 2,500 police-reported crashes annually. According to crash statistics for this scenario shown in Figure 12, 71 percent of fatal and 87 percent of all crashes happen while motorcycles are drifting into the opposite lanes. Some key observations of the crashes are summarized below in terms of the vehicle role (i.e., whether the motorcycle is drifting or driving straight).

- Motorcyclist speed is a contributing factor when drifting in 25 percent of fatal crashes. Speed is a factor in 10 percent of fatal crashes when the other vehicles are drifting.
- Drifting motorcyclists are reported as driver drinking in 34 percent of fatal crashes. Drivers of the other vehicles are reported as driver drinking in 29 percent of fatal crashes when drifting.
- Drivers of the other vehicles are distracted in 22 percent of fatal crashes and 32 percent of all crashes when drifting. In contrast, drifting motorcyclists are distracted in 4 percent and 7 percent of fatal and all crashes, respectively.
- Drivers of the other vehicles are impaired in 41 percent of fatal crashes and 28 percent of all crashes when drifting, as compared to 17 percent of fatal crashes and 4 percent of all crashes by impaired motorcyclists when drifting.
- About 30 percent of fatal crashes happen during non-daylight conditions regardless of whether motorcyclists are drifting or driving straight. When all crashes are considered, the percentages are higher at 36 percent for motorcyclists driving straight and slightly lower at 28 percent for motorcyclists drifting.
- Roads are not level when motorcyclists are drifting in 41 percent of fatal crashes and in 36 percent of all crashes.
- Motorcyclists are drifting on curves in 63 percent of fatal crashes and in 40 percent of all crashes.

Opposite Direction/No Maneuver Crashes Average 2011-2015	Total FARS	Total GES
	265	2,574

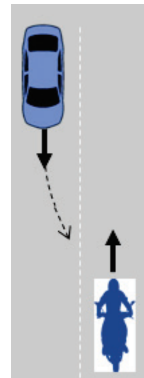
Motorcycle Drifting into Opposite Lane



Crash Characteristics	FARS	GES
Crashes	189	2,243
% of Total	71%	87%
Clear Weather	97%	96%
Non-Daylight	30%	28%
Motorcyclist Fatality	99%	8%

	Motorcycle Drifting		Other Vehicle Driving Straight/ Drifting	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	95%	94%	95%	95%
Not Level	41%	36%	42%	53%
Curve	63%	40%	59%	59%
Driveway Access	2%	12%	2%	27%
Known Vision Obstruction	3%	6%	2%	8%
Known Distraction	4%	7%	2%	1%
Impaired	17%	4%	6%	0%
Driver Drinking	34%	6%	7%	2%
Speed Related	25%	12%	3%	6%
Body Type*= Light Vehicle	-	-	85%	81%
Body Type = Motor Cycle	100%	100%	4%	10%
Body Type = Med. Heavy	-	-	9%	7%

Other Vehicle Drifting into Opposite Lane



Crash Characteristics	FARS	GES
Crashes	76	331
% of Total	29%	13%
Clear Weather	96%	96%
Non-Daylight	29%	36%
Motorcyclist Fatality	95%	21%

	Other Vehicle Drifting		Motorcycle Driving Straight	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	94%	96%	94%	96%
Not Level	36%	21%	36%	21%
Curve	41%	50%	40%	50%
Driveway Access	0%	1%	0%	1%
Known Vision Obstruction	2%	1%	0%	3%
Known Distraction	22%	32%	0%	0%
Impaired	41%	28%	3%	0%
Driver Drinking	29%	16%	12%	0%
Speed Related	10%	2%	3%	0%
Body Type= Light Vehicle	96%	94%	-	-
Body Type = Motor Cycle	0%	0%	100%	100%
Body Type = Med. Heavy	3%	6%	-	-

Characteristics exclude unknowns.

**Other body types not shown are bus, other, and unknown.*

Figure 12. Statistical Characteristics of Opposite Direction/No Maneuver Crashes

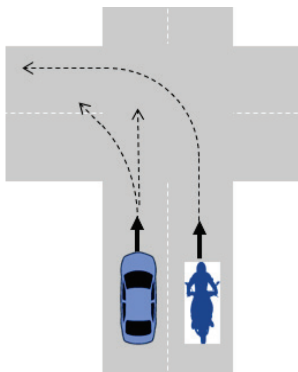
3.1.8 Turning, Same Direction

In the turning, same direction pre-crash scenario involving a motorcycle, there were 106 fatal crashes and slightly over 4,400 police-reported crashes annually. The turning direction of the individual vehicles was not distinguished in the analysis, so the direction of the turn is either left or right. According to crash statistics for this scenario shown in Figure 13, 85 percent of fatal crashes and 70 percent of all crashes happen while motorcyclists are driving straight and the other vehicles are turning left or right. Some key observations of the crashes are summarized below in terms of the vehicle role (i.e., whether motorcyclists are turning or driving straight).

- Motorcyclist speed is a contributing factor in 31 percent of fatal crashes when driving straight, as compared to 14 percent of fatal crashes for other vehicles driving straight or turning while motorcyclists are also turning. Speed is a factor in 10 percent of all crashes when the other vehicles are turning into motorcyclists going straight.
- Motorcyclists are reported as driver drinking in about 20 percent of fatal crashes when turning or driving straight.
- Motorcyclists are distracted while turning in 13 percent of both fatal crashes and all crashes.
- Motorcyclists are impaired while turning in 15 percent of fatal crashes, while drivers of the other vehicles are impaired in 18 percent of fatal crashes.
- When motorcyclists are turning, 28 percent of fatal crashes and 17 percent of all crashes happen during non-daylight conditions. When motorcyclists are going straight, 24 percent of fatal crashes and 21 percent of all crashes happen during non-daylight conditions.

Turning*/Same Direction Crashes Average 2011-2015	Total FARS	Total GES
	106	4,411

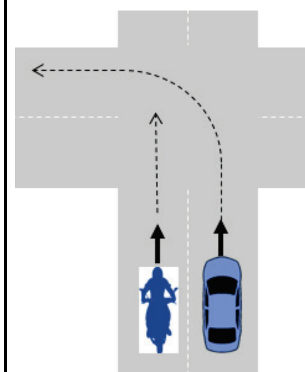
Motorcycle Turning/Other Vehicle Driving Straight or Turning



Crash Characteristics	FARS	GES
Crashes	16	1,315
% of Total	15%	30%
Clear Weather	96%	96%
Non-Daylight	28%	17%
Motorcyclist Fatality	84%	0%

Vehicle Characteristics	Motorcycle Turning		Other Vehicle Driving Straight/ Turning	
	FARS	GES	FARS	GES
Dry Road	94%	94%	94%	94%
Not Level	24%	8%	25%	8%
Curve	10%	7%	10%	7%
Driveway Access	30%	18%	30%	18%
Known Vision Obstruction	0%	2%	1%	1%
Known Distraction	13%	13%	8%	4%
Impaired	15%	4%	18%	0%
Driver Drinking	19%	0%	20%	7%
Speed Related	5%	1%	14%	1%
Body Type**= Light Vehicle	-	-	61%	88%
Body Type = Motor Cycle	100%	100%	23%	5%
Body Type = Med. Heavy	-	-	15%	4%

Other Vehicle Turning/Motorcycle Driving Straight



Crash Characteristics	FARS	GES
Crashes	90	3,095
% of Total	85%	70%
Clear Weather	98%	96%
Non-Daylight	24%	21%
Motorcyclist Fatality	100%	1%

Vehicle Characteristics	Other Vehicle Turning		Motorcycle Driving Straight	
	FARS	GES	FARS	GES
Dry Road	97%	95%	97%	95%
Not Level	17%	13%	17%	13%
Curve	6%	4%	5%	5%
Driveway Access	34%	33%	34%	33%
Known Vision Obstruction	1%	3%	2%	1%
Known Distraction	5%	10%	7%	8%
Impaired	5%	1%	7%	3%
Driver Drinking	5%	1%	18%	3%
Speed Related	0%	1%	31%	10%
Body Type = Light Vehicle	80%	95%	-	-
Body Type = Motor Cycle	0%	0%	100%	100%
Body Type = Med. Heavy	15%	4%	-	-

Characteristics exclude unknowns.

** Turning direction is left or right. Left turn shown in diagrams for illustration only.*

*** Other body types not shown are bus, other, and unknown.*

Figure 13. Statistical Characteristics of Turning, Same Direction Crashes

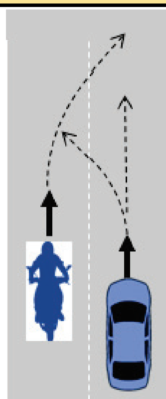
3.1.9 Changing Lanes, Same Direction

In the changing lanes, same direction pre-crash scenario involving a motorcycle, there were 106 fatal crashes and nearly 5,100 police-reported crashes annually. According to the scenario statistics shown in Figure 14, 71 percent of fatal and 45 percent of all crashes happen while motorcyclists are changing lanes and another vehicles are either going straight or changing lanes at the same time. Some key observations of the crashes are summarized below in terms of the vehicle role (i.e., whether motorcyclists are turning or driving straight).

- Motorcyclist speed is a contributing factor in 34 percent of fatal crashes when changing lanes, compared to 7 percent of fatal crashes when another vehicles are changing lanes.
- Motorcyclists are reported as driver drinking in about 27 percent of fatal crashes when changing lanes. In contrast, drivers of the other vehicles are under the influence in 19 percent of fatal crashes when changing lanes.
- Motorcyclists are impaired while changing lanes in 12 percent of fatal crashes, while drivers of the other vehicles are impaired in 5 percent of the same fatal crashes.
- Non-daylight conditions are reported in 40 percent of fatal crashes and 20 percent of all crashes when motorcyclists are driving straight. When motorcyclists are changing lanes, non-daylight conditions are reported in 32 percent of fatal crashes and in 19 percent of all crashes.
- Roads are not level in 21 percent of fatal crashes and 8 percent of all crashes when motorcyclists are changing lanes.
- Motorcyclists are changing lanes on a curve in 16 percent of fatal crashes and 4 percent of all crashes.

Changing Lane/Same Direction Crashes Average 2011-2015	Total FARS	Total GES
	106	5,095

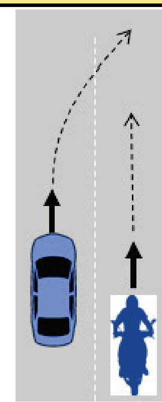
Motorcycle Changing Lane



Crash Characteristics	FARS	GES
Crashes	75	2,270
% of Total	71%	45%
Clear Weather	99%	99%
Non-Daylight	32%	19%
Motorcyclist Fatality	92%	1%

	Motorcycle Changing Lane		Other Vehicle Changing Lane/ Driving Straight	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	97%	98%	97%	98%
Not Level	21%	8%	21%	8%
Curve	16%	4%	15%	4%
Driveway Access	3%	2%	3%	3%
Known Vision Obstruction	1%	0%	0%	0%
Known Distraction	6%	3%	2%	1%
Impaired	12%	4%	5%	0%
Driver Drinking	27%	4%	9%	0%
Speed Related	34%	12%	6%	1%
Body Type*= Light Vehicle	-	-	71%	97%
Body Type = Motor Cycle	100%	100%	11%	2%
Body Type = Med. Heavy	-	-	15%	1%

Other Vehicle Changing Lane



Crash Characteristics	FARS	GES
Crashes	31	2,825
% of Total	29%	55%
Clear Weather	99%	97%
Non-Daylight	40%	20%
Motorcyclist Fatality	99%	0%

	Other Vehicle Changing Lane		Motorcycle Driving Straight	
Vehicle Characteristics	FARS	GES	FARS	GES
Dry Road	97%	96%	97%	96%
Not Level	17%	3%	16%	3%
Curve	10%	4%	10%	4%
Driveway Access	3%	2%	3%	2%
Known Vision Obstruction	2%	1%	1%	0%
Known Distraction	7%	4%	1%	0%
Impaired	7%	1%	8%	2%
Driver Drinking	8%	1%	19%	2%
Speed Related	7%	2%	19%	7%
Body Type = Light Vehicle	88%	99%	-	-
Body Type = Motor Cycle	0%	0%	100%	100%
Body Type = Med. Heavy	5%	0%	-	-

Characteristics exclude unknowns.

**Other body types not shown are bus, other, and unknown.*

Figure 14. Statistical Characteristics of Changing Lanes, Same Direction Crashes

3.2 Single Vehicle - Priority Scenario Characteristics

Two of the priority pre-crash scenarios shown in Table 6 are primarily single-vehicle crashes. Various statistics related to the driving environment, vehicle characteristics, and driver factors are shown in Figure 15 for the control loss pre-crash scenario and in Figure 16 for the road departure pre-crash scenario. Definitions of the individual characteristics are presented in Appendix C.

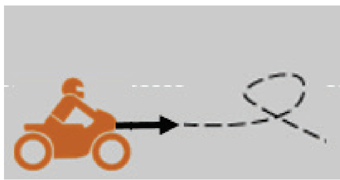
3.2.1 Control Loss

In the control loss/no vehicle action pre-crash scenario, there were 590 fatal crashes and about 14,100 police-reported crashes annually. Some key observations related to the crash statistics shown in Figure 15 are summarized below:

- About 41 percent of fatal crashes and 28 percent of all crashes happen during non-daylight conditions.
- About 39 percent of fatal crashes and 33 percent of all crashes occur on non-level roads.
- About 64 percent of fatal crashes and 58 percent of all crashes happen on curves.
- A distraction is reported in 6 percent of fatal and all crashes.
- Motorcyclists are impaired in 24 percent of fatal crashes and 11 percent of all crashes.
- Motorcyclists are reported as driver drinking in 41 percent of fatal crashes and 12 percent of all crashes.
- Speed is a contributing factor in 67 percent of fatal crashes and 46 percent of all crashes.

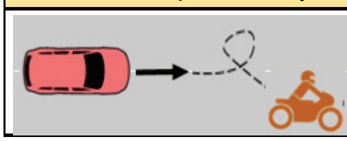
Control Loss/No Vehicle Action Crashes Average 2011-2015	Total FARS	Total GES
	590	14,181

Motorcycle Lost Control		
Crash Characteristics	**FARS**	**GES**
Crashes	582	14,148
% of Total	99%	100%
Clear Weather	95%	92%
Non-Daylight	41%	28%
Motorcyclist Fatality	100%	4%



Vehicle Characteristics	FARS	GES
Dry Road	93%	83%
Not Level	39%	33%
Curve	64%	58%
Driveway Access	1%	2%
Known Vision	1%	1%
Known Distraction	6%	6%
Impaired	24%	11%
Driver Drinking	41%	12%
Speed Related	67%	46%

Other Vehicle Lost Control (Motorcycle Involved in the 1st Event)



Crash Characteristics	FARS	GES
Crashes	8	33
% of Total	1%	0.2%

All characteristics exclude unknowns.

Figure 15. Statistical Characteristics of Control Loss/No Vehicle Action Crashes

3.2.2 Road Departure

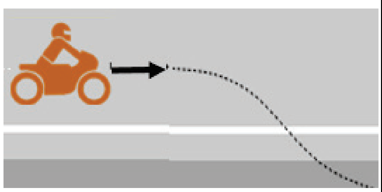
In the road departure/no vehicle maneuver pre-crash scenario, there were 1,125 fatal crashes and 10,000 police-reported crashes annually. Some key observations related to the crash statistics shown in Figure 16 are summarized below:

- Non-daylight conditions are reported in 49 percent of fatal crashes and 34 percent of all crashes.
- Non-level roads are reported in 35 percent of fatal crashes and 30 percent of all crashes.
- About 69 percent of fatal crashes and 56 percent of all crashes happen on curves.
- Motorcyclists are distracted in 8 percent of fatal crashes and 14 percent of all crashes.
- Motorcyclists are impaired in 26 percent of fatal crashes and 16 percent of all crashes.

- Motorcyclists are reported as driver drinking in 49 percent of fatal crashes and 17 percent of all crashes.
- Speed is a contributing factor in 42 percent of fatal crashes and 25 percent of all crashes.

Road Edge Departure/No Maneuver Crashes Average 2011-2015	Total FARS	Total GES
	1,125	10,008

Motorcycle Departs Road



Crash Characteristics	FARS	GES
Crashes	1,125	10,008
Clear Weather	96%	95%
Non-Daylight	49%	34%
Motorcyclist Fatality	100%	5%
Vehicle Characteristics	**FARS**	**GES**
Dry Road	95%	92%
Not Level	35%	30%
Curve	69%	56%
Driveway Access	0%	1%
Known Vision	1%	2%
Known Distraction	8%	14%
Impaired	26%	16%
Driver Drinking	49%	17%
Speed Related	42%	25%

Figure 16. Statistical Characteristics of Road Departure/No Maneuver Crashes

4 Depiction of Priority Motorcycle Pre-Crash Scenarios

All the two-vehicle priority pre-crash scenarios listed in Table 6 are depicted to dynamically describe the key aspects of the crashes. This information can help in the research and development of crash avoidance applications to address these scenarios. The following information is provided in Sections 4.1 through 4.5 for each of the two-vehicle priority pre-crash scenarios..

- A depiction of the configuration of the pre-crash scenario;
- Equations to describe the pre-crash scenario and detail when a collision will occur; and
- Plots to show the time history of the moments leading to the crash, showing distances to the intersection, the vehicle speeds throughout the pre-crash event, and/or the difference in heading between the two vehicles.

Each two-vehicle pre-crash scenario also includes an equation that calculates the collision timing of the pre-crash event when no crash countermeasure is applied.[9] Table 7 lists the variables used in the equations for the pre-crash scenarios.

Table 7. Kinematic Parameters Used in Pre-Crash Scenario Equations

Variable	Description
a_{LV}	acceleration of the light vehicle
h	a sub-portion of an equation
l_{LV}	length of the light vehicle
l_{MC}	length of the motorcycle
LV	light vehicle
MC	motorcycle
R_{lat}	latitudinal range
R_{long}	longitudinal range
r_{turn}	turning radius of the turning vehicle
t_{clear}	time for a vehicle to clear the collision zone
t_{reach}	time for a vehicle to reach the collision zone
TTC	time to collision
v_{LV}	speed of the light vehicle
v_{MC}	speed of the motorcycle
w_{LV}	width of the light vehicle
w_{MC}	width of the motorcycle
α	degrees turned around circle at a given moment
θ	average change in heading

[9] While countermeasures are usually necessary to avoid collisions in actual crashes, specific countermeasures and the equations to describe their kinematics are not included in this report.

The timing in some pre-crash scenarios is dependent on a "collision zone," which is the area on the road where the paths of the two vehicles overlap. The collision zone is represented in the depictions as a semi-transparent red area, as seen in Figure 17. Also shown in Figure 17 are the images used to represent a motorcycle and a light vehicle.

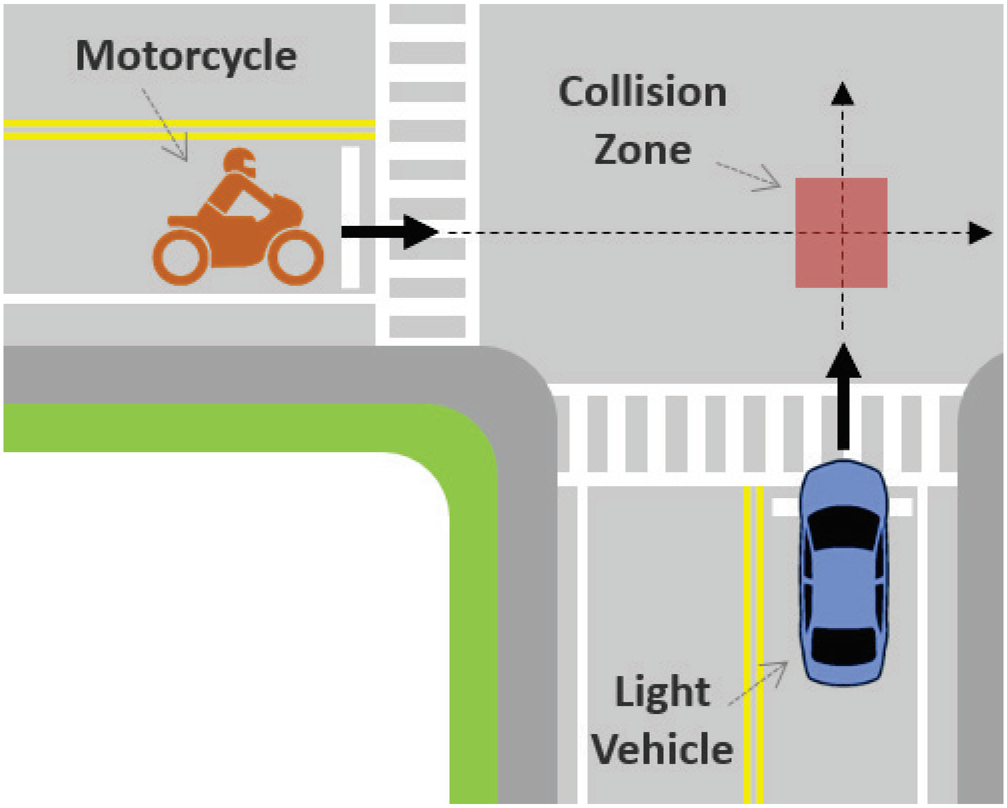


Figure 17. Example Depiction of a Collision Zone

For the pre-crash scenarios that include a turn, the turning vehicle is assumed to turn in a perfect circle with a constant radius, and the vehicle's path is assumed to be tangent to the circle at all times as measured from the center of the vehicle. An example of this is shown below in Figure 18.

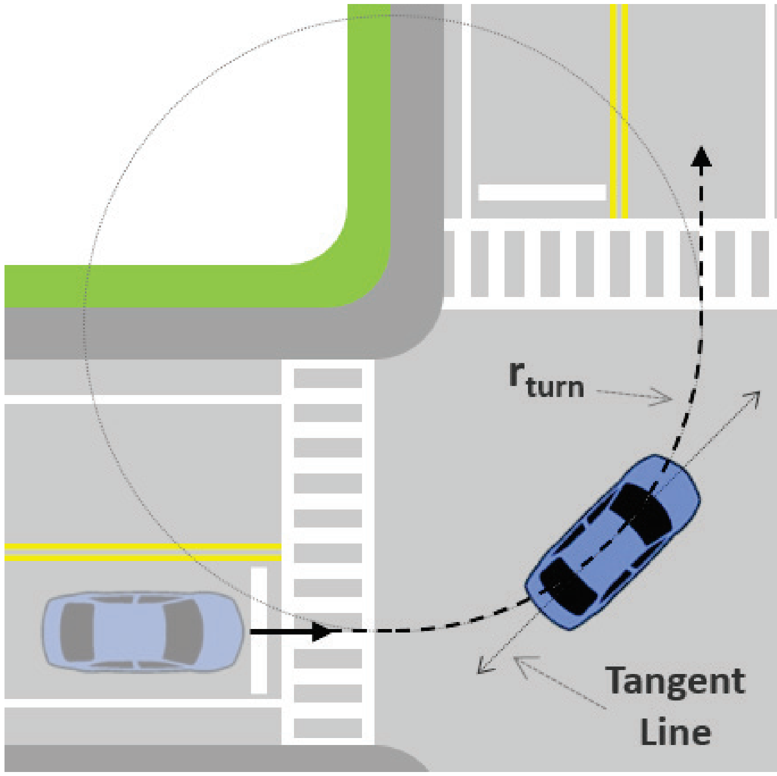


Figure 18. Example of Constant Turning Radius throughout Turn

The crash statistics presented in Figure 6 through Figure 14 were used to determine the turning-vehicle body type (motorcycle or light vehicle) in each depiction of the priority pre-crash scenarios (e.g., the light vehicle is depicted as the turning vehicle in the LTAP/OD pre-crash scenario because light vehicles are statistically more likely to be the turning vehicle in this scenario). This is also reflected in the equations. If the vehicle roles were swapped in a pre-crash event, then the equations should be swapped as well.

The two-vehicle pre-crash scenarios are discussed in Sections 4.1 through 4.5. The single-vehicle control loss and road departure pre-crash scenarios are discussed in Section 4.6

4.1 Left Turn Across Path, Opposite Direction

The configuration for an LTAP/OD scenario is shown in Figure 19.

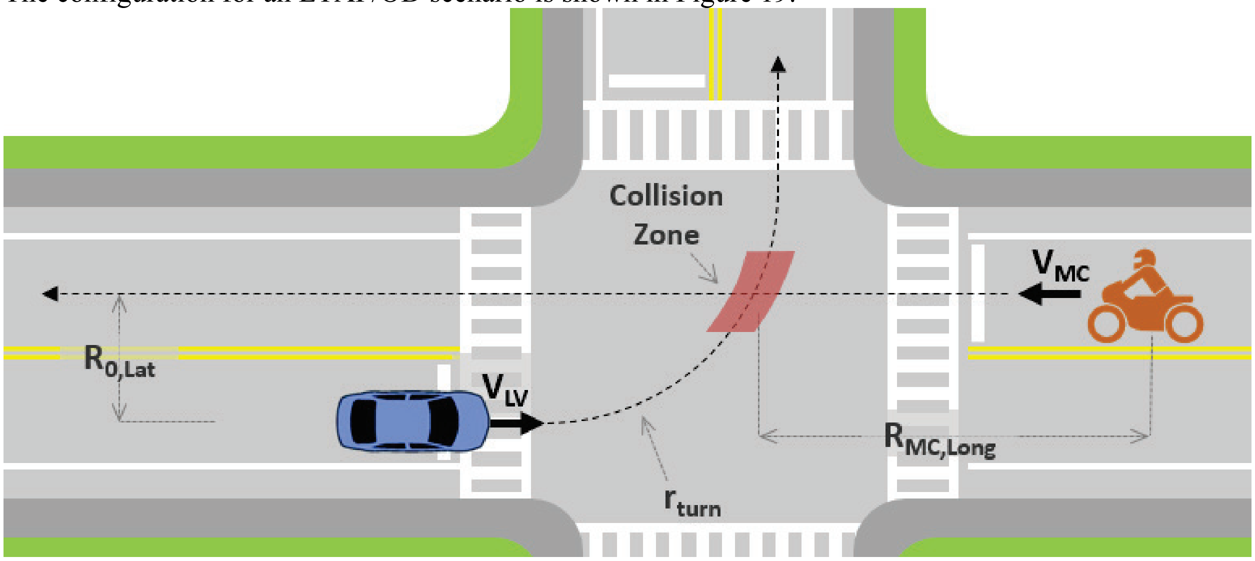


Figure 19. Left Turn Across Path - Opposite Direction Scenario Configuration

A collision will occur in the LTAP/OD pre-crash scenario if both vehicles occupy the collision zone at the same time. This relationship is expressed in Equations 1 and 2 as:

$$t_{reach,LV} < t_{clear,MC} < t_{clear,LV} \quad (1)$$

or

$$t_{reach,MC} < t_{clear,LV} < t_{clear,MC} \quad (2)$$

If the turn is completed before the light vehicle enters the collision zone (i.e., $R_{0,lat} - \frac{1}{2}(w_{MC} + l_{LV}) > r_{turn}$), then the times at which both vehicles reach the collision zone are expressed in Equations 3 and 4 as:

$$t_{reach,LV} = \frac{\frac{\pi}{2}r_{turn} + \left[R_{0,lat} - r_{turn} - \frac{1}{2}(w_{MC} + l_{LV})\right]}{v_{LV}} \quad (3)$$

$$t_{reach,MC} = \frac{R_{MC,long} - \frac{1}{2}(l_{MC} + w_{LV})}{v_{MC}} \quad (4)$$

If the light vehicle is still turning when it reaches the collision zone, the times at which both vehicles reach the collision zone are expressed in Equations 5 and 6 as:

$$t_{reach,LV} = \frac{h\alpha_1}{v_{LV}} \quad (5)$$

$$t_{reach,MC} = \frac{R_{MC,long} - \frac{1}{2}l_{MC} - \frac{1}{2}(w_{LV}\cos\alpha_1 + l_{LV}\sin\alpha_1)}{v_{MC}} \quad (6)$$

Where the variables α_1 and h are equal to the expressions shown in Equations 7 and 8:

$$\alpha_1 = \cos^{-1}\left(\frac{r_{turn} + \frac{1}{2}w_{MC} - R_{0,lat}}{h}\right) - \tan^{-1}\left(\frac{l_{LV}}{2r_{turn} + w_{LV}}\right) \quad (7)$$

$$h = \sqrt{\left(\frac{1}{2}l_{LV}\right)^2 + \left(r_{turn} - \frac{1}{2}w_{LV}\right)^2} \quad (8)$$

If the turn is completed before the light vehicle clears the collision zone (i.e., $R_{0,lat} + \frac{1}{2}(w_{MC} + l_{LV}) > r_{turn}$), then the times for both vehicles to clear the collision zone are shown in Equations 9 and 10:

$$t_{clear,LV} = \frac{\frac{\pi}{2}r_{turn} + \left[R_{0,lat} - r_{turn} + \frac{1}{2}(w_{MC} + l_{LV})\right]}{v_{LV}} \quad (9)$$

$$t_{clear,MC} = \frac{R_{MC,long} + \frac{1}{2}(l_{MC} + w_{LV})}{v_{MC}} \quad (10)$$

Otherwise, if the light vehicle is still turning when it clears the collision zone, the times at which both vehicles clear the collision zone are expressed in Equations 11 and 12 as:

$$t_{clear,LV} = \frac{h\alpha_2}{v_{LV}} \quad (11)$$

$$t_{clear,MC} = \frac{R_{MC,long} + \frac{1}{2}l_{MC} + \frac{1}{2}(w_{LV}\cos\alpha_2 + l_{LV}\sin\alpha_2)}{v_{MC}} \quad (12)$$

Where the variables α_2 and h are equal to the expression in Equations 13 and 14.

$$\alpha_2 = \tan^{-1}\left(\frac{l_{LV}}{2r_{turn} + w_{LV}}\right) + \cos^{-1}\left(1 - \frac{2R_{0,lat} + w_{MC}}{2h}\right) \quad (13)$$

$$h = \sqrt{\left(\frac{1}{2}l_{LV}\right)^2 + \left(r_{turn} - \frac{1}{2}w_{LV}\right)^2} \quad (14)$$

A timeline of the vehicles' times to reach and clear the collision zone in this scenario is shown in Figure 20. The time range at which both vehicles occupy the collision zone is represented as the space within the dashed green lines.

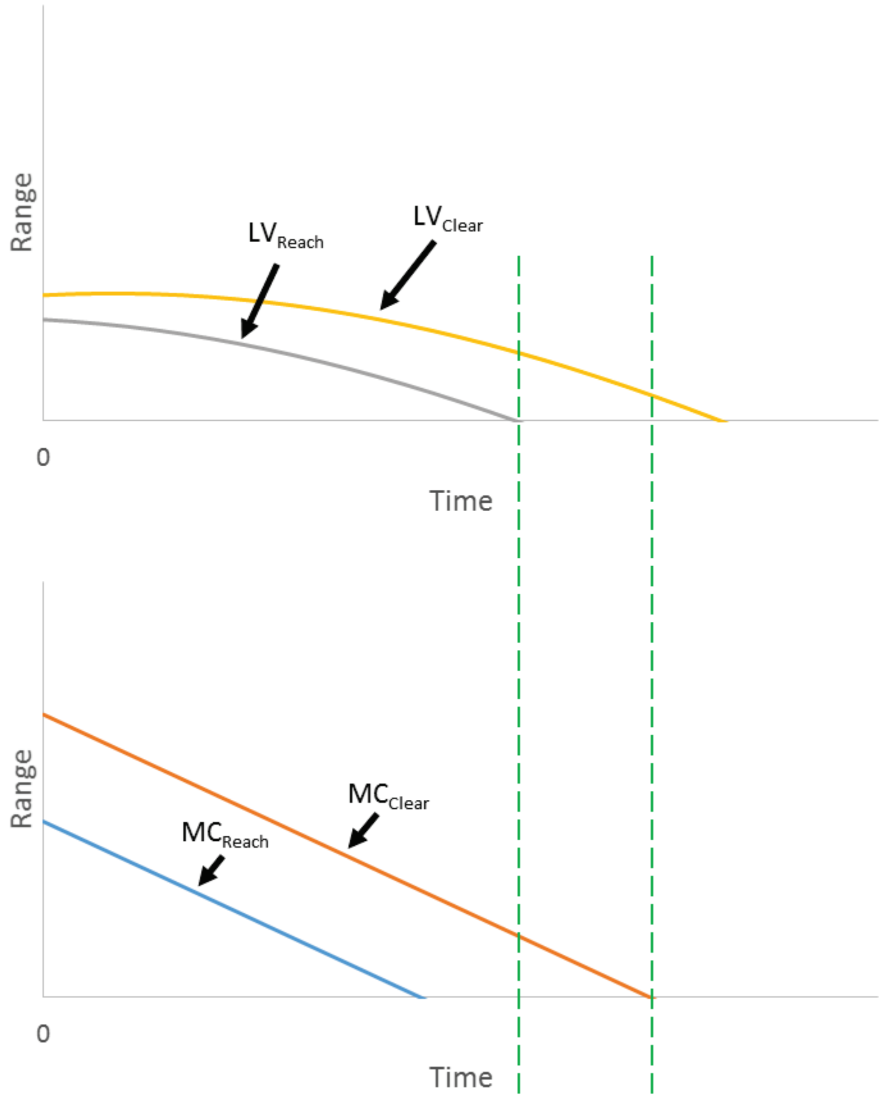


Figure 20. Timeline of the Left Turn Across Path - Opposite Direction Pre-Crash Scenario

To have the best chance at preventing a collision, a safety application will warn the turning vehicle (i.e., the motorcycle or other vehicle) as soon as it begins its turning maneuver. If the turning vehicle has its turn signal on, the safety application could interpret that as an intent to turn and could warn the turning vehicle before it begins its turning maneuver.

4.2 Left Turn Across Path, Lateral Direction

The configuration for a LTAP/LD scenario is shown in Figure 21.

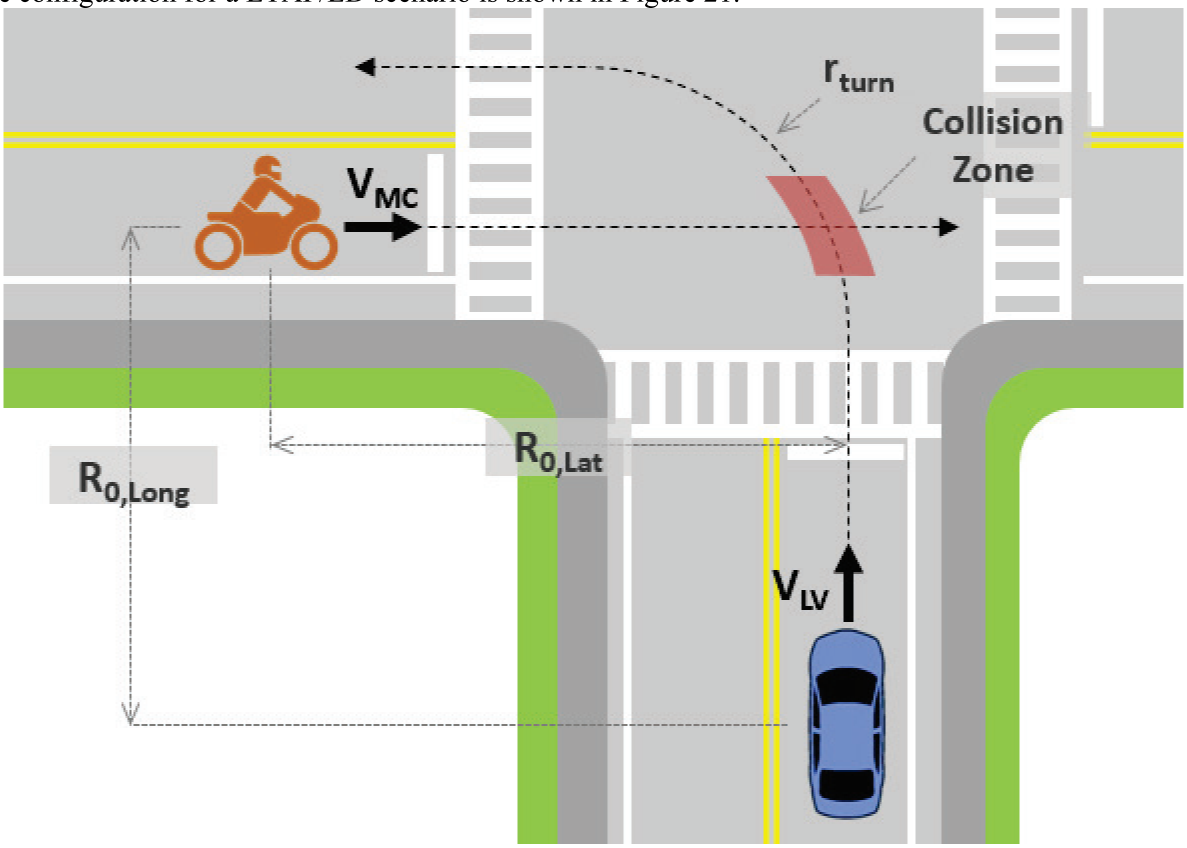


Figure 21. Left Turn Across Path - Lateral Direction Scenario Configuration

A collision will occur in this scenario if both vehicles occupy the collision zone at the same time. This relationship is expressed earlier in Equations 1 and 2. A crash will occur if both vehicles occupy the collision zone at the same time. The times at which the vehicle will enter and exit the collision zone are shown in Equations 15 and 16:

$$t_{reach,LV} = \frac{r_{turn}}{v_{LV}} \times \left[\sin^{-1}\left(\frac{R_{LV,long} - \frac{1}{2}w_{MC}}{\sqrt{\left(r_{turn} + \frac{1}{2}w_{LV}\right)^2 + \left(\frac{1}{2}l_{LV}\right)^2}} \right) - \tan^{-1}\left(\frac{\frac{1}{2}l_{LV}}{r_{turn} + \frac{1}{2}w_{LV}} \right) \right] \quad 15$$

$$t_{clear,LV} = \frac{r_{turn}}{v_{LV}} \times \left[\sin^{-1}\left(\frac{R_{LV,long} + \frac{1}{2}w_{MC}}{\sqrt{\left(r_{turn} - \frac{1}{2}w_{LV}\right)^2 + \left(\frac{1}{2}l_{LV}\right)^2}} \right) + \tan^{-1}\left(\frac{\frac{1}{2}l_{LV}}{r_{turn} - \frac{1}{2}w_{LV}} \right) \right] \quad 16$$

The times at which the motorcycle will enter and exit the collision zone are approximated in Equations 17 and 18:

$$t_{reach,MC} \cong \frac{R_{0,Lat} - \frac{1}{2}(l_{MC} + w_{LV})}{v_{MC}} \quad (17)$$

$$t_{clear,MC} \cong \frac{R_{0,Lat} + \frac{1}{2}(l_{MC} + w_{LV})}{v_{MC}} \quad (18)$$

The timeline of events in this scenario is shown below in Figure 22. The time range within the dashed green lines represents the time at which both vehicles occupy the collision zone.

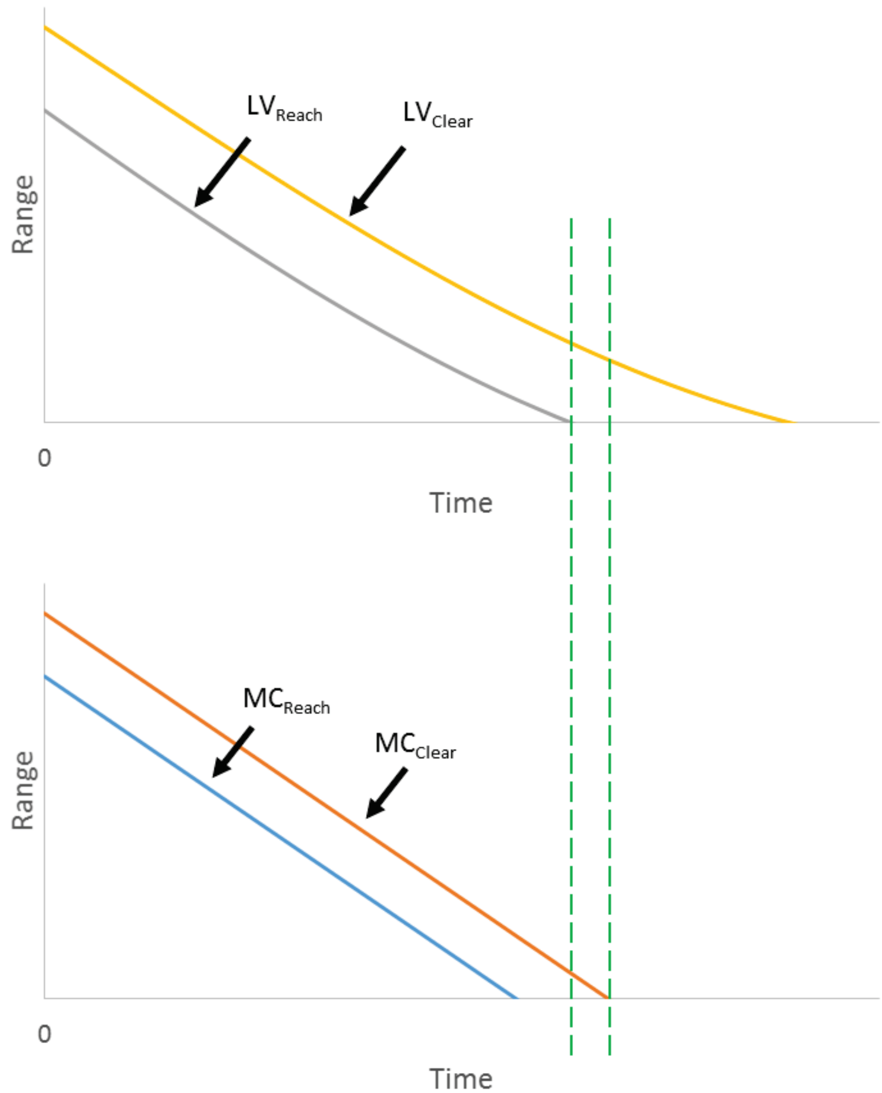


Figure 22. Timeline of the Left Turn Across Path - Lateral Direction Pre-Crash Scenario

To have the best chance at preventing a collision, a safety application will warn the turning vehicle as soon as it begins its turning maneuver. If the turning vehicle has its turn signal on, the safety application could interpret that as an intent to turn and could warn the turning vehicle before it begins its turning maneuver.

4.3 Straight Crossing Paths

The configuration for the straight crossing paths scenario is shown in Figure 23.

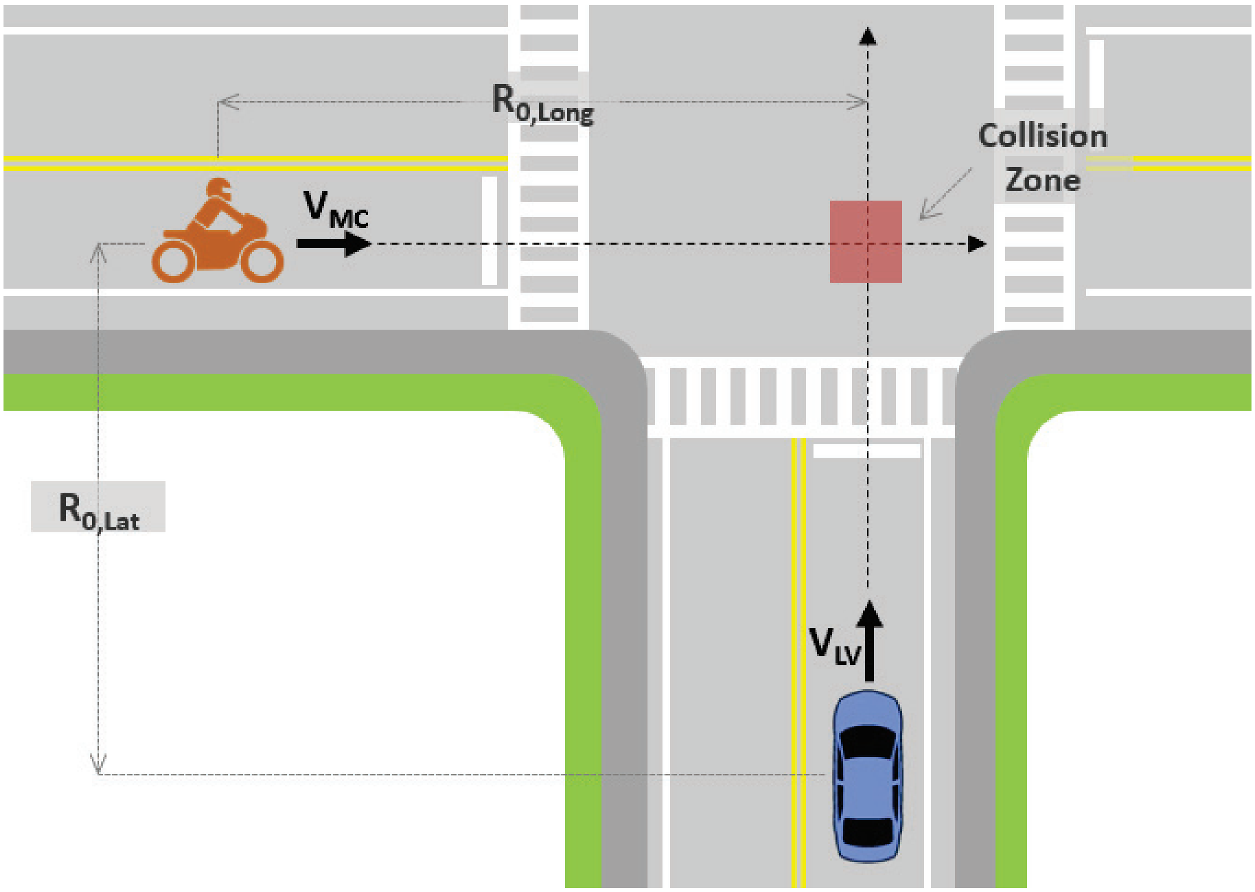


Figure 23. Straight Crossing Paths Scenario Configuration

A collision will occur in this scenario if both vehicles occupy the collision zone at the same time. This relationship is expressed earlier in Equations 1 and 2. The times at which the motorcycle reaches and clears the collision zone are shown in Equations 19 and 20:

$$t_{reach,MC} = \frac{R_{0,long} - \frac{1}{2} \times (l_{MC} + w_{LV})}{v_{MC}} \quad (19)$$

$$t_{clear,MC} = \frac{R_{0,long} + \frac{1}{2} \times (l_{MC} + w_{LV})}{v_{MC}} \quad (20)$$

The times at which the light vehicle reaches and clears the collision zone are shown in Equations 21 and 22:

$$t_{reach,LV} = \frac{R_{0,lat} - \frac{1}{2} \times (l_{LV} + w_{MC})}{v_{LV}} \quad (21)$$

$$t_{clear,LV} = \frac{R_{0,lat} + \frac{1}{2} \times (l_{LV} + w_{MC})}{v_{LV}} \quad (22)$$

If neither vehicle yields, then a crash will occur. A timeline of this pre-crash scenario is shown below in Figure 24. The time range at which both vehicles occupy the collision zone is represented as the space within the dashed green lines.

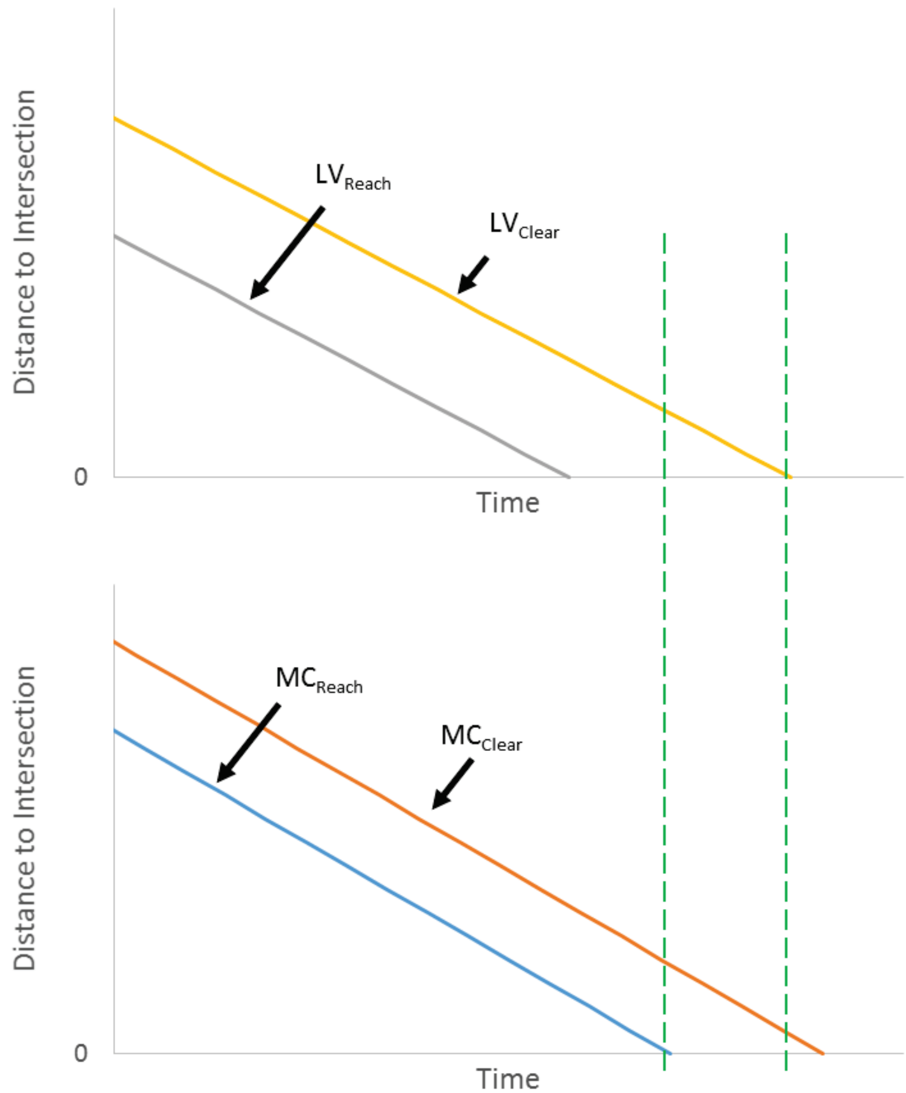


Figure 24. Timeline of Straight Crossing Paths Pre-Crash Scenario

A safety application will warn one of the vehicles in a timely manner so that it can perform a countermeasure to mitigate or avoid a collision. If one of the vehicles is coming from a stop, the safety application will warn that vehicle when it begins moving. If both vehicles are initially moving, only one vehicle will receive a warning so that they do not both perform uncoordinated countermeasures and collide with each other.

4.4 Opposite-Direction and Rear-End Crashes

The opposite-direction and rear-end scenarios, while fundamentally different, are included in the same section because of their similar kinematics. The rear-end crash type includes three significant pre-crash scenarios where the lead vehicle is either moving (LVM), stopped (LVS), or decelerating (LVD) when a crash occurs. The configurations for opposite direction are shown in Figure 25. The configurations for rear-end – LVM, rear-end – LVS, and rear-end – LVD are shown in Figures 26, 27, and 28, respectively.

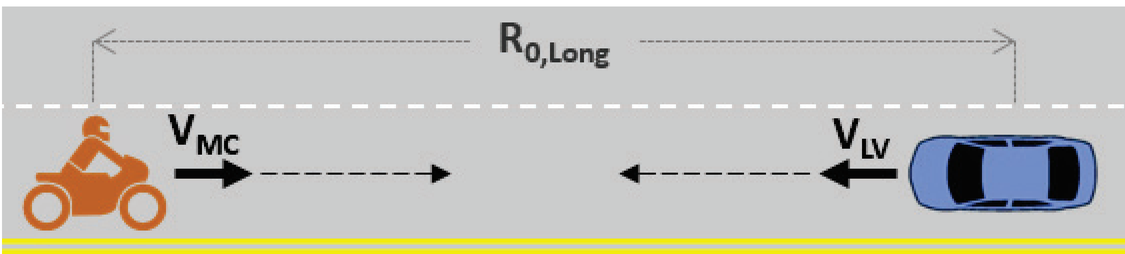


Figure 25. Opposite-Direction Scenario Configuration

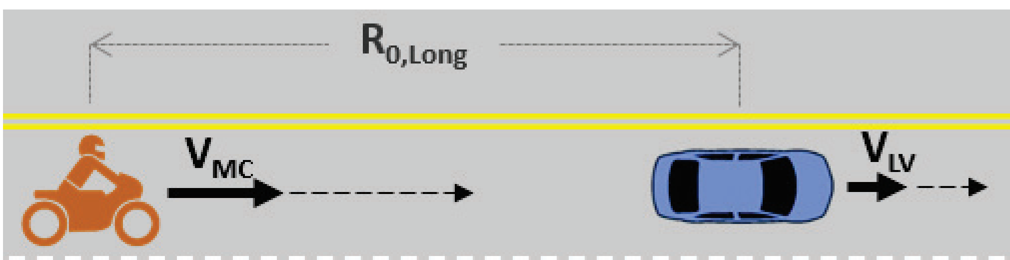


Figure 26. Rear-End - Lead Vehicle Moving Scenario Configuration

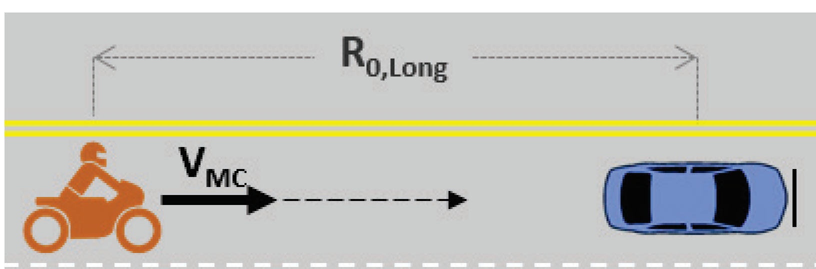


Figure 27. Rear-End - Lead Vehicle Stopped Scenario Configuration

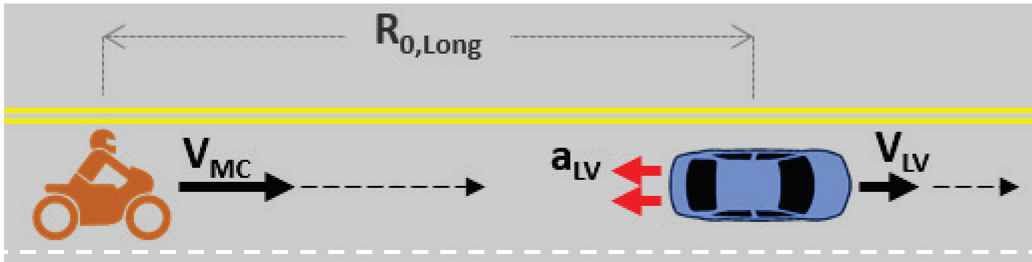


Figure 28. Rear-End - Lead Vehicle Decelerating Scenario Configuration

If the motorcycle does not yield to the forward presence of the light vehicle, then a collision will occur. The times-to-collision (TTCs) are shown in Equations 23, 24, 25, and 26 for the opposite-direction and rear-end pre-crash scenarios:

$$TTC_{Opp.Dir.} = \frac{R_{0,long} - \frac{1}{2}(l_{MC} + l_{LV})}{v_{MC} + v_{LV}} \quad (23)$$

$$TTC_{LVM} = \frac{R_{0,long} - \frac{1}{2}(l_{MC} + l_{LV})}{v_{MC} - v_{LV}} \quad (24)$$

$$TTC_{LVS} = \frac{R_{0,long} - \frac{1}{2}(l_{MC} + l_{LV})}{v_{MC}} \quad (25)$$

$$TTC_{LVD} = \frac{(v_{MC} - v_{LV}) - \sqrt{(v_{MC} - v_{LV})^2 - 2 * \left[R_{0,long} - \frac{1}{2}(l_{MC} + l_{LV})\right] * a_{LV}}}{a_{LV}} \quad (26)$$

The timeline of these pre-crash scenarios is shown in Figure 29. The dashed green lines represent the separate TTCs for each pre-crash scenario.

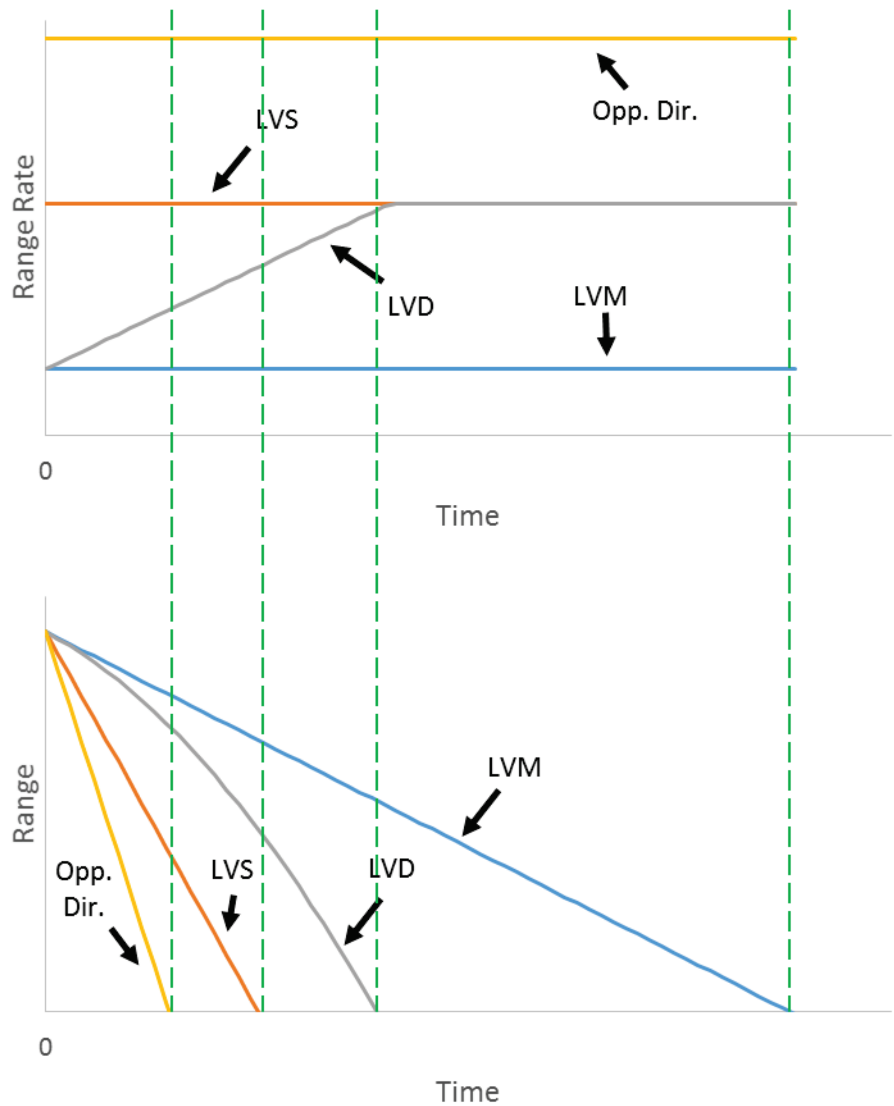


Figure 29. Timeline of Opposite-Direction and Rear-End Pre-Crash Scenarios

As the range rate increases in these scenarios, the TTC decreases and the driver would have less time to react to a warning. It is important that warnings be issued in a timely manner for all potential crashes to allow drivers enough time to perform a countermeasure.

4.5 Lane-Change Crashes

There are two main types of priority lane-change pre-crash scenarios. These are the scenarios where:

- The vehicle leaving its lane is turning and cuts off the other vehicle, and
- The vehicle leaving its lane is changing lanes into the lane of the other vehicle.

The configuration for these lane-change scenarios, “turning, same direction” and “changing lanes, same direction” are shown in Figures 30 and 31, respectively.

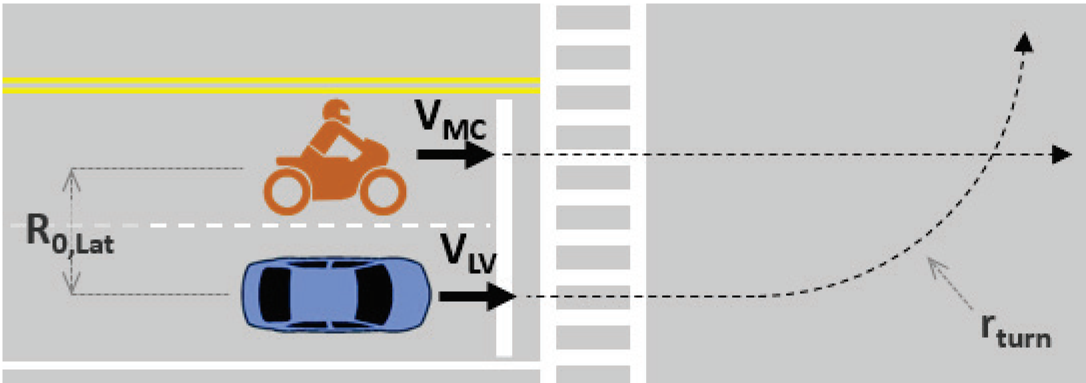


Figure 30. Turning, Same Direction Scenario Configuration

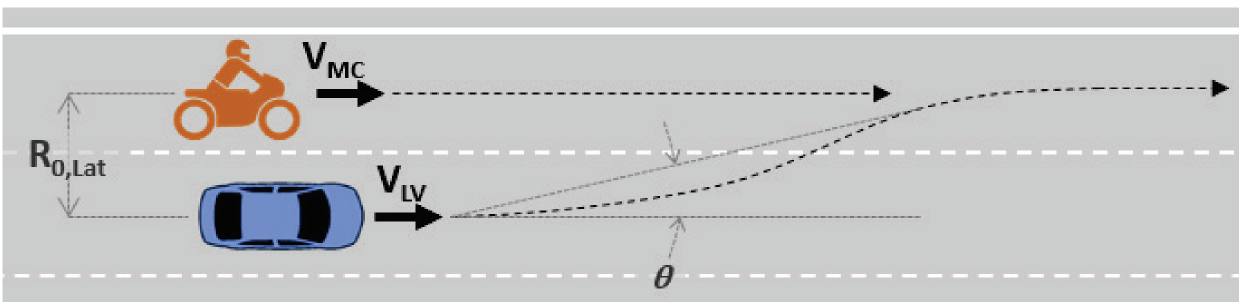


Figure 31. Changing Lanes, Same Direction Scenario Configuration

A collision will occur in both scenarios when the interior side of the light vehicle impacts the motorcycle. The TTCs in these scenarios are approximated in Equations 27 and 28 for the turning and changing lanes configurations, respectively:

$$TTC_{Turning} = \frac{h\alpha}{v_{LV}} \quad (27)$$

$$TTC_{Changing\ Lanes} \cong \frac{R_{0,lat} - \frac{1}{2}(w_{MC} + w_{LV})}{v_{LV} \times \sin\theta} \quad (28)$$

The variable, θ, is the average change in heading of the changing-lanes light vehicle. The variables α and h are described in Equations 29 and 30, respectively:

$$\alpha = \cos^{-1}\left(\frac{r_{turn} + \frac{1}{2}w_{MC} - R_{0,lat}}{h}\right) - \tan^{-1}\left(\frac{l_{LV}}{2r_{turn} + w_{LV}}\right) \quad (29)$$

$$h = \sqrt{\left(\frac{1}{2}l_{LV}\right)^2 + \left(r_{turn} - \frac{1}{2}w_{LV}\right)^2} \quad (30)$$

A timeline of the two lane-change pre-crash scenarios is shown below in Figure 32. It includes the horizontal distance between the two vehicles and the difference in heading between the motorcycle and light vehicle throughout the maneuver. The dashed green lines represent the separate TTCs for each pre-crash scenario.

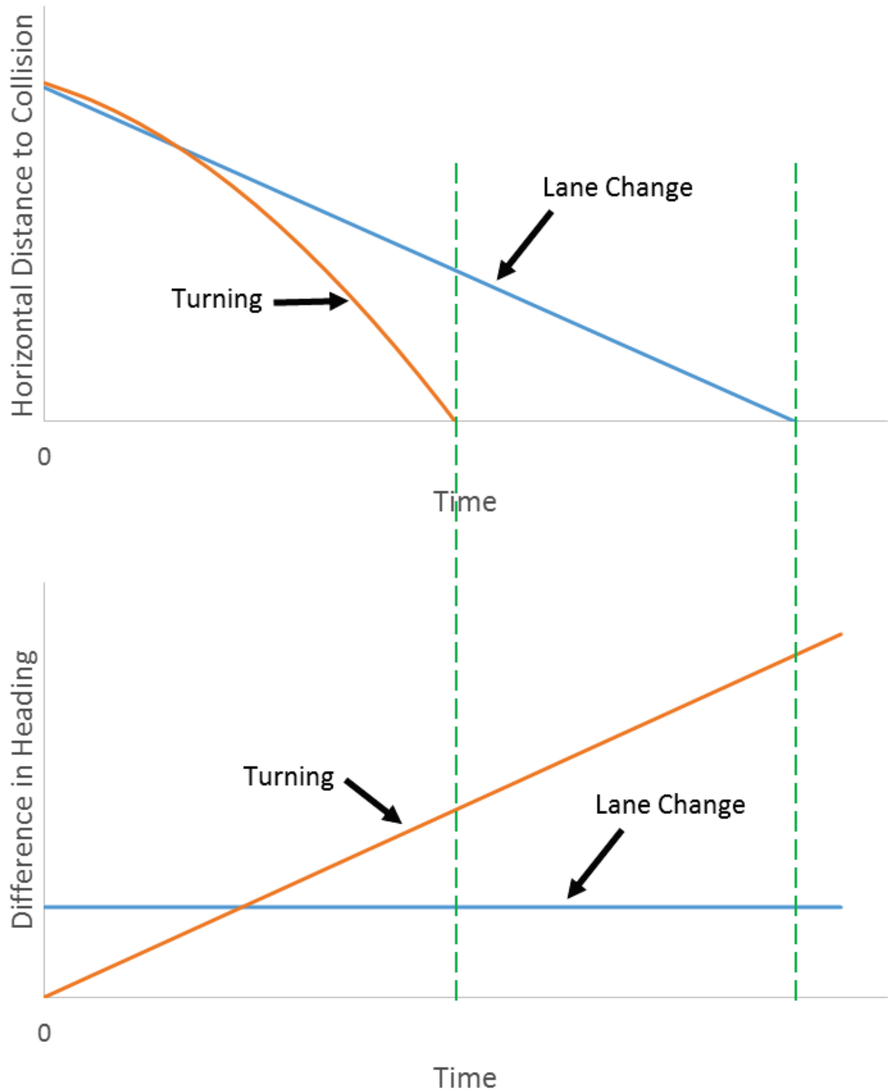


Figure 32. Timeline of the Lane-Change Pre-Crash Scenarios

To have the best chance at preventing a collision, a safety application will warn the turning vehicle as soon as it begins its turning maneuver. If the turning vehicle has its turn signal on, the safety application could interpret that as an intent to turn and could warn the turning vehicle before it begins its turning maneuver.

4.6 Single-Vehicle Crashes

The motorcycle "control loss with no vehicle action" and "road departure with no maneuver" pre-crash scenarios are single-vehicle crashes and may potentially benefit from vehicle-based technologies that alert drivers to adverse road conditions, dangerous curves in road, or other hazards. However, these control losses and road departures are both the two most frequent and the two costliest motorcycle pre-crash scenarios.

A depiction of the configurations for these control-loss and road-departure scenarios is shown in Figures 33 and 34, respectively.

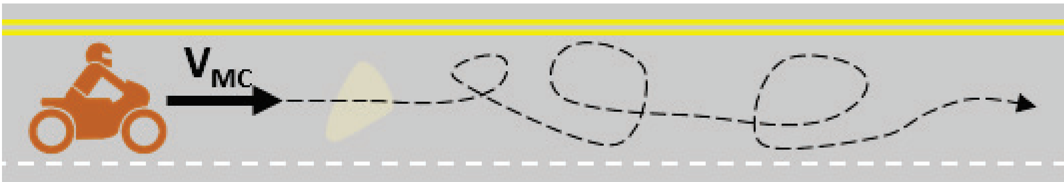


Figure 33. Control-Loss Scenario Configuration

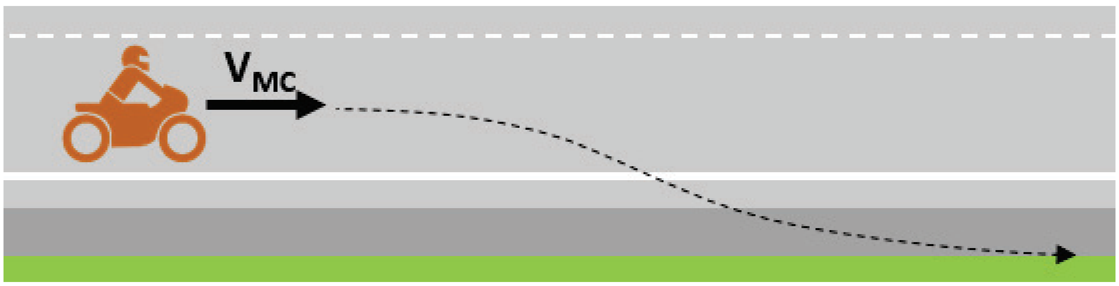


Figure 34. Road-Departure Scenario Configuration

While these scenarios may not be prevented using V2M technology, they could be prevented or mitigated with other methods such as:

- Vision-based crash avoidance systems,
- On-board GPS mapping,
- Motorcycle-to-infrastructure safety applications,
- Anti-lock braking systems, or
- Crowd-sourced applications that allow some drivers to alert other drivers of road hazards.

4.7 Crash Avoidance Requirements

A summary of the possible crash avoidance requirements associated with avoiding the crashes in the priority pre-crash scenarios is listed in Table 8. The information is organized by pre-crash scenario group and denotes similar light-vehicle crash avoidance technology that can address the similar pre-crash scenarios. It also identifies the similarities among the technology applicable to motorcycle crashes. The main consideration of applying crash avoidance technology to motorcycles as compared to a light vehicle is that motorcycles are faced with different dynamic challenges than vehicles with four wheels. This difference results in stability issues when the sudden braking or steering requirements of the crash technology are applied to a motorcycle. Also when compared to a light vehicle, a motorcycle is subject to many more circumstances that can cause stability issues. Various situations such as potholes, objects in road, slick or grooved pavement, etc. subject a motorcycle to crash more easily than a light vehicle and very often, the injury sustained in the crash is fatal.

Table 8. Crash Avoidance Requirements and Comparison to Light-Vehicle Technology

<table>
<tr><th>Scenario Group</th><th>Pre-Crash Scenario</th><th>Crash Avoidance Measure</th><th>Examples of Light-Vehicle (LV) Crash Avoidance Technology to Address Crashes</th><th>Is the LV Crash Avoidance Technolgy Applicable to Motorcycle?</th><th>Additional Motorcycle Crash Avoidance Concerns/ Issues</th></tr>
<tr><td>Control Loss</td><td>Control Loss with No Vehicle Action</td><td>Stabilize Vehicle</td><td>Electronic Stability Control</td><td>Yes</td><td rowspan="7">• Motorcycles tip over easily/the driver must maintain balance of the motorcycle

• Braking/steering may cause additional instability and difficult maneuverability

• The size of the motorcycle creates issues of visibility

• Difficult for other vehicles to judge the distance and speed of the motorcycle

• Motorcycles can drive between lanes

• Equipment adds weight to motorcycle</td></tr>
<tr><td>Road Departure</td><td>Road Departure / No Maneuver</td><td>Steering</td><td>Lane and Road Departure Warning Systems</td><td>Yes</td></tr>
<tr><td>LTAP/OD</td><td>LTAP/OD</td><td>Steering, Braking, Accelerating</td><td>Left Turn Assist</td><td>Yes</td></tr>
<tr><td>Crossing Paths</td><td>Straight Crossing Paths, LTAP/LD</td><td>Steering, Braking, Accelerating</td><td>Intersection Movement Assist</td><td>Yes</td></tr>
<tr><td>Rear-End</td><td>LVS, LVM, LVD</td><td>Steering, Braking</td><td>Forward Collision Warning,
Automatic Emergency Braking</td><td>Yes</td></tr>
<tr><td>Lane Change</td><td>Changing Lanes or Turning/Same Direction</td><td>Steering</td><td>Lane Departure Warning Systems,
Blind Spot Detection</td><td>Yes</td></tr>
<tr><td>Opposite Direction</td><td>Opposite Direction</td><td>Steering</td><td>Lane-Keeping Support</td><td>Yes</td></tr>
</table>

5 Conclusion

This report defined the motorcycle crash problem, including the identification and characterization of pre-crash scenarios that serve as a basis for the development of applicable crash avoidance systems. This analysis focused on pre-crash scenarios that could be addressed by V2M technology applications. Such applications have the potential to prevent an impending collision between a motorcycle and another vehicle through the use of wireless communication. The applications may use warnings to alert drivers of the motorcycle or the other vehicles and, if no action is taken, may take control of the other vehicles or motorcycle, if at all possible, to prevent the crash.

National crash data from the 2011 to 2015 FARS and GES databases were queried to quantify motorcycle crashes and to identify their per-crash scenarios. Eleven priority pre-crash scenarios were chosen for further analysis, which involved motorcycles in the critical event of the crashes. These 11 pre-crash scenarios represented 3,779 (81 percent) fatal crashes, about 71,000 (70 percent) crashes of all severities, and 79 percent of the comprehensive costs of motorcycle crashes. These priority scenarios included single-vehicle crashes such as control loss and road departure, and multi-vehicle crashes such as left turn across path, lane change, opposite direction, rear-end, and lateral crossing paths.

There were 3 prominent pre-crash scenarios that ranked the highest in fatal crashes, all crashes, and comprehensive costs. Of these 3 pre-crash scenarios, 2 were single-vehicle crash scenarios: control loss and road edge departure. These 2 scenarios accounted for 37 percent of fatal motorcycle crashes, 24 percent of all motorcycle crashes, and 33 percent of their comprehensive costs. Such scenarios could potentially benefit from the use of vehicle-based crash technology to avoid the associated crashes. The third prominent pre-crash scenario was the two-vehicle LTAP/OD scenario that accounted for 13 percent of fatal crashes, 9 percent of all crashes, and 12 percent of the comprehensive costs.

This report statistically described the 11 priority pre-crash scenarios in terms of environmental conditions, vehicle role, road geometry, and other contributing factors. Table 9 provides a summary of the fatal two-vehicle crash percentages of some characteristics for the motorcycle and the other vehicles based on the vehicle's role in the crash. Similar information is shown for the control-loss and road-departure single-vehicle crashes in Table 10.

Speeding statistics were much higher for motorcyclists than for drivers of the other vehicles in all the fatal priority pre-crash scenarios involving two vehicles. The same was true for alcohol involvement. In the two single-vehicle pre-crash scenarios, motorcyclists was speeding in 67 percent of fatal road-departure crashes and 42 percent of fatal control-loss crashes. Moreover, motorcyclists was under the influence of alcohol in 49 percent of fatal road-departure crashes and 41 percent of fatal control-loss crashes.

When considering driver impairment, the fatal crash percentages were more comparable between motorcyclists and drivers of the other vehicles. The exception was in the opposite-direction pre-crash scenario where drivers of the other vehicles was impaired in 41 percent of fatal crashes, compared to the motorcyclist's impairment in 17 percent of fatal crashes. Drivers of the other vehicles was distracted more than motorcyclists in all pre-crash scenarios except for the turning, same-direction scenario.

Table 9. Priority Two-Vehicle Fatal Crash Percentages by Pre-Crash Scenario, Vehicle Role, and Crash Characteristics

Crash Characteristic	Vehicle	Rear-End	LTAP/OD	Lateral Crossing Paths		Opposite Direction	Lane Change	
		Priority Pre-Crash Scenario						
		LVS, LVD, LVM	LTAP/OD	LTAP/LD	Straight Crossing Paths	Opposite Direction/ No Maneuver	Turning, Same Direction	Changing lanes
		Vehicle Role						
		Striking vehicle	Left-Turning Vehicle	Left-Turning Vehicle	Driving straight	Drifting only	Turning only	Changing lanes only
Driver's Speed Related to the Crash	**Motorcycle**	39%-59%	1%	2%	22%	25%	5%	34%
	Other Vehicle	31%-38%	1%	<1%	2%	10%	<1%	7%
Driver Drinking	**Motorcycle**	21%-46%	24%	18%	19%	34%	19%	27%
	Other Vehicle	10%-24%	8%	6%	5%	29%	5%	8%
Driver Impaired	**Motorcycle**	11%-23%	11%	16%	8%	17%	15%	12%
	Other Vehicle	14%-26%	8%	6%	5%	41%	5%	7%
Driver Distracted	**Motorcycle**	11%-21%	6%	6%	3%	4%	13%	6%
	Other Vehicle	21%-39%	8%	9%	6%	22%	5%	7%
Vehicle on Curved Road	**Motorcycle**	5%-7%	5%	2%	4%	63%	10%	16%
	Other Vehicle	2%-10%	4%	4%	2%	41%	6%	10%
Vehicle on Unlevel Road	**Motorcycle**	20%-22%	10%	27%	15%	41%	24%	21%
	Other Vehicle	21%-23%	16%	12%	13%	36%	17%	17%
Driver Vision Obstruction	**Motorcycle**	1%-3%	4%	4%	3%	3%	<1%	1%
	Other Vehicle	2%-5%	6%	10%	6%	2%	1%	2%

Priority Group

Table 10. Priority Single-Vehicle Fatal Crash Percentages by Pre-Crash Scenario and Crash Characteristics

Characteristic	Priority Scenario	
	Average 2011-2015 FARS	
	Road Departure/ No Vehicle Action	Control Loss/ No Maneuver
Driver's Speed Related to the Crash	67%	42%
Driver Drinking	49%	41%
Impaired	26%	24%
Distracted	8%	6%
Curve Road	69%	64%
Not Level Road	35%	39%
Vision Obstruction	1%	1%

Finally, crashes involving motorcycles can present unique issues and challenges to the development of applicable crash avoidance systems. Motorcycle stability and maneuverability are major factors for consideration in setting requirements for crash avoidance technologies. Motorcycles may lose control easily during braking or turning maneuvers, or experience decreased braking ability, diminished turning capability, and limited traction in turns, as compared to other vehicles types. Moreover, the size of the motorcycle creates issues of visibility (i.e., other drivers do not see the motorcycle) and makes it difficult for other vehicles to judge the distance and speed of the motorcycle. Crash avoidance technologies (e.g., forward collision warning, blind spot warning, lane departure warning) in use on light-vehicles could also potentially work for motorcycle use. The transferability of the crash avoidance technology to motorcycles, the weight that the technology adds to the motorcycle, and the public's acceptance of the technology (e.g., people may turn off systems) are just some of the issues faced when exploring these application of this advanced technologies to motorcycles.

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Appendix A: Pre-Crash Scenario Descriptions

A description for each of the 36 pre-crash scenarios is shown below. Diagrams related to the intersection crashes, scenarios 25 to 30, are also shown in Figure 35 for better understanding of the vehicle positions and movements.

1. Vehicle Failure - A vehicle crashes due to a component/mechanical problem or failure (e.g., tire blowout, steering issue).
2. Control Loss/Vehicle Action - A vehicle loses control while performing a maneuver (e.g., passing, turning at an intersection).
3. Control Loss/No Vehicle Action - A vehicle loses control while driving straight or negotiating a curve.
4. Road Edge Departure/Maneuver - A vehicle departs the road while performing a maneuver (e.g., passing, turning, changing lanes).
5. Road Edge Departure/No Maneuver - A vehicle departs the road while driving straight or negotiating a curve.
6. Road Edge Departure/Backing - A vehicle departs the road while backing.
7. Animal/Maneuver - A vehicle impacts an animal while performing a maneuver (e.g., passing, turning).
8. Animal/No Maneuver - A vehicle impacts an animal while driving straight or negotiating a curve.
9. Pedestrian/Maneuver - A vehicle impacts a pedestrian while performing a maneuver (e.g., passing, turning).
10. Pedestrian/No Maneuver - A vehicle impacts a pedestrian while driving straight or negotiating a curve.
11. Pedalcyclist/Maneuver - A vehicle impacts a pedalcyclist while performing a maneuver (e.g., passing, turning).
12. Pedalcyclist/No Maneuver - A vehicle impacts a pedalcyclist while driving straight or negotiating a curve.
13. Backing into Vehicle - A vehicle collides with another vehicle while backing.
14. Turning/Same Direction - A vehicle turns and cuts across the path of another vehicle initially traveling in the same direction.
15. Parking/Same Direction - A vehicle is entering or leaving a parked position and collides with another vehicle.
16. Changing Lanes/Same Direction - A vehicle changes lanes and encroaches into another vehicle traveling in the same direction.
17. Drifting/Same Direction - A vehicle drifts into an adjacent vehicle traveling in the same direction.
18. Opposite Direction/Maneuver - A vehicle makes a maneuver (e.g., passing) and encroaches into another vehicle traveling in the opposite direction.
19. Opposite Direction/No Maneuver - A vehicle drifts and encroaches into another vehicle traveling in the opposite direction.
20. Rear-End/Striking Maneuver - A vehicle changes lanes or passes another vehicle, and closes in on a vehicle ahead in the same lane.
21. Rear-End/Lead Vehicle Accelerating (LVA) - A vehicle closes in on an accelerating lead vehicle ahead in the same lane.
22. Rear-End/Lead Vehicle Moving (LVM) - A vehicle closes in on a moving vehicle ahead in the same lane.
23. Rear-End/Lead Vehicle Decelerating (LVD) - A vehicle closes in on a decelerating lead vehicle ahead in the same lane.
24. Rear-End/Lead Vehicle Stopped (LVS) - A vehicle closes in on a stopped lead vehicle ahead in the same lane.

25. Right Turn into Path (RTIP) - A vehicle is turning right at an intersection and turns into the same direction of another vehicle crossing from a lateral direction (Figure 35).
26. Right Turn Across Path (RTAP) - A vehicle is turning right at an intersection and turns into the opposite direction of another vehicle crossing from a lateral direction (Figure 35).
27. Straight Crossing Paths (SCP) - A vehicle is going straight and collides with another straight crossing vehicle from a lateral direction at an intersection (Figure 35).
28. Left Turn Across Path, Lateral Direction (LTAP/LD) - A vehicle turns left at an intersection and crosses the path of another vehicle traveling in the opposite direction from a lateral direction (left) (Figure 35).
29. Left Turn into Path (LTIP) - A vehicle turns left at an intersection and turns into the path of another vehicle traveling in the same direction from a lateral direction (right) (Figure 35).
30. Left Turn Across Path, Opp. Dir. (LTAP/OD) - A vehicle turns left at an intersection and crosses the path of another vehicle traveling in the opposite direction (Figure 35).
31. Avoidance/Maneuver - A vehicle attempts a maneuver to avoid something while turning, passing, etc.
32. Avoidance/No Maneuver - A vehicle attempts a maneuver to avoid something while driving straight or negotiating a curve.
33. Non-Collision / No Impact - A vehicle makes no contact with another vehicle but it experiences a damaging or injury-producing event (fire, an occupant fell/jumped from vehicle, etc.).
34. Object/Maneuver - A vehicle impacts an object while performing a maneuver (e.g., passing, turning).
35. Object/No Maneuver - A vehicle impacts an object while driving straight or negotiating a curve.
36. Other - Includes rollovers, hit-and-runs, and other crashes where specific details are missing to accurately define the scenario.

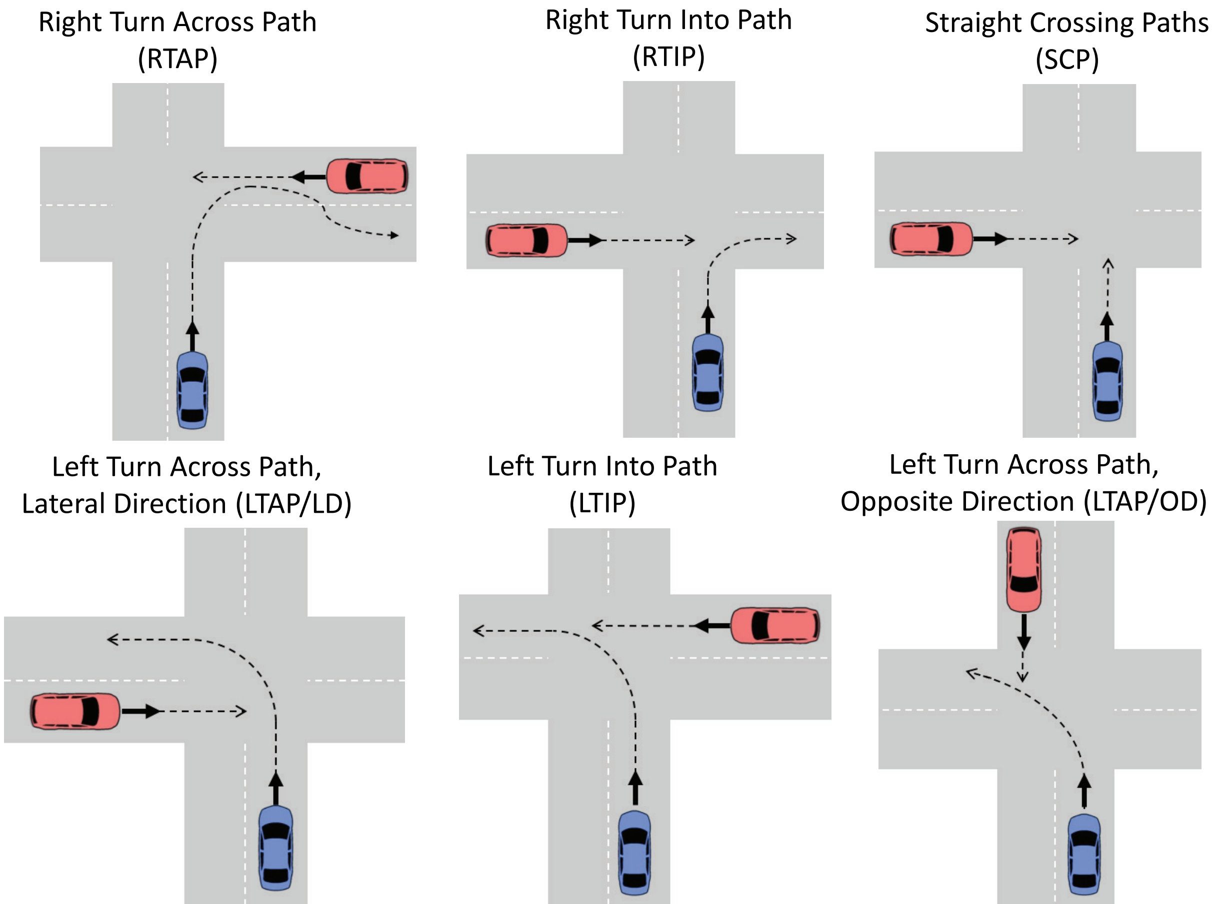
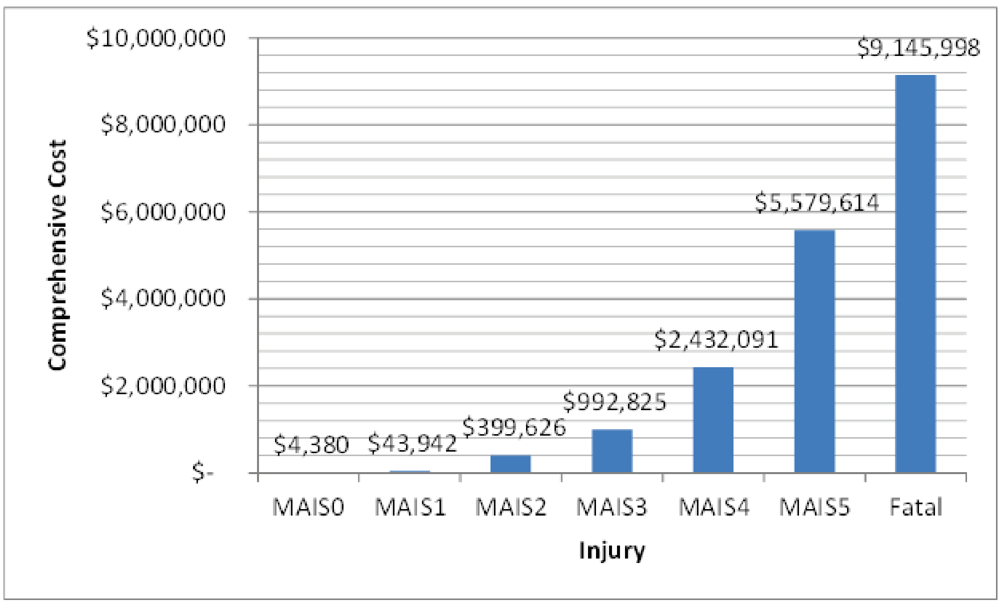


Figure 35. Schematics of Intersection Pre-Crash Scenarios

Appendix B: Comprehensive Costs

Comprehensive costs are the costs associated with the outcome of the crash based on the subsequent injury. They include costs associated with lost productivity, medical costs, legal and court costs, emergency service costs, insurance administration costs, travel delay, property damage, and workplace losses. Intangible consequences of the crash, such as pain and suffering or loss of life, are also included. Comprehensive costs also include the value of quality-adjusted life-years. The comprehensive costs are based on injuries using the Maximum Abbreviated Injury Scale (MAIS) while the FARS and GES databases report injuries using the KABCO[10] scale. The KABCO non-fatal injuries reported in the GES need to be translated into MAIS values. Appendix C contains details on how this conversion is done. To calculate a more precise cost of the crashes, the fatalities from FARS replace those in GES since fatalities in FARS are actual counts and those in GES represent a weighted sample.

The comprehensive cost is computed from the maximum injury of all the injured people involved in a specific crash using the Abbreviated Injury Scale (AIS). The AIS is a classification system for assessing impact injury severity developed by the Association for the Advancement of Automotive Medicine. It provides the basis for stratifying the economic costs of crashes by injury severity. The MAIS is a function of AIS on a single injured person, which measures overall maximum injury severity. Figure 36 illustrates the values of comprehensive cost associated with each MAIS level based on 2010 economics (Blincoe et al., 2015).



Note: Costs are per-person for all injury levels.

Figure 36. Comprehensive Cost by MAIS Level

Since detailed information regarding injury severity in FARS and GES is retrieved from police reports, the KABCO scale is used to classify injuries versus the AIS scale. The KABCO scale classifies crash victim injuries as: K - killed, A - incapacitating injury, B - non-incapacitating injury, C - possible injury, O - no apparent injury, or ISU - injury severity unknown. The KABCO coding scheme allows non-medically trained people to make on-scene injury assessments without a hands-on examination. The

[10] The KABCO scale is used for classifying injuries. Refer to Appendix C for more information regarding the individual classifications.

possibility exists that the KABCO ratings are imprecise and inconsistently coded between States and over different years. Table 11 provides the matrix for KABCO to MAIS injury severity conversion.

Table 11. Injury Severity Scale Conversion Matrix

KABCO-to-MAIS Conversion Table							
MAIS	Police-Reported Injury Severity System						
	O	C	B	A	K	U	
	No Injury	Possible Injury	Non Incapacitating	Incapacitating	Fatality	Injured, Severity Unknown	Unknown
0	0.92535	0.23431	0.08336	0.03421	0.00000	0.21528	0.42930
1	0.07257	0.68929	0.76745	0.55195	0.00000	0.62699	0.41027
2	0.00198	0.06389	0.10884	0.20812	0.00000	0.10395	0.08721
3	0.00008	0.01071	0.03187	0.14371	0.00000	0.03856	0.04735
4	0.00000	0.00142	0.00619	0.03968	0.00000	0.00442	0.00606
5	0.00003	0.00013	0.00101	0.01775	0.00000	0.01034	0.00274
Fatal	0.00000	0.00025	0.00128	0.00458	1.00000	0.00046	0.01707
Total	1.00001	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000

Appendix C: Variable Definitions

1. Clear Weather - the atmospheric conditions at the time of the crash were clear (includes cloudy).
2. Non-Daylight - the lighting conditions were dark without street lighting, dark and unknown if street lighting present, dawn, and dusk conditions.
3. Motorcyclist Fatality - an occupant of the motorcycle had a fatal injury.
4. Dry Road - the road surface condition that would have most affected the vehicle's traction at the time of the crash was dry and not wet/slippery.
5. Not Level - the vertical alignments of the road the vehicle was traveling on prior to the crash included: uphill, downhill, hillcrest, sag (bottom), and graded with an unknown slope.
6. Curve - the road that the vehicle was traveling on prior to the crash was curved to the right or left, or curved in an unknown direction.
7. Driveway Access - the portion of the traffic way at the end of a driveway. The vehicle was not on a traffic way but was entering/leaving one prior to its critical pre-crash event.
8. Vision Obstruction - any obstructions to the driver's field of vision including:
    a. External objects – vehicles, buildings, signs, trees, etc.
    b. Internal objects – blind spots, stickers, mirrors, etc.
    c. Weather conditions - rain, snow, fog, smoke, sand, dust, sunlight glare, etc.
    d. Roadway environment – curves, hills, roadway design feature, etc.
9. Distraction - circumstances that cause the driver to lose attention (e.g., talking, eating, smoking, using devices, moving objects, daydreaming, etc.). Note that the police reports may have underestimated accounts of distraction since a driver may not report the distraction
10. Impaired - any physical impairment of the driver of the vehicle that may have contributed to the crash including the influence of alcohol, drugs, medication, sickness, blackout, drowsiness (sleepy or fatigued), physical impairment, emotional (depressed, angry, disturbed, etc.).
11. Driver Drinking - describes cases of alcohol involvement of the driver where the law enforcement believes and report that alcohol was present. It also includes cases where alcohol was reported but legal tests were under the limits.
12. Speed Related - the police report identifies that the driver's speed was related or a contributing factor to the crash.
13. Body Type - Light Vehicle - includes all passenger cars, vans, minivans, sport utility vehicles, or light pickup trucks with a gross vehicle weight rating ≤ 10,000 pounds.

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