Task B: MCCS Data Analysis Report and Literature Review

Final Report

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TABLE OF CONTENTS

TABLE OF TABLES

INTRODUCTION

Overview

While great strides have been made over the past 20 years in reducing the frequency of overall traffic fatalities in the United States (NHTSA, 2016), the data portray a very different perspective with respect to motorcycle crashes. The number of rider fatalities has more than doubled from 2,227 in 1995 to 5,286 by 2016 (NHTSA, 1997, 2017). The increase from 2015 to 2016 alone was a staggering 5.1% (NHTSA, 2017). The magnitude of the motorcycle safety problem is further demonstrated when the number of fatalities in relation to total traffic fatalities as well as the time at-risk of a crash as estimated by vehicle miles travelled is considered. In 1995, rider fatalities accounted for five percent of all fatalities (NHTSA, 1996). This proportion increased nearly three-fold to 14 percent in 2015. This is a significant overrepresentation given that in 2015, motorcycles accounted for less than one percent of all vehicle miles travelled and three percent of all registered vehicles (NHTSA, 2017).

In addition, motorcycle riders are far more likely to die or be injured in a crash compared to other motorists. In 2015, motorcycle riders were 29 times as likely to die in a crash compared to occupants in vehicles (NHTSA, 2016). Based on the rate of injury per vehicle mile traveled, motorcycle riders are nearly 5 times as likely as vehicle occupants to sustain an injury in a crash. In addition to the tremendous number of lives lost each year in motorcycle crashes, a number of riders may experience debilitating nonfatal injuries with the potential to cause long-term health problems and decreased quality of life. In 2015 alone, 88,000 motorcycle riders were injured in crashes (NHTSA, 2017). It is clear from the magnitude of the motorcycle safety problem and from fatality and injury data that there is a significant opportunity to impact overall transportation safety for this high-risk road-user group.

Motorcycle Safety Research

Compared to passenger vehicles, there is very little research focusing on rider safety, particularly with respect to the identification or evaluation of infrastructure-based safety countermeasures. This traditional approach to rider safety is exemplified by the fact that the design standards that guide roadway design in the United States generally focus on a passenger vehicle where the driver's eye height is assumed to be 3.5 feet above the pavement surface, and the vehicle's response to roadway horizontal curvature and associated cross slope is based on dynamics that assume a vehicle with four wheels (AASHTO, 2010). Roads and even highway exit ramps are designed to accommodate heavy trucks and buses. The design standards do not consider similar rider and motorcycle characteristics.

The limited number of studies examining motorcycle safety provided detailed descriptive analyses of the circumstances surrounding the crash, including in-depth examinations of risk factors at the person and vehicle levels (see Table 1 for a summary of the key studies that have examined overall motorcycle safety). Considerable evidence from these studies supports countermeasures targeting the increased use of helmets and decreased riding while impaired by alcohol (Goodwin et al., 2015). These studies did provide some evidence for the utility of infrastructure-based motorcycle crash countermeasures. However, despite these investigations, the role of infrastructure in motorcycle crash causation has yet to be substantially explored. Although there are some exceptions. Recently the Federal Highway Administration created the Motorcycle Advisory Council and conducted both international and domestic scans for motorcycle crash countermeasures.

Table 1. Key Motorcycle Studies in the United States and Europe.

Study	Years of Crash Data	Study Design and Sample	Geographic Location	Infrastructure or Infrastructure Related Variables
Hurt Report (Hurt et al., 1981)	1978-1979	Case / control analysis 900 crashes / 505 scene revisits. 2310 interviews; 3600 police reports.	Los Angeles, CA	• Blatant roadway defects. • Roadway functional class/roadway type, intersection type, traffic density, traffic controls, view obstructions.
MAIDS (Motorcycle Accidents In-Depth Study [ACEM, 2009,])	1999-2000	Case / control analysis 921 crashes / 923 controls. Motorcycles, mopeds, and scooters.	France, Germany, Netherlands, Spain, Italy	• High level roadway type, alignment, condition, defects, barriers, and traffic controls.
MSF 100 Motorcyclists Naturalistic Study (Williams et al., 2015)	2011-2012	Naturalistic driving study 100 scooters & motorcycles.	Arizona, California, Florida, and Virginia	• High level examination of intersection versus non-intersection and surface type.
Comprehensive Analysis of Motorcycle Crashes in Texas (Shipp et al., 2016)	2010-2015	All motorcycle crash records 2010-2015. Person, vehicle, and environmental factors.	Texas-statewide	• Roadway geometry, functional classification, roadway type, intersection type, and manner of collision in relation to the roadway.
FHWA MCCS (Motorcycle Crash Causation Study [Nazemetz et al., 2016])	2011-2016	Case / control analysis of 351 crashes / 702 control rider interviews	Orange County, CA	• Extensive infrastructural variables collected.

Project and Task Objectives

The overall project goal is to create a plan to develop and field test three to five infrastructure-based motorcycle safety countermeasures. Task B, "MCCS Data Analysis Report and Literature Review", is the first step to accomplish this goal. Task B consisted of three activities that included:

- Review of Literature. The Project Team conducted a review of literature of existing, planned, and proposed infrastructure-based motorcycle safety countermeasures with a

particular focus on current state-of-the-practice motorcycle crash countermeasures being implemented.
- MCCS Database Analysis. The Project Team used the MCCS database to identify infrastructure-based countermeasures that might be feasibly implemented to improve rider safety.
- Stakeholder Identification. As part of Task B, the Project Team generated a list of potential non-FHWA stakeholders who may be considered for inclusion in the forthcoming workshop.

This report serves as the primary output and deliverable of Task B. The information contained in this report will directly support the completion of Task C which includes the conduct of a workshop to review the infrastructure-based countermeasures identified in Task B. The remainder of this report is structured into three main sections entitled 1) Review of Literature Activity, 2) MCCS Database Analysis, and 3) Stakeholder Identification. Appendices are located at the end of this report.

REVIEW OF LITERATURE ACTIVITY

Overview

The objective of this activity was to identify existing, planned, or proposed infrastructure-based motorcycle crash countermeasures. This was accomplished by conducting two sub-activities that consisted of a literature review and interviews with key domestic and international stakeholders. The results of these two activities resulted in a list of countermeasures that were investigated further to develop a broad-based understanding (i.e., summary) of each including, but not limited to, their specific purpose, application, and limitations. The remainder of this section summarizes the literature review methods and the interview methods and results.

Literature Review

Methods

The literature review was initiated by developing a list of categories of infrastructure-based motorcycle crash countermeasures. The categories were generated based on the experience of the Project Team members with infrastructure-based crash countermeasure experience and from categories employed in infrastructure crash countermeasure-based literature available publically. The categorization provided a framework to guide the literature review and provide a basis for keyword search terms. The categories included

- Infrastructure crashworthiness (e.g., guardrails)
- Intersection design (e.g., configuration)
- Intelligent transportation systems (e.g., connected vehicles, vehicle-infrastructure communications)
- Maintenance
- Operations
- Pavement markings
- Pavement surface quality
- Roadway and roadway design
- Signage
- Work zones
- Other (i.e., not applicable to above categories but related to infrastructure)

- Non-infrastructure

The Project Team then generated an initial list of infrastructure-based crash countermeasures that would have the potential to address rider safety for each category. In parallel, the Project Team reviewed all MCCS data base crash narratives and identified those countermeasures that could have reduced the propensity for a crash or may have prevented a crash.

The literature review consisted of manual and computerized searches of infrastructure-based crash countermeasures using search terms related to each category and countermeasure. The Project Team searched the following scientific and non-scientific sources:

- Highway Research Information Service database
- Highway Research in Progress database
- International Road Research Database
- Transportation Research Information Service (TRIS)
- Science Direct
- Bing
- Google

The Project Team searched for specific information elements relative to all countermeasures that would be useful for stakeholders when reviewing and selecting countermeasures in Task C. The primary information elements included:

- Name. Name of the countermeasure.
- Description. A summary of the countermeasure.
- Applications. A summary of the different types of infrastructure applications (e.g., curves, overpasses)
- Effectiveness. A summary of the quantitative or qualitative results of relevant research indicating the effectiveness of the countermeasure to improve motorcyclist safety.
- Design Considerations. A description of any specific considerations when employing the countermeasures (e.g., the treatment should extend through the exit tangent of the curve so motorcyclists can complete their cornering maneuver and return to an upright position).
- Cost and Timeframe. An identification of the approximate installation cost and installation timeframe.
- Maintenance Needs. An identification of the short and long-term maintenance needs/requirements that may impact the overall utility of a countermeasure (e.g., repeated sweeping of loose aggregate).
- Limitations and Concerns. A list of potential countermeasure limitations and associated concerns that might impact the utility of the countermeasure (e.g., effectiveness at intersections is inconclusive).
- Key References. A list of references found during the literature review activity and references providing additional information regarding the countermeasure.

Interviews

The literature review identified a wide range of infrastructure-based motorcycle (and non-motorcycle) crash countermeasures that may improve rider safety. However, because it is possible that some countermeasures may not be present in literature, the Project Team conducted nine informational interviews with roadway engineering staff and researchers. The goal of this activity was to identify infrastructure-based motorcycle (and non-motorcycle) crash countermeasures not identified in the literature review.

Methods

To accomplish the goal of this sub-activity, the Project Team reviewed the stakeholder list (see the Identification of Potential Stakeholders Activity section of this report) and identified seven United States-based and two European, Asian, and Eurasian-based roadway engineering staff or researchers at Departments of Transportation, transportation research organizations, or consulting firms specializing in infrastructure-based crash countermeasures. The Project Team selected interviewees from geographically diverse areas in the United States and abroad to better identify a broad range of infrastructure-based motorcycle crash countermeasures. The Project Team included interviewees from States or countries with high numbers and/or rates of rider fatalities and severe injuries. The list of potential interviewees was then approved by the FHWA TOCOR and then interviewed by the Project Team.

The domestic interviewees included staff from the following organizations and/or agencies:

- Arizona Department of Transportation
- Florida Department of Transportation
- Michigan Department of Transportation
- National Motorcycle Institute
- New Hampshire Department of Transportation
- Texas Department of Transportation
- University of South Florida

The international interviewees included staff from the following organizations and/or agencies:

- Centre for Accident Research and Road Safety, Queensland University of Technology (Australia)
- Deakin University (Australia)
- Motorcycle Council of New South Wales (Australia)
- SVBRF (Sweden)
- TNO (Netherlands)
- University Maribor (Slovenia)
- University of New South Wales (Australia)

Each interviewee was presented a series of questions that included:

- What infrastructure-based motorcycle crash countermeasures do you or your agency use or are aware of?
- What and where are each of the countermeasures applied?
- Are there published or documented results of their effectiveness? Can you please share these with the Project Team and describe them?
- What are the design considerations associated with each countermeasure, if any?
- What is the cost to install/implement each countermeasure?
- What is the timeframe to install each countermeasure?
- What are the short and long-term maintenance needs of each countermeasure?
- Any limitations or concerns of each countermeasure?
- What motivated your decision to use each of these countermeasures?

Additional countermeasures identified through the interviews were also subjected to the manual and computerized searches employed in the literature review.

Results

Interview results of U.S. and International-based stakeholders provided information beyond that already captured in the literature review activity and was specific to countermeasures or was related to a broad class of countermeasures. Where necessary, their information was added to the countermeasure summaries that appear in Appendix A. The Michigan Department of Transportation stakeholder did identify informal testing in their state of motorcycle rider responses to various type of rumble strips; however, the test was not formalized using scientifically rigorous evaluation procedures nor are the results publically available.

Researchers in Australia are starting to examine the utility of turn phases specifically designed for vulnerable road user groups such as riders and pedestrians. This could include systems that alter signal phase and timing to accommodate the capabilities and limitations of a user group, such as pedestrians, or to provide a protected turning phase.

At least one stakeholder indicated that new countermeasures that employ sensors to detect motorcycles may experience deployment issues due to sensor limitations. For example, in-pavement sensors to detect motorcycles may not be 100% accurate and may result in increased perceptions of countermeasure failure. This can lead to riders ignoring a countermeasure. Conversely, if a sensor, such as those used to detect motorcycle speed when approaching a curve, does not detect a motorcycle then a countermeasure cannot provide appropriate and useful warning information (e.g., reduce speed). The accuracy and reliability of sensors must be improved during research so that subsequent implementation can be successful.

Guardrails and cable barriers continue to be a safety risk for riders. Several stakeholders indicated the preliminary use of continuous guardrail protection devices and fencing on jersey barriers to reduce injury severity. One stakeholder indicated there were specific efforts underway to reduce rider injuries relative to when riders pass through cable barriers but could not elaborate due to intellectual property considerations.

Several trends in the interviews were not directly related to a single countermeasure or class of countermeasures. One trend emphasized the notion that many cold-weather states (i.e., northern states) have an interest in improving rider safety but, due to the short riding season the Departments of Transportation most often focus on infrastructure-based crash countermeasures that apply to the broadest range of road users (e.g., vehicles) and not specifically to motorcycles. A second trend was that Departments of Transportation are reluctant to implement motorcycle specific countermeasures, particularly if they are expensive, in the absence of rigorous scientific studies supporting their effectiveness. Several stakeholders indicated a need for guidance relative to motorcycle specific infrastructure-based countermeasure use (e.g., location, when to use, design information). The implementation of most countermeasures should involve a multidisciplinary approach that includes input/continued involvement from stakeholders in the education, outreach, enforcement, and engineering domains.

A concern raised by constituents and conveyed to several stakeholders who we interviewed focused on the risk associated with “tar snakes” which are formed when tar is laid in long roadway cracks during maintenance operations. Riders perceive the tar snakes as dangerous. However, it is noted that no data exist that implicates this maintenance procedure in rider crashes.

Findings

Information gathered from the literature review and interviews resulted in the identification and investigation of the infrastructure-based crash countermeasures that were designed specifically to improve rider safety or, more commonly, were designed to address motor vehicle crashes but that could also improve rider safety. Short summaries, describing each infrastructure-based motorcycle crash countermeasure, can be found in Appendix A.

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MCCS DATABASE ANALYSIS ACTIVITY

Introduction

The goal of the MCCS database analysis activity was to estimate the potential benefits of implementing infrastructure-based countermeasures at the national level. These data, along with the literature review and knowledge gained from expert interviews, will provide the workshop participants the necessary background information needed to prioritize countermeasures for more rigorous assessment in the future. Findings will also help workshop participants to identify and prioritize study questions associated with infrastructure-related countermeasures that the unique MCCS database can be used to answer.

Approach

The overall approach for this activity involved three main components.

- The first component focused on understanding how well MCCS represents motorcycle crashes at the national level. This involved comparing the distribution of crash variables that were common between the MCCS and national databases.
- The second component consisted of a deep dive into the MCCS crashes that went beyond simple analysis of the structured data and took advantage of the availability of crash photos, narratives, and diagrams. The purpose was to identify specific infrastructure-based countermeasures that could have prevented the crash or lessened its severity.
- The third component involved applying the knowledge gained by the first two components to the end goal of estimating the potential benefit of implementing infrastructure-based countermeasures at the national level.

Specific details for each component are provided below under the sections, “Comparison of MCCS to National Automotive Sampling System/General Estimates System (NASS/GES) and Fatality Analysis Reporting System (FARS) Databases” and “Potential Benefits of Infrastructure-Based Countermeasures” for components two and three.

Comparison of MCCS to NASS/GES and FARS Databases

The MCCS database contains detailed information on 351 motorcycle and moped/scooter crashes that took place in Orange County, CA between 2011 and 2016. It also includes data on 702 control rider interviews. Given that this is a follow-up to the Hurt Report, the study design closely approximated the landmark study with variables collected on the nearly all aspects of each crash. This included human factors, environment, roadway, traffic and control factors, vehicle factors including mechanical factors, speed factors, trip-related factors, motorcycle and rider conspicuity, training, protective equipment, crash types, and crash configurations. Data are in the form of structured fields along with photographs (e.g., crash scene, vehicles, and motorcycle helmets), crash diagrams and crash narratives. MCCS differs from prior studies in that it includes extensive information on the state of the infrastructure at the time of the crash.

One of the challenges of using the MCCS database to evaluate crash countermeasures is that it is small (i.e., 351 crashes) and was collected in a limited geographical area. Because the sampling was completed (i.e., all police-reported motorcycle crashes were included) within the geographical area and timeframe, the extent to which the database does not directly represent the national crash population is a function of that geography (primarily). In other words, the MCCS database is a random sample of crashes in one limited area. However, that area's crashes may be different from a random sample of all crashes in the U.S.

The NASS/GES database has a national probability sample of police-reported crashes in the U.S., including motorcycle crashes. However, NASS/GES has substantially less detail on causation of crashes. Thus, NASS/GES provides a high-level picture of the types of motorcycle crashes that occur in the U.S. and their relative proportions, while MCCS provides a detailed view of causation for a smaller sample of such crashes.

In addition to NASS/GES, FARS is a census of all crashes on public roads in the U.S. in which someone died as a result of injuries within 30 days of the crash. Motorcycle crashes that result in fatality are in this database, and thus FARS provides a sample of the worst crashes (i.e., in terms of outcome) and their general characteristics. The detail level for FARS is similar to NASS/GES, which has a common coding scheme.

To provide a national context (and an indication of potential benefits) for results of analysis of MCCS, we first determined how MCCS differed from the weighted estimates from NASS/GES, which we defined as representing the national population of police-reported motorcycle-involved crashes. In addition, we compared MCCS crashes (and NASS/GES crashes) to FARS to understand the conditions that led to fatality outcomes. For this comparison, we used 5 years of FARS and NASS/GES from 2011 to 2015.

Comparing MCCS to NASS/GES, four variables stood out as having a considerably different distribution. They were number of vehicles involved, type of intersection, posted speed limit, and roadway type. MCCS had a lower proportion of single motorcycle crashes (24 percent versus 44 percent). More MCCS crashes occurred at an intersection (70 percent versus 39 percent), on roadways with posted speed limits of 50 mph or lower (81 percent versus 65 percent), and on a roadway type of two-way, divided, no median barrier (54 percent versus 11 percent). Table 2 – Table 5 provide the distribution of these four key variables. This comparison was critical for completing subsequent analysis steps related to applying information from MCCS to the national level.

With respect to FARS, MCCS was compared to both FARS for the U.S. and to FARS only in California. Two variables stood out as notably different: type of intersection and roadway type. Approximately half of fatal crashes in MCCS occurred at intersections compared to 32 percent in FARS national dataset and 31 percent in FARS California dataset. Approximately 60 percent of fatal crashes in MCCS were on two-way divided roadways with no median barrier compared to 16 percent in FARS national dataset and 14 percent in FARS California dataset.

Appendix B contains the complete comparison of MCCS to NASS/GES, FARS, and FARS specific to California.

Table 2. Comparison of Number of Vehicle Involved in MCCS Versus NASS/GES.

MCCS Crash Form (CF006_OVCOUNT)			
Code	Description	Count	%

NASS/GES (2011-2015) Accident Data (VE_TOTAL)			
Code	Description	Count	%

00	None	85	24.2
01	One	240	68.4
02	Two	24	6.8
03	Three	0	0.0
04	Four	2	0.6
05	Five or more	0	0.0
	Total	351	100.0

		(weighted)	
1	MC Only	221,581	44.3
2	One OV	258,698	51.8
3	Two OVs	16,603	3.3
4	Three OVs	2,201	0.4
5	Four OVs	626	0.1
6+	Five or More OVs	51	0.0
	Total	499,761	100.0

Table 3. Comparison of Type of Intersection in MCCS Versus NASS/GES.

MCCS Environment Form (EF003_INTERSECTIONCONFIG)			
Code	Description	Count	%
00	Not at intersection	106	30.2
01, 02	Four-leg intersection, not skewed; four-leg intersection, skewed	102	29.06
03	T intersection	70	19.94
04	Y intersection	4	1.14
08	Roundabout; Traffic Circle	0	0.0
05, 06, 07, 10	Alley, driveway; Offset intersection; Intersection as part of interchange; Rail/light-rail crossing	69	19.64
09	Multi-leg Intersection	0	0.0
	Total	351	100.0

NASS/GES (2011-2015) Accident Data (TYP_INT)			
Code	Description	Count (weighted)	%
1	Not at intersection	305,737	61.2
2	Four-leg intersection	101,012	20.2
3	T intersection	58,877	11.8
4	Y intersection	2,046	0.4
5, 6	Roundabout; Traffic Circle	2,030	0.4
7	Five-Point, or More	890	0.2
98	L Intersection	238	0.0
10	Not Reported	27,644	5.5
99	Unknown	1,287	0.3
	Total	499,761	100.0

Table 4. Comparison of Posted Speed Limit (MPH) in MCCS Versus NASS/GES.

MCCS Environment Form (EF006_SPEEDLIMIT)			
Code	Description	Count	%
1- 25	1- 25 mph	33	9.4
26-30	26-30 mph	10	2.9
31-35	31-35 mph	39	11.1
36-40	36-40 mph	75	21.4
41-45	41-45 mph	127	36.2
46-50	46-50 mph	32	9.1
51-55	51-55 mph	17	4.8
56-60	56-60 mph	4	1.1
61-65	61-65 mph	7	2.0
66-70	66-70	0	0.0
71-75	71-75	0	0.0
> 75	> 75 mph	7	2.0
NA	NA	0	0.0
	Total	351	100.0

NASS/GES (2011-2015) Vehicle Data (VSPD_LIM)			
Code	Description	Count (weighted)	%
1- 25	1- 25 mph	54,738	11.0
26-30	26-30 mph	37,948	7.6
31-35	31-35 mph	102,495	20.5
36-40	36-40 mph	45,761	9.2
41-45	41-45 mph	80,802	16.2
46-50	46-50 mph	13,067	2.6
51-55	51-55 mph	55,866	11.2
56-60	56-60 mph	10,173	2.0
61-65	61-65 mph	25,388	5.1
66-70	66-70	7,365	1.5
71-75	71-75	2,358	0.5
> 75	> 75 mph	57,400	11.5
NA	NA	6,100	1.2
	Total	499,761	100.0

Table 5. Comparison of Roadway Type in MCCS Versus NASS/GES.

MCCS Environment Form (EF004_TRAFFICPATTERN)			
Code	Description	Count	%
05	One-way	7	2.0
03	Two-way, divided, no median barrier	188	53.6
04	Two-way, divided, with median barrier	10	2.9
01	Two-way, undivided	111	31.6
02	Two-way, with a continuous left-turn lane	34	9.7

NASS/GES (2011-2015) Vehicle Data (VTRAFWAY)			
Code	Description	Count (weighted)	%
4	One-Way Traffic way	10,475	2.1
2	Two-Way, Divided, Unprotected (Painted > 4 Feet) Median	57,091	11.4
3	Two-Way, Divided, Positive Median Barrier	70,356	14.1
1	Two-Way, Not Divided	240,983	48.2
5	Two-Way, Not Divided With a Continuous Left-Turn Lane	31,840	6.4

98, 99	Other, specify	1	0.3
03	Unknown	0	0.0
Total		351	100.0

	Other, specify	0	0.0
6	Entrance/Exit Ramp	13,265	2.7
0	Non-Traffic way Area	5,752	1.2
8	Not Reported	68,879	13.8
9	Unknown	821	0.2
Total		499,761	100.0

Potential Benefits of Infrastructure-Based Countermeasures

To evaluate the potential benefits of infrastructure-based countermeasures, we capitalized on the strengths of MCCS and NASS/GES. NASS/GES is preferred to FARS because NASS/GES includes all crash severities rather than only fatal events. The detail in MCCS enables identifying which specific crashes were caused by factors that could be addressed by a particular infrastructure countermeasure or class of countermeasures. For example, if poor sight distance is a causal factor for a crash, then a countermeasure that improves sight distance would be relevant to that crash, such that it could potentially prevent that crash. MCCS offers sufficient detail to support this type of assessment.

In contrast, NASS/GES provides good estimates of the number of annual crashes that fall into coarse categories, within which crashes *could* be relevant to a countermeasure (e.g., sight distance). However, the limited detail in NASS/GES does not allow us to evaluate for a specific crash, whether the crash would have been addressable by a given countermeasure.

To use these datasets together, we completed the following basic steps, which are described in greater detail in the following subsections:

1. Calibrate MCCS to NASS/GES.
2. Assign Countermeasures to MCCS Crashes.
3. Define Potentially Relevant Crashes in MCCS.
4. Calculate Relevance Proportion from MCCS.
5. Calculate Potentially Addressable Problem Size from NASS/GES.
6. Calculate Potential Benefits.

Step 1- Calibrate MCCS to NASS/GES

The purpose of calibrating MCCS data to NASS/GES is to identify relevant issues at the national level by combining the richness of the MCCS database with the nationally representative NASS/GES. To calibrate MCCS data, we developed a coarse weighting procedure that reweights or redistributes MCCS cases to be distributed more like NASS/GES on key variables. This calibration accounts for broad differences that arise from the localized sampling of MCCS. Note that because MCCS is a small sample, it cannot support detailed reweighting, so the calibration addressed the key factors identified in the previous section. The four key variables were: intersection versus non-intersection, road type, posted speed limit (mph), and number of other vehicles.

We determined the weighting factor for each combination group by using Equation (1)

$$\text{Calibration Factor}_k = \frac{Prop_{GES}}{Prop_{MCCS}} \quad (1)$$

Where,

$\text{Calibration Factor}_k$ = Weighting factor for *k* combination group

$Prop_{GES}$ = Number of sub-category total NASS/GES weighted crashes divided by the total NASS/GES weighted crashes

$Prop_{MCCS}$ = Number of sub-category MCCS crashes divided by the total MCCS crashes

Table 6 displays the results of the MCCS calibration to NASS/GES along with supporting parameters. With respect to NASS/GES weighted counts, the term "weighted" here refers to the use of counts that have been adjusted, as recommended by NASS, in a way that takes into account the sampling methodology used in NASS/GES and ensures that results are nationally representative.

Table 6. Results of MCCS Calibration to NASS/GES.

Combination Groups	MCCS Crash Counts (N=351)	NASS/GES Weighted Crash Counts (N=499,761)	$Prop_{MCCS}$	$Prop_{GES}$	Calibration Factor
Road type= Others, Other Vehicle= MC Only, Location= Intersection related, Posted Speed= < 46 mph	18	8,208	0.0513	0.0164	0.32
Road type= Others, Other Vehicle= MC Only, Location= Intersection related, Posted Speed= > 45 mph	5	22,508	0.0142	0.0451	3.17
Road type= Others, Other Vehicle= MC Only, Location= Segment related, Posted Speed= <46 mph	18	21,176	0.0513	0.0424	0.83
Road type= Others, Other Vehicle= MC Only, Location= Segment related, Posted Speed= > 45 mph	10	77,670	0.0285	0.1555	5.46

Road type= Others, Other Vehicle= Two or more, Location= Intersection related, Posted Speed= < 46 mph	116	73,692	0.3305	0.1475	0.45
Road type= Others, Other Vehicle= Two or more, Location= Intersection related, Posted Speed= > 45 mph	28	26,307	0.0798	0.0527	0.66
Road type= Others, Other Vehicle= Two or more, Location= Segment related, Posted Speed= < 46 mph	34	18,960	0.0969	0.0380	0.39
Road type= Others, Other Vehicle= Two or more, Location= Segment related, Posted Speed= > 45 mph	11	33,266	0.0313	0.0666	2.13
Road type= Two way undivided, Other Vehicle= MC Only, Location= Intersection related, Posted Speed= < 46 mph	11	29,984	0.0313	0.0600	1.92
Road type= Two way undivided, Other Vehicle= MC Only, Location= Intersection related, Posted Speed= > 45 mph	2	30,492	0.0057	0.0610	10.70
Road type= Two way undivided, Other Vehicle= MC Only, Location= Segment related, Posted Speed= < 46 mph	16	25,525	0.0456	0.0511	1.12
Road type= Two way undivided, Other Vehicle= MC Only, Location= Segment related, Posted Speed= > 45 mph	5	14,576	0.0142	0.0292	2.06

Road type= Two way undivided, Other Vehicle= Two or more, Location= Intersection related, Posted Speed= < 46 mph	57	8,685	0.1624	0.0173	0.11
Road type= Two way undivided, Other Vehicle= Two or more, Location= Intersection related, Posted Speed= > 45 mph	5	57,573	0.0142	0.1153	8.12
Road type= Two way undivided, Other Vehicle= Two or more, Location= Segment related, Posted Speed= < 46 mph	14	19,436	0.0399	0.0389	0.97
Road type= Two way undivided, Other Vehicle= Two or more, Location= Segment related, Posted Speed= > 45 mph	1	31,703	0.0028	0.0635	22.68

Step 2- Assign Countermeasures to MCCS Crashes.

Given the unique characteristics of individual crashes, it can be difficult to identify applicable infrastructure-based countermeasures by only examining crash type and other factors coded in the structured crash data. This can be particularly problematic in datasets with a small number of observations. In this case, relying solely on the structured data could lead to collapsing crashes into very broad categories of crash type or another characteristic to which a countermeasure may be applied. The result could be an overestimation of the impact or effectiveness of a countermeasure since not every crash in that categorization truly could have been prevented or injury severity improved by that countermeasure. For example, consider the category of crashes grouped as single motor vehicle crashes occurring on curves. Not all crashes in this category can be addressed by a curve speed warning sign (e.g., not all crashes occurred due to high speed).

To overcome this potential limitation in the MCCS analysis, Project Team raters manually reviewed each individual crash. They identified the countermeasures that could have prevented the crash or reduced its injury severity. The raters based the manual review on the crash narrative, diagram, and photographs along with the structured data. They identified applicable countermeasures based on the crash type, grouped into seven broad categories, and a decision process for each crash type. The raters also applied general criteria. Table 7 outlines this process. Two raters reviewed each crash, one of whom was an experienced motorcycle rider and the other of whom was an experienced crash data analyst. The raters made a decision for each crash only after reaching agreement in their assessment.

During this identification process, the raters also noted when technology in the form of vehicle-to-infrastructure communication or vehicle-to-vehicle communication could have prevented a crash. Finally, the raters noted two behavioral factors assigned to either the motorcycle or other vehicle: driver impairment due to alcohol or drugs and speeding/speed unsafe for conditions. The extent to which these behavioral factors overlapped infrastructure-related countermeasures was examined using frequency distributions.

Table 7. Crash-Based Decision Process for Identifying Applicable Countermeasures

Crash Type	Decision Process
Head-On (Due to left turn conflict)	• If no signal was in place or the signal was permissive for left turns, then add signal with a protected left turn phase or add protected left turn phase to permissive signals. • If signal is not feasible, consider warning sign. • Sight distance if it was an obvious factor or it was explicitly mentioned in the narrative. • Complete intersection re-design (rare) if design was the root or proximate cause and other minor modifications were unlikely to be sufficient to prevent the crash. • Red light violation warning/camera if there is evidence of a violation.
Right Angle (Due to left turn conflict)	• If no signal was in place or the signal was permissive for left turns, then add signal with a protected left turn phase or add protected left turn phase to permissive signals. • If signal is not feasible, consider warning sign. • Sight distance if it was an obvious factor or it was explicitly mentioned in the narrative. • Complete intersection re-design (rare) if design was the root or proximate cause and other minor modifications were unlikely to be sufficient to prevent the crash. • Red light violation warning/camera if there is evidence of a violation.
Right Angle (Not a left turn conflict)	• If no signal was in place or the signal was permissive for left turns, then add signal with a protected left turn phase or add protected left turn phase to permissive signals. • If signal is not feasible, consider warning sign. • Sight distance if it was an obvious factor or it was explicitly mentioned in the narrative. • Complete intersection re-design (rare) if design was the root or proximate cause and other minor modifications were unlikely to be sufficient to prevent the crash. • Red light violation warning/camera if there is evidence of a violation.
Rear-End Collision	• Typically, a rider or other vehicle driver error. • Lane splitting prohibition if explicitly related. • Sight distance if it was an obvious issue or it was mentioned in the narrative.
Sideswipe	• Most common during lane merge, lane change, or a weaving maneuver (particularly by the motorcycle).

	• Consider sight distance if there was an obvious issue or it was mentioned in the narrative. • If access road or driveway a factor, consider signal. If signal not feasible, consider stop sign. If stop sign was not applicable, consider warning sign (e.g., driveway ahead). • Sight distance if it was an obvious issue or it was mentioned in the narrative.
Single Motor Vehicle	• If curved roadway, install curve speed warning sign or curve warning sign. If visibility is an issue, consider retro-reflective striping. • If bike was dropped without another obvious cause, consider surface issues.
U-Turn (From a parked position and at an intersection)	• Protected signal phase if signal present. If no signal is present or signal not feasible, prohibit u-turn sign.
General Decision Rules	• Red light violation warning/red light camera considered when evidence of red light violation was present. • Road surface considered if bike dropped making a standard maneuver and no other prominent cause was present. • Improved lighting considered if dark conditions present • Retro-reflective striping considered if dark conditions present and lane drift or curve an issue. • Barriers or medians considered for run-off-road / lane departure crashes. • Barrier retrofitting considered if contact with barrier was an issue.

Table 8 displays the results of the review of all 351 crashes. Many crashes (44 percent) did not have an identified infrastructure-related countermeasure. Of the 196 crashes with assigned countermeasures, the majority (63 percent) were assigned 1 countermeasure, 21 percent, 11 percent, 4 percent, and less than 1 percent were assigned 2, 3, 4, and 5 countermeasures, respectively. Approximately 53 percent of crashes could have potentially benefitted from vehicle to infrastructure technology while 70 percent could have potentially benefitted from vehicle to vehicle technology. Among crashes not flagged with an infrastructure-based countermeasure, 19 percent and 66 percent, could have benefitted from vehicle to infrastructure and vehicle to vehicle technology, respectively.

Overall, 13 percent of crashes involved impairment due to alcohol or drugs as identified by the crash narrative and 17 percent involved speeding or speed unsafe for conditions. Concerning individual infrastructure-based countermeasures, the most frequent included improving sight distance, new signals with a protected left-turn phase or adding a protected phase to an existing light, red light violation warning/camera, retro-reflective striping, curve speed warning sign, and warning sign for oncoming or merging traffic ahead. Driving under the influence (DUI) was noted in a third or more crashes assigned to retro-reflective striping, ensuring proper cross slope, retrofit concrete barrier, set back utility poles or remove other similar structures, and stop sign. Speed related issues were noted in a third or more of crashes assigned to improve sight distance, retro-reflective striping, curve speed warning, warning sign for intersection/driveway ahead, or merging oncoming traffic, and set back utility pole or remove other similar structures.

Table 8 displays the data for countermeasures with at least five applicable crashes only. Additional countermeasures that were identified, but were not assigned to at least five crashes included: resurfacing an object in the roadway (e.g., manhole cover, bot dot), correct flushed pavement, correct severe damage, high friction surface treatments, install textured striping, new barrier or median, redesign median, clear trees, remove railroad tracks no longer in operation, no driving on shoulder sign, no right turn on red sign, curve warning sign, change in pavement warning sign, warn dip ahead sign, warn speed bump sign, warn construction ahead sign, wildlife warning sign, warning sign to watch for u-turns, lower existing speed limit, and retrofit guardrail.

Table 8. Crash Frequency by Identified Countermeasure and Behavioral Factors, MCCS.

Countermeasure Name	Number of Crashes in MCCS (Proportion of Total Crashes)	Frequency of Behavioral Factors for Each Countermeasure	
		Number of DUI-Related (Proportion of Countermeasure-Specific Crashes)	Number of Speed-Related (Proportion of Countermeasure-Specific Crashes)
Sight Distance Improvement			
Intersection	26 (7%)	1 (4%)	9 (35%)
Segment	11 (3%)	2 (2%)	0 (0%)
New Signal with Protected Turn Cycle (Usually Left, Only if Feasible)	24 (7%)	1 (4%)	0 (0%)
Add a Protected Turn Phase to Existing Signal (Usually Left)	19 (5%)	1 (5%)	3 (16%)
No Left Turn Sign	11 (3%)	1 (9%)	0 (0%)
Stop Sign	5 (1%)	2 (40%)	1 (20%)
Red Light Violation Warning/Camera	21 (6%)	3 (14%)	1 (5%)
Warn Intersection or Driveway Ahead or Merging Oncoming Traffic	16 (5%)	0 (0%)	6 (38%)
Complete Intersection Redesign	10 (3%)	0 (0%)	3 (30%)
No U Turn Sign	7 (2%)	0 (0%)	0 (0%)
Park in Roadway Policy	9 (3%)	2 (22%)	2 (22%)
Curve Speed Warning Sign	16 (5%)	2 (13%)	8 (50%)
Retro-reflective Striping	23 (7%)	9 (39%)	8 (35%)
Increase Lighting	9 (3%)	1 (11%)	2 (22%)
Ensure Proper Cross-slope	7 (2%)	3 (43%)	2 (29%)
Retrofit Concrete Barrier	6 (2%)	5 (83%)	6 (100%)
Set Back Utility Pole or Remove Other Structure	6 (2%)	2 (33%)	5 (83%)
Remove Debris from Roadway	5 (1%)	0 (0%)	0 (0%)

No Applicable Infrastructure Countermeasure Identified (Excluding Technological Assistance)	155 (44%)	19 (12%)	23 (15%)
Technological Assistance Vehicle to Infrastructure Vehicle to Vehicle	 187 (53%) 244 (70%)	 21 (11%) 21 (9%)	 42 (22%) 33 (14%)

Step 3- Define Potentially Relevant Crashes in MCCS.

Based on the literature review and Step 2 above, a set of crashes that could have been ameliorated by a specific countermeasure was defined. This set is referred to as potentially relevant crashes. The goal of identifying this set of potentially relevant crashes was to select similar variables present in NASS/GES (and MCCS) that would capture the smallest set (i.e., the most precise definition) and that would (if possible) contain all crashes addressable by a particular countermeasure. For example, the countermeasure “improve sight distance at an intersection” could, in theory, reduce all intersection-related crashes. Therefore, all intersection crashes became the set of potentially relevant crashes.

Table 9 shows each of the countermeasures, the definition of the potentially relevant crashes (applied to MCCS), the count of crashes in MCCS, and the adjusted count after the calibration factor is applied. As described above, the calibration factor is a multiplier assigned to each crash to adjust for its under- or over-representation in MCCS compared to NASS/GES. As shown in Table 9 below, there were 242 crashes in MCCS that met the criteria for a potentially relevant crash for sight distance improvement at intersections. After the calibration factors from Table 6 were applied to these crashes, the total for this category was 200.

Countermeasures listed in Step 2 were not included in Step 3 if a reasonable set of potentially relevant crashes could not be defined between for MCCS and NASS/GES. Countermeasures that were eliminated during Step 3 included retrofit concrete barrier, remove debris from the roadway, park in roadway policy, and a complete redesign of intersection.

Table 9. Number of Potentially Relevant and Calibrated Crashes for Each Countermeasure within MCCS.

Countermeasure Name	MCCS Data Codes	MCCS Potentially Relevant Crashes	MCCS Calibrated Potentially Relevant Crashes
Sight distance improvement (Intersection)	EF002_RELATIONTOJUNCTION=1- 2	242	200
Sight distance improvement (Segment)	EF002_RELATIONTOJUNCTION=0 AND EF014_ROADWAYGRADE=3, 5 OR EF015_ROADWAYCURVATURE=2, 3, 6, 7	55	93
New signal with protected turn cycle (usually left)	MR001_PRECRASHMCOPERATION=5-12 17, 18, 19, 20 OR OD001_PRECRASHMCOPERATION=	92	103

	5-12 17, 18, 19, 20 AND EF018_TRAFFICCONTROLS=Exclude 4, 12- 16		
Add a protected turn cycle to existing signal (usually left)	MR001_PRECRASHMCOPERATION= 5-12 17, 18, 19, 20 OR OD001_PRECRASHMCOPERATION= 5-12 17, 18, 19, 20 AND EF018_TRAFFICCONTROLS=Exclude 12-16	92	103
No left turn sign	EF002_RELATIONTOJUNCTION=1- 2 AND EF018_TRAFFICCONTROLS=0	138	110
Stop sign	EF002_RELATIONTOJUNCTION=1, 2 AND EF018_TRAFFICCONTROLS= 0, 1, 5, 6, 7, 8, 9, 10, 11, 18	140	111
Red light violation warning	EF021_OVSIGNALVIOLATION =1	19	12
Warn intersection or driveway ahead or merging oncoming sign	EF002_RELATIONTOJUNCTION=1- 2 AND EF018_TRAFFICCONTROLS=0	138	110
No u-turn sign	MR001_PRECRASHMCOPERATION=17, 18 OR OD001_PRECRASHMCOPERATION=17, 18	15	12
Curve speed warning sign	EF015_ROADWAYCURVATURE=2,3,6- 7	34	22
Retro-reflective striping	CF011_AMBIENTLIGHT=3-8	40	35
Increase lighting	CF011_AMBIENTLIGHT=3-8	40	35
Set back poles lighting or other structures	EF040_FIRSTHARMEVNTWFIXED=4-6, 19-22, 27	32	71

Step 4- Calculate Relevance Proportion from MCCS Weighted Crashes.

In Step 3, we defined a subset of MCCS crashes that might potentially be addressed by a given countermeasure. The subset definition was constrained by what could also be defined in NASS/GES. However, in MCCS, the detail allows us to identify a smaller subset of crashes within the potentially relevant subset that we judged to be *actually* relevant or addressable by the countermeasure. The calibration factors defined in Step 1 are applied to all crashes in this analysis.

We determined the "relevance proportion," r_j by using Equation (2)

$$\mathrm{r}_j = \frac{k_j}{m_j} \quad (2)$$

Where,

r_j = Relevance proportion for each countermeasure, j

m_j = Number of calibrated MCCS crashes that fit into the countermeasure-specific category definition in Step 3 (from Table 9)

k_j = Number of calibrated MCCS crashes that were labeled as potentially relevant by the countermeasure

For example, for sight distance improvement at intersections, the calibrated number of crashes ($k_{j,}$) that were deemed addressable by this countermeasure (m_j), was 11. The calibrated number of crashes in MCCS that *potentially* could have been addressed by this countermeasure, from Table 9, was 200. Both of these calibrated values (k_j and m_j) were computed using the calibration factors from Table 6. The relative proportion (r_j) of these two values was 0.06.

Table 10. Proportion of Relevant Crashes for Each Countermeasure, MCCS.

Countermeasure Name	Number of MCCS Crashes Assigned to Countermeasures	MCCS Calibrated Crashes Assigned to Countermeasures (k_j)	MCCS Calibrated Potentially Relevant Crashes (m_j)	Relevance Proportion (r_j)
Sight distance improvement (Intersection)	26	11	200	0.06
Sight distance improvement (Segment)	11	13	93	0.14
New signal with protected turn cycle (usually left)	24	13	103	0.13
Add a protected turn cycle to existing signal (usually left)	19	6	103	0.06
No left turn sign	11	13	110	0.12
Stop sign	5	4	111	0.04
Red light violation warning	21	10	12	0.83
Warn intersection or driveway ahead or merging oncoming sign	16	5	110	0.05
No u-turn sign	7	6	12	0.50
Curve speed warning sign	16	20	22	0.91
Retro-reflective striping	23	29	35	0.83
Increase lighting	9	4	35	0.11

Set back poles lighting or other structures	6	6	71	0.08

Step 5- Calculate Potentially Addressable Problem Size from NASS/GES.
Step 5 is similar to Step 3 except the focus was on NASS/GES rather than MCCS. A set of crashes in NASS/GES was defined based on the variable sets developed for MCCS in Step 2. Again, the goal was to identify similar variables present in NASS/GES (and MCCS) that would capture the smallest set (i.e., the most precise definition) and that would, if possible, contain all crashes addressable by a particular countermeasure. To generate the potential addressable problem size from NASS/GES for each countermeasure, *j,* the countermeasure set definition was applied to NASS/GES and the weighted count in that category over the five years of NASS/GES data used as our estimate of the number of potentially addressable crashes. The average annual number of crashes, $n_{j,}$ was computed and displayed in Table 11. As an example for sight distance improvement at intersections, there were 193,074 crashes from 2011-2015 (after applying appropriate NASS/GES sampling weights) or 38,615 crashes annually that were coded to signify that these crashes were intersection related.

Table 11. Number of Potentially Addressable Crashes for Each Countermeasure, NASS/GES.

Countermeasure Name	NASS/GES Data Codes	NASS/GES Weighted Addressable Crash Counts (2011-2015)	NASS/GES Weighted Addressable Crash Counts (Annual) (n_j)
Sight distance improvement (Intersection)	RELJCT2_IM=2, 3	193,074	38,615
Sight distance improvement (Segment)	RELJCT2_IM=1, 4-8, 16-20, 98, 99 AND VALIGN (MC and OV)=2, 3, 4 OR VPROFILE (MC and OV)=3, 4	95,982	19,196
New signal with protected turn cycle (usually left)	PCRASH1_IM (MC or OV)=10-12 AND VTRAFCON (MC or OV)=Exclude 1-4, 8, 9	29,605	5,921
Add a protected turn cycle to existing signal (usually left)	PCRASH1_IM (MC or OV)=10-12 AND VTRAFCON (MC or OV)=1-3	11,994	2,399
No left turn sign	RELJCT2_IM (MC or OV)=2-4,8, 18, 19 AND VTRAFCON (MC or OV)=0	136,287	27,257
Stop sign	RELJCT2_IM (MC or OV)=2-4 ,8, 18, 19 AND VTRAFCON (MC or OV)=0, 7, 21, 23, 28, 29, 40, 50, 65	141,238	28,248

Red light violation warning	MVIOLATN=31-34	3,069	614
Warn intersection or driveway ahead or merging oncoming sign	RELJCT2_IM (MC or OV)=2-4,8, 18, 19 AND VTRAFCON (MC or OV)=0	136,287	27,257
No U turn sign	PCRASH1_IM (MC or OV)=12	450	90
Curve speed warning sign	VALIGN=2-4	2,912	582
Retro-reflective striping	LGT_COND=2- 6	9,500	1,900
Increase lighting	LGT_COND=2-6	11,994	2,399
Set back poles lighting or other structures	SOE=30, 31, 41, 42	11,708	2,342

Step 6- Calculate Potential Benefits.

Finally, to generate the annual potential benefit, or crashes that could be prevented or crash severity decreased, for each countermeasure, *j,* we multiplied the ratio r_j by n_j to obtain b_j, the number of motorcycle crashes that could be prevented each year by *100 percent deployment of a perfectly effective version* of the infrastructure countermeasure being evaluated.

We determined the annual potential benefit, b_j, for each countermeasure by using Equation (3)

$$\mathrm{b}_j = \mathrm{r}_j \mathrm{n}_j \quad (3)$$

Where,

b_j = Annual potential benefit for each countermeasure, *j*

r_j = Relevance proportion for MCCS crashes (Table 10 in Step 4)

n_j = Number of weighted NASS/GES crash counts (Table 11 in Step 5)

For example, for sight distance improvement at intersections, when the MCCS relevance proportion (r_j) of 0.06 from Table 10 is applied to the number of addressable weighted NASS/GES crash counts (n_j) from Table 11, the annual potential benefit or number of crashes prevented or severity decreased annually at the national level by improving sight distance at intersections is 2,317. Table 12 contains the results for each countermeasure.

Applying crash modification factors or other measures of how a countermeasure performs were not incorporated into the analysis because none of the most frequent countermeasures assigned have been evaluated specifically for motorcycles. The rationale for not using effectiveness measures estimated for four-wheeled vehicles is that two-wheeled vehicles differ greatly from four-wheeled vehicles in a number of areas with respect to safety including that motorcycles do not enclose riders and they are far less stable than vehicles with four wheels.

Table 12. Estimated Number of Crashes Prevented or Severity Decreased by Specific Countermeasures.

Countermeasure Name	MCCS Relevance Proportion (r_j)	NASS/GES Weighted Addressable Crash Counts (Annual) (n_j)	Potential Benefits Annual (Crashes Prevented or Severity Decreased) (b_j)
Sight distance improvement (Intersection)	0.06	38,615	2,317
Sight distance improvement (Segment)	0.14	19,196	2,687
New signal with protected turn cycle (usually left)	0.13	5,921	770
Add a protected turn cycle to existing signal (usually left)	0.06	2,399	144
No left turn sign	0.12	27,257	3,271
Stop sign	0.04	28,248	1,130
Red light violation warning	0.83	614	489
Warn intersection or driveway ahead or merging oncoming sign	0.05	27,257	1,363
No u-turn sign	0.50	90	45
Curve speed warning sign	0.91	582	530
Retroreflective striping	0.83	1,900	1,577
Increase lighting	0.11	2,399	264
Set back poles lighting or other structures	0.08	2,342	187

Summary

This analysis drew upon detailed crash data from Orange County, CA to identify appropriate infrastructure-based countermeasures, and extrapolate those countermeasures to the national level. The goal was to estimate the potential benefits of implementing these countermeasures. Inherent limitations of the analytical approach need to be acknowledged given how they may impact interpretation of the findings. For example, the MCCS sample was relatively small with few fatalities and only crashes occurring in Orange County, CA were selected. Therefore, these data cannot simply be applied to all motorcycle crashes in the U.S. Evidence to support this assertion can be found in the comparison of MCCS to NASS/GES. Notable differences from an infrastructure perspective were that MCCS included a higher proportion of intersection-related crashes and a lower proportion of single motorcycle crashes. A larger proportion of crashes occurred on roadways with lower posted speed limits and were a road type of two-way, divided, with no median barrier. Although MCCS crashes can be calibrated to overcome this limitation, it may not be possible to address issues at the national level that are uncommon in MCCS. One example is that very few crashes involved a rider hitting a guardrail. Therefore, it is nearly impossible to examine the impact of retrofitting guardrails using MCCS data.

MCCS is highly valuable given the fine details that are available. Unlike MCCS, NASS/GES is representative of the U.S., but it lacks the granularity found in MCCS. This creates an issue in that only coarse categories of potentially relevant crashes can be defined if the goal is to extend information, such as the relevance proportion, from MCCS to the national level. This limits precise analyses or extensive examination of very specific crash types. Similarly, for some countermeasures, it was not feasible, without greater detail in NASS/GES to develop a potential relevant set of crashes. For example, ensuring proper cross slope was assigned to nine crashes in MCCS, but could not be examined further since an appropriate definition for a relevant set of crashes in MCCS and NASS/GES was not feasible.

Despite limitations, this activity demonstrated that there is tremendous value in analyzing MCCS from an infrastructure and safety perspective. Although many MCCS crashes were not linked to an infrastructure-based countermeasure, nearly 56 percent of crashes had at least one infrastructure-based countermeasure identified. The MCCS crash review highlighted the role that technology may play in the future of motorcycle crash prevention. Vehicle to infrastructure technology could have positively impacted 53 percent of MCCS crashes overall and 19 percent of crashes where no other infrastructure-based countermeasure was identified. Vehicle to vehicle technology could have addressed 70 percent of crashes overall and 66 percent of crashes where no other infrastructure-based countermeasure was identified. By integrating data from MCCS with NASS/GES, 8 countermeasures were identified that could benefit at least 500 motorcycle crashes a year. These countermeasures included:

- improve sight distance for intersections and non-intersections,
- install new signals with protected turn cycle,
- install no left turn signs,
- install retro-reflective striping,
- install warning signs for intersections ahead and merging/oncoming traffic,
- install stop signs, and
- install curve speed warning signs.

IDENTIFICATION OF POTENTIAL STAKEHOLDERS ACTIVITY

Stakeholder Identification

Overview

A successful Infrastructure-Based Motorcycle Crash Countermeasure workshop to be conducted within Task C will be dependent on the input of motorcycle safety stakeholders. The objective of the Identification of Potential Stakeholders Activity was to identify and document motorcycle safety stakeholders that could be considered by FHWA for inclusion in the workshop.

Methods

To accomplish this activity, the Project Team generated a list of potential non-FHWA stakeholders representing public, private, and academic sector individuals who have interests in motorcycling safety. Potential stakeholders were identified during the review of literature activity, during a review of recent motorcycle safety related publications, through a review of motorcycle safety-related stakeholders, through a review of members of motorcycle-related committees and organizations (e.g., FHWA Motorcyclist Advisory Council, TRB ANF30 Transportation Research Board's Motorcycles and Mopeds Committee, Motorcycle Safety Foundation), and in consultation with the TOCOR. Recorded stakeholder information included the following information fields:

- Name
- Affiliation (company or agency to which the stakeholder belongs)
- Job title
- Email address and phone number
- Mailing address
- Classification of employer (i.e., private, research, academic, federal government, state government, local government, other)
- Biography
- Related motorcycle publications
- Related research or other experience (e.g., current committees)
- Expertise area (i.e., outreach, research, training)
- Topic area of expertise (e.g., roadside barriers)
- Involvement in motorcycle research in the last five years (yes, no, maybe)

Stakeholder List

This activity resulted in the identification of over 85 proposed stakeholders to be considered by FHWA for inclusion in the Task C workshop. Table 1 provides a summary list of the stakeholders ordered alphabetically by last name. The table is followed by short descriptions of each proposed stakeholder.

Table 1. Proposed Stakeholders.

Name	Affiliation	Job Title	E-Mail Address	Phone Number	Employer Classifi-cation	Related Activities
Omar Ahmad	University of Iowa: National Advanced Driving Simulator, United States	Deputy Director	omar-ahmad@uiowa.edu	(319) 335-4788	Academic	1. Member of the TRB Motorcycles and Mopeds Committee 2. Co-Chair of the TRB Standing Committee on Simulation and Measurement of Vehicle and Operator Performance
Marco Anghileri	Politechnico di Milano, Italy	Associate Professor	marco.anghileri@polimi.it	+39.02.2399.7162	Academic	1. On planning committee for the 1st International Roadside Safety Conference held in 2017 2. Head of the Passive safety section of the Transport Safety Lab (LA.S.T.)
James Baron	American Traffic Safety Services Association, United States	Director of Commu-nications	james.baron@atssa.com	(540) 368-1701	Private	1. Member of the second Motorcyclist Advisory Council with the Federal Highway Administration
Fran Bents	Westat	Vice President	FranBents@westat.com	(240) 314-7557	Private	1. PI for the Motorcycle Crash Causes and Outcomes Pilot Study 2. Senior Advisor for the MCCS 3. Subject Matter Expert for the Domestic Scan of Leading Practices for Motorcycle Safety 4. Facilitator for the charter Motorcyclists Advisory Council

Mark Bloschock	Walter P Moore and Associates, Inc., United States	Principal, Infra-structure Group	mbloschock @walterpmo ore.com	(512) 501-4306	Private	1. Appointed in 2006 by the US Secretary of Transportation to the Motorcyclist Advisory Council. 2. Appointed to the FHWA International Motorcycle Safety Scan in 2010, report entitled, Infrastructure Countermeasures to Mitigate Motorcycle Crashes in Europe. 3. Reviewed 2012 ATSSA Report, "Emerging Opportunities for ATSSA Members in Motorcycle Safety"
Genevieve Boye	Motorcycle Industry Council, United States	Sr. Legisla-tive Analyst	gboye@ mic.org	(703) 416-0444	Private, Non-Profit	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
Tim Buche	Motorcycle Safety Foundation, Powersports Safety and Trade Associations, United States	CEO	tbuche@ mic.org	(949) 727-4211	Private	1. President and CEO of the Motorcycle Industry Council 2. President and CEO of the Motorcycle Safety Foundation 3. President and CEO of the Specialty Vehicle Institute of America 4. President and CEO of the Recreational Off-Highway Vehicle Association
Sue Chrysler	Texas A&M Transpor-tation Institute	Senior Research Scientist	s-chrysler@ tti.tamu.edu	(979) 845-4443	Research, Academic	1. Appointed to the FHWA International Motorcycle Safety Scan in 2010, report entitled, Infrastructure Countermeasures to Mitigate Motorcycle Crashes in Europe
Cecile Coquelet	IFSTTAR (French Institute of science and technology for transport, develop-	Certified Engineer-Sociolo-gist	cecile.coquel et@ifsttar.fr	33490577980	Private	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds

	ment, and networks), France					
Keith Cota	New Hampshire Department of Transportation, United States	Chief Project Manager	keith.cota@dot.nh.gov	(603) 271-1615	State Government	1. AASHTO Committee for Roadside Safety 2. Technical Committee for Road Safety for the World Road Association
Saskia de Craen	SWOV Institute for Road Safety Research, Netherlands	Senior Researcher	saskia.de.craen@swov.nl	070 3173 333	Private	None Identified
Michael Crow	Colorado Department of Transportation, United States	Engineer	m.crow@state.co.us	(970) 350-2121	State Government	1. Member of the FHWA Motorcyclist Advisory Council
Matthew Dana	Virginia DOT, United States	District L&D Engineer	matt.dana@vdot.virginia.gov	(540) 332-9118	State Government	None Identified
Glenn Davis	Colorado Department of Transportation, United States	Highway Safety Manager	glenn.davis@state.co.us	(303) 757-9462	State Government	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
Liz de Rome	Neuroscience Research, Australia	Research Scholar	l.derome@neura.edu.au	+612 9399 1872	Research, Academic	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds 2. Leading the Motorcycle Safety Study at Neuroscience Research

Ashim Debnath	Victoria University, Australia	Lecturer	ashim.debnath@vu.edu.au	+61 3 9919 5872	Academic	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds 2. Member, Committee on Work Zone Traffic Control (AHB55), Transportation Research Board, USA.
Paul Degges	Tennessee Department of Transportation, United States	Deputy Commissioner & Chief Engineer	paul.degges@tn.gov	(615) 741-0791	State Government	None Identified
Joseph Elliott	National Motorcycle Institute, United States	Scientist	confidential, but can be contacted		Private, Non-Profit	1. Founder of National Motorcycle Institute
Eric Emery	National Transportation Safety Board, United States	Transportation Analyst	eric.emery@ntsb.gov	(202) 314-6175	Federal Government	None Identified
David Ennis	National Highway Traffic Safety Administration, United States	Highway Safety Specialist	david.ennis@dot.gov	(410) 962-0052	Federal Government	None Identified
James Evans	Evans Accident Reconstruction, United States	Mechanical Engineer	james@evansar.com	(979) 703-7227	Private	None Identified

Michael Fitzharris	Monash University, Australia	Associate Professor	michael.fitzharris@monash.edu	+61 3 9902 6011	Academic	None Identified
Joseph Foglietta	HVEA Engineers, United States	Senior Project Manager	jfoglietta@hveapc.com	(845) 838-3600	Private, Consulting	Member, Domestic Scan of Leading Practices for Motorcycle Safety
Michael Fox	National Transportation Safety Board, United States	Highway Accident Investigator	michael.fox@ntsb.gov	(202) 314-6250	Federal Government	1. Has published several online articles
Clay Gabler	Virginia Tech Wake Forest University, United States	Professor and Chair for Biomedical Engineering Graduate Studies	gabler@vt.edu	(540) 231-7190	Academic	1. Transportation Research Board, Committee on Roadside Safety Design, AFB20 (2007-present) 2. Session Chair, Motorcycle Crash Compatibility with Roadside Barriers, TRB Summer Meeting, AFB20 Roadside Safety Committee, Rapid City, SD (July 2007)
Srinivas Geedipally	Texas A&M Transportation Institute, United States	Associate Research Engineer	srinivas-g@tti.tamu.edu	(817) 462-0519	Research, Academic	1. Young member on the ANF30 Standing Committee on Motorcycles and Mopeds 2. member of the TRB ANB20-(3) Subcommittee on Surrogate Measures of Safety and a friend of TRB ANB20 Committee on Safety Data, Analysis and Evaluation and ABJ80 Statistical Methodology.
Konstantina Gkritza	Purdue University, United States	Associate Professor	nadia@purdue.edu	(765) 494-4597	Academic	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
Lois Goldman	North Jersey Transpor-	Director of	lgoldman@njtpa.org	(973) 639-8413	State Government	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds

	tation Planning Authority, United States	Regional Planning				
Raphael Grezbieta	University of New South Wales, Australia	Professor	r.grzebieta@unsw.edu.au	+61 (0)2 9385-4479	Academic	None Identified
Patricia Groeber	New York State Police, United States	Deputy Superin-tendent/ Colonel	nyspmail@troopers.ny.gov	(518) 783-3211	State Government	None Identified
Jeremy Gunderson	National Highway Traffic Safety Administra-tion, United States	Highway Safety Specialist	jeremy.gunderson@dot.gov	(202) 366-0521	Federal Government	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
Jim Halvorsen	Worcester County Sheriff's Office, United States	Deputy Sherriff	unknown	(410) 632-1111	State Government	1. Published an article in the Motorcycle Consumer News in 2017
Narelle Haworth	Queensland University of Technology, Australia	Centre Director	n.haworth@qut.edu.au	+61 7 3138 8417	Academic	1. Chair of Standing Committee ANF30 Motorcycles and Mopeds 2. Awarded Peter Vulcan prize for the best scientific paper at the 2007 Australasian Road Safety Research, Policing and Education Conference for paper entitled "Motorcycle protective clothing: Are stars better than standards?"
Dennis Heuer	Transpor-tation	Vice President	dheuer@	(919) 576-2100	Private, Consulting	1. Co-Chair on 2012 Motorcycle Scan Report

	Services at Clark Nexsen, United States		clarknexsen.com			2. Reviewed 2012 ATSSA Report, "Emerging Opportunities for ATSSA Members in Motorcycle Safety" 3. Co-Chair of the Leading Practices for Motorcyclist Safety Scan
David Hough	Self-Employed, United States	Journalist	bentspoke93@gmail.com	unknown	Self-Employed	1. Inducted into the AMA Motorcycle Hall of Fame in 2009
Tien-Pen Hsu	Department of Civil Engineering National Taiwan University, Taiwan	Associate Professor	hsutp@ntu.edu.tw	3366-4273 、2363-8946	Academic	None Identified
Richard Huey	WESTAT, Inc., United States	Sr. Research Engineer	rickhuey@westat.com	(301) 251-1500	Private	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
Mouyid Islam	University of South Florida, United States	Research Faculty Member	mouyid@cutr.usf.edu	(813) 974-7146	Research, Academic	1. Researcher in the Motorcycle Injury Prevention Institute program under the Center for Urban Transportation Research (CUTR) as a Research Faculty at the University of South Florida
Siwon Jang	University of South Florida, United States	Research Associate	sjang2@cutr.usf.edu	(813) 974-3296	Research, Academic	1. Faculty in the Motorcycle Injury Prevention Institute at the Center for Urban Transportation Research at the University of South Florida
Tri Basuki Joewono	Department of Civil Engineering, Parahyangan Catholic	Lecturer	vftribas@unpar.ac.id	(022) 2032655, 2042004	Academic	None Identified

	University, Indonesia					
Blaine Krauter	College Station Police Department, United States	Sergeant	bkrauter@ cstx.gov	(979) 764-3635	State Government	None Identified
Anders Kullgren	Chalmers University of Technology, Sweden	Adjunct Professor	anders.kullgren@chalmers.se	08-7727435	Academic	None Identified
Chanyoung Lee	Center for Urban Transportation Research University of South Florida, United States	Program Director	cylee@ cutr.usf.edu	(813) 974-5307	Research, Academic	1. Program Director of the Motorcycle Injury Prevention Institute at the CUTR at USF. 2. Member of the FHWA Motorcyclist Advisory Council 3. Committee Communications Director for the TRB Motorcycles and Mopeds Committee
Shaun Lennard	Australian Motorcycle Council, Australia	Chairman	lennards@southcom.com.au	0409 197 056	Private	None Identified
Eric Line	Michigan Department of Transportation, United States	Design/ Safety	linee@ michigan.gov	(517) 335-2984	State Government	1. Member of the FHWA Motorcyclist Advisory Council 2. Co-Chair of the Motorcycle Safety Governor's Traffic Safety Advisory Commission Action Team in Michigan
Maurice Maness	Texas Department of Transportation, United States	Transportation Engineer	maurice.maness@txdot.gov	(979) 778-9654	State Government	Active Motorcycle Stakeholder

Michael Manser	Texas A&M Transporta-tion Institute	Senior Research Scientist	m-manser@tti.tamu.edu	(979) 845-1605	Research, Academic	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds 2. Texas Motorcycle Safety Coalition Project Director
Robert Maynard	Gannett Fleming, United States	Senior Traffic Safety and Opera-tions Specialist	rmaynard@gfnet.com	(717) 763-7211	Private	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
Darren McDaniel	Texas Department of Transpor-tation, United States	Safety Engineer	darren.mcdaniel@txdot.gov	(512) 416-3331	State Government	None Identified
Melinda McGrath	Mississippi Department of Transpor-tation, United States	Executive Director	mmcgrath@mdot.state.ms.us	(601) 359-7004	State Government	None Identified
Shane McLaughlin	Virginia Tech Transpor-tation Institute, United States	Center Director	smclaughlin@vtti.vt.edu	(540) 231-1077	Research, Academic	1. Member of the FHWA Motorcyclist Advisory Council 2. Group leader of the Virginia Tech Transportation Institute Motorcycle Research Group
David Milling	Australian Road Research Board	Senior Advisor	david.milling@arrb.com.au	+61 3 9881 1694	Research	None Identified
Mario Mongiardini	University of New South Wales, Australia	Postdoc-toral Research Associate	mario.mongiardini@unsw.edu.au	+61 (0)2 9385-4452	Research, Academic	None Identified

Edward Moreland	Harley Davidson Motor Company, United States	Director, Govern-ment Affairs	edward.moreland@harley-davidson.com	(414) 343-4056	Private	1. Charter member of the Motorcyclists Advisory Council
John Nazemetz	Oklahoma State University, United States	Emeritus Associate Professor	john.nazemetz@okstate.edu	(405) 744-9137	Academic	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds 2. PI on the Motorcycle Crash Causation Study, 2012-2015
David Nicol	Delaware Department of Transpor-tation, United States	Assistant Director	david.nicol@state.de.us	(302) 760-2298	State Government	1. Co-Chair on 2012 Motorcycle Scan
Anna Okola	The World Bank, United States	Transport Engineer	aokola@worldbank.org	(202) 473-1187	Research	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
Dietmar Otte	Medical University Hannover, Germany	Scientific Re-searcher and Director Biomed-TEC Hannover	otte.dietmar@mh-hannover.de	+49 (0) 511 532 4080	Academic	1. Member of Steering Committee for the 2013 Motorcycle Safety Foundation International Motorcycle Safety Conference
Lee Parks	Total Control Training, United States	CEO and Chief Instruc-tor	info@totalcontroltraining.net	(800) 943-5638	Private	1. Former editorial director of Motorcycle Consumer News and Auto Restorer 2. Founded Lee Parks Design in April 2001
Greg Patzer	Wisconsin Department of Transpor-	Wiscon-sin Motor-cycle	gregory.patzer@dot.wi.gov	(608) 266-7855	State Government	1. Member of the Motorcycle Safety Advisory Council in Wisconsin 2. State Voting Member for Wisconsin for

	tation, United States	Safety Program Manager				the National Association of State Motorcycle Safety Administrators
James Perry	Dynamic Science, Inc., United States	Technical Director	jperry1@ ix.netcom.co m	(602) 995-3700	Private	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds 2. Developed a Stiffness Calculator from barrier crash data 3. Data collection manager for the MCCS
Raphael Pless	Technical University of Darmstadt, Germany	Research Assistant	pless@ fzd.tu-darmstadt.de	+49 6151 16-24234	Research, Academic	None Identified
Jana Price	National Transpor-tation Safety Board, United States	Accident Inves-tigator	jana.price@ ntsb.gov	(202) 314-6000	Federal Government	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
Joel Provenzano	Florida Department of Transpor-tation, United States	District Permits Review Manager & Traffic Engineer-ing Specialist	joel.provenza no@dot.state .fl.us	(813) 975-6755	State Government	1. Vice Chairman of FHWA Motorcyclist Advisory Council
Randa Radwan	Citizant, Inc., United States	Senior ITS Engineer	radwan@ citizant.com	(703) 667-9420	Private	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
Thomas Rice	UC Berkeley Safe Transpor-tation Research and Education	Research Scientist	tomrice@ berkeley.edu	(510) 643-1778	Research, Academic	None Identified

	Center, United States					
Peter Savolainen	Iowa State University, United States	Associate Professor	pts@ iastate.edu	(515) 294-3381	Research, Academic	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
Michael Sayre	American Motorcyclist Association, United States	Govern-ment Relations Manager	membership mailbox@ ama-cycle.org	(614) 856-1900	Private	1. Member of the FHWA Motorcyclist Advisory Council
William Schneider	University of Akron, United States	Assistant Professor	whs4@ uakron.edu	(330) 972-2426	Research, Academic	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
Jude Schexnyder	Texas Department of Transpor-tation, United States	Traffic Safety Specialist	jude.schexnyder@txdot.gov	(512) 832-7035	State Government	None Identified
Craig Shankwitz	Western Transpor-tation Institute at Montana State University, United States	Senior Research Scientist	craig.shankwitz@montana.edu	(406) 994-6030	Research, Academic	1. Member of the FHWA Motorcyclist Advisory Council 2. Selected by the Volpe National Transportation Systems Center to serve on the Motorcycle Safety Research Consortium
Eva Ship	Texas A&M Transpor-tation Institute	Research Scientist	e-shipp@tti.tamu.edu	(979) 458-4398	Research, Academic	1. Author, Comprehensive Analysis of Motorcycle Crashes in Texas (Shipp et al., 2016)
Terry Smith	Dynamic Research,	Senior Principal	tas@ dynres.com	(310) 212-5211	Private	1. Member of the Steering Committee for the 2013 Motorcycle Safety Foundation

	Inc., United States	Re-searcher				International Motorcycle Safety Conference 2. Provided Guidance on the NCHRP Report 500 Volume 22: A Guide for Addressing Collisions Involving Motorcycles 3. Presented at MSF Motorcycle Safety Symposium in October 2013- "Visual Scanning of Motorcycle Riders-A Preliminary Look"
Larry Starkey	California Highway Patrol, United States	Sergeant / CHP CMSP Coordinator	lstarkey@ chp.ca.gov	(916) 843-3370	State Government	None Identified
Chad Teachout	Michigan Office of Highway Safety Planning, United States	State Coordi-nator	teachoutc@ michigan.gov	(517) 241-2579	State Government	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
Eric Teoh	Insurance Institute for Highway Safety, United States	Senior Statisti-cian	eteoh@ iihs.org	(703) 247-1500	Private	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
Pradeep Tiwari	Arizona Department of Transpor-tation, United States	Transportation Safety Engineer	ptiwari@ azdot.gov	(602) 712-8589	State Government	None Identified
Wouter Van den Berghe	VIAS Institute	Research Director	wouter.vandenberghe@ vias.be	02 244 15 11	Private	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds

Mark Vincent	Irving Police Department Motorcycle Unit, United States	Sergeant	vincent@lemvi.com	(972) 721-7839	State Government	None Identified
Reginald Viray	Virginia Tech Transportation Institute, United States	Research Associate Center for Advanced Automotive Research	rviray@vtti.vt.edu	(540) 231-2418	Research, Academic	None Identified
Eleni Vlahogianni	National Technical University of Athens, Greece	Assistant Professor	elenivl@central.ntua.gr	+30 210.772.1369	Research, Academic	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds
David Wieder	Yeh and Associates, United States	Senior Project Manager	dwieder@yeh-eng.com	(719) 434-1643	Private, Consulting	Member, Domestic Scan of Leading Practices for Motorcycle Safety
Gert Jan Wijlhuizen	SWOV Institute for Road Safety Research, Netherlands	Senior Researcher	gert.jan.wijlhuizen@swov.nl	070 3137 333	Private	None Identified
Hermann Winner	Technical University of Darmstadt, Germany	Professor	winner@fzd.tu-darmstadt.de	+49 6151 16-24200	Academic	1. Member of the Steering Committee for the 2013 Motorcycle Safety Foundation International Motorcycle Safety Conference
Kathryn Wochinger	National Highway Traffic Safety Administra-	Research Psychologist	kathryn.wochinger@dot.gov.	(202) 366-4300	Federal Government	1. Member of the ANF30 Standing Committee on Motorcycles and Mopeds 2. Task Order Managers for NHTSA Project looking at Changes to Puerto Rico's Motorcycle Rider Law

	tion, United States					
Jinn-Tsai Wong	Institute of Traffic and Transpor-tation, National Chiao Tung University, Taiwan	Professor	jtwong@mail.nctu.edu.tw	02-23494959	Academic	None Identified
Craig Wucivic	University of Wisconsin-Whitewater, United States	Lecturer	wucivicc@uww.edu	(262) 472-1234	Academic	1. Member of the Motorcycle Safety Advisory Council in Wisconsin
John Young	Texas Department of Public Safety, United States	Program Supervi-sor Motor-cycle Safety Unit	johng.young@txdps.state.tx.us	(512) 424-2021	State Government	None Identified
Anna Zee	British Motorcyclists Federation, United Kingdom	Political and Technical Services Director	anna.zee@bmf.co.uk	+44 116 279 5111 95112	Private	1. President of the Federation of European Motorcyclists' Association 2. Former Chairman of the British Motorcyclists Federation 3. Awarded the Women's International Motorcycle Association Ellen Pfeiffer Award

Stakeholder Summaries

The following section provides brief summaries of each proposed stakeholder. Stakeholders are listed in alphabetical order sorted by last name.

Omar Ahmad, The University of Iowa National Advanced Driving Simulator, Iowa City, Iowa, United States

Mr. Ahmad is the Deputy Director for the National Advanced Driving Simulator at the University of Iowa. He has significant experience in driving simulation. His research interests include vehicle safety and human performance in the areas of active safety, impairment, driver distraction, and driver modeling. He is currently the Co-Chair for the TRB Standing Committee on Simulation and Measurement of Vehicle and Operator Performance. He is a member of the TRB ANF 30 Committee on Motorcycles and Mopeds.

Marco Anghileri, Ph.D., Politechnico di Milano, Milan, Italy

Dr. Angileri is an Associate Professor in the Department of Aerospace Science and Technology at Politechnico de Milano in Milan, Italy. He is the head of the passive safety section of the Transport Safety Lab (LA.S.T.) at Politechnico de Milano. He has significant experience in roadside safety, particularly in the area of motorcycle infrastructure-based countermeasures. He was a member of the planning committee for the 1st International Roadside Safety Conference held in 2017.

James Baron, American Traffic Safety Services Association, Fredericksburg, Virginia, United States

Mr. Baron specializes in media relations and communications within transportation, roadway safety, and motorcycle rider safety. He has been an avid motorcyclist for over thirty years. Mr. Baron was the principle author of the ATSSA's *Emerging Opportunities for ATSSA Members in Motorcycle Safety* report. He is an author on the FHWA *Infrastructure Countermeasures to Mitigate Motorcyclist Crashes in Europe* report and currently a member of the FHWA Motorcyclist Advisory Council.

Fran Bents, Westat, Rockville, Maryland, United States

Ms. Bents is Vice President of Westat, a private research agency located in Rockville, Maryland. Ms. Bents has been active in motorcycle safety for over 20 years. She was the Principal Investigator on the Motorcycle Crash Causes and Outcomes Pilot Study, was a Senior Advisor for the FHWA Motorcycle Crash Causation Study, is a facilitator of the Motorcycle Advisory Council, and was a subject matter expert for the Domestic Scan of Leading Practices for Motorcycle Safety.

Mark Bloschock, PE, Walter P Moore, Austin, Texas, United States

Mr. Bloschock has over 39 years of transportation engineering experience, with a majority of that being with the Texas Department of Transportation. He focuses on the design of bridges, interchanges, and ramps, as well as the safety designs for highways. He is an author on the FHWA *Infrastructure Countermeasures to Mitigate Motorcyclist Crashes in Europe* report and was a reviewer of the 2012 ATSSA report *Emerging Opportunities for ATSSA Members in Motorcycle Safety.* He formerly served on the Motorcyclist Advisory Council after being appointed in 2006 by the US Secretary of Transportation.

Genevieve Boye, Motorcycle Industry Council, Arlington, Virginia, United States

Ms. Boye is a Senior Legislative Analyst for the Motorcycle Industry Council. She is a member on the TRB ANF30 Standing Committee on Motorcycles and Mopeds.

Tim Buche, Motorcycle Safety Foundation and Powersports Safety and Trade Association, Irvine, California, United States

Mr. Buche is the President and CEO of four nonprofit trade associations, including Recreational Off-Highway Vehicle Association, Motorcycle Industry Council, Specialty Vehicle Institute of America, and the Motorcycle Safety Foundation.

Sue Chrysler, Ph.D., Texas A&M Transportation Institute, College Station, Texas, United States

Dr. Chrysler has conducted human factors transportation safety research for over 20 years specializing in infrastructure-based signs and devices. She was appointed to the FHWA International Motorcycle Safety Scan in 2010 which led to the report entitled, Infrastructure Countermeasures to Mitigate Motorcycle Crashes in Europe.

Cecile Coquelet, Ph.D., Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseau (IFSTTAR), France

Dr.Coquelet works for the Institut Francais des Sciences et Technologies des Transports. She is a certified engineer in road safety and sociologist. Her research interests include young drivers, pedestrians, and motorcyclists' road risk. She is a member of the TRB ANF30 Standing Committee on Motorcycles and Mopeds.

Keith Cota, P.E., New Hampshire Department of Transportation, Concord, New Hampshire, United States

Mr. Cota is a Chief Project Manager at the New Hampshire Department of Transportation. Keith is on the American Association of State Highway and Transportation Officials (AASHTO) Technical Committee for Roadside Safety and the Technical Committee for Road Safety for the World Road Association. He is an author on the FHWA *Infrastructure Countermeasures to Mitigate Motorcyclist Crashes in Europe* report.

Saskia de Craen, Ph.D., SWOV Institute for Road Safety Research, Netherlands

Dr. de Craen is a Senior Researcher at the SWOV Institute for Road Safety Research. Her research interests include novice drivers, accompanied driving, powered two-wheelers, and self-driving vehicles. She was a member of the Organization for Economic Development (OECD) "Powered Two-wheeler Safety" team. She has several peer-reviewed publications with several focusing on motorcycle crashes, such as conspicuity and crash characteristics.

Michael Crow, Colorado Department of Transportation, Greeley, Colorado, United States

Mr. Crow is an Engineer for the Colorado Department of Transportation. He has over fifteen years of transportation experience. He previously worked for the Kansas Department of Transportation and the Kansas Asphalt Pavement Association. He is a member of the FHWA Motorcyclist Advisory Council.

Matthew Dana, P.E., Virginia Department of Transportation, Staunton, Virginia, United States

Mr. Dana is a District Location and Design Engineer for the Virginia Department of Transportation.

Glenn Davis, Colorado Department of Transportation, Denver, Colorado, United States

Mr. Davis is a Highway Safety Manager at the Colorado Department of Transportation. He is responsible for impaired driving, police services, motorcycle safety, young drivers, and speed enforcement. Glenn currently holds leadership positions on the Colorado Task Force on Drunk and Impaired Driving, Motorcycle Safety Board, Teen Driving Alliance, and Persistent Drunk Driver and Traffic Committees. He is a member of the TRB ANF30 Standing Committee on Motorcycles and Mopeds.

Liz de Rome, Ph.D., NeuRA, Randwick, New South Wales, Australia

Dr. Rome is a Research Scholar at the Neuroscience Research Australia. She is trained in public health and focuses on road safety; specifically, she focuses on motorcycle safety. Within motorcycle safety, she is interested in improving the quality and usage of protective clothing. She has several peer-reviewed motorcycle safety-related publications. She is a member of the TRB ANF30 Standing Committee on Motorcycles and Mopeds.

Ashim Debnath, Ph.D., Victoria University, Melbourne, Victoria, Australia

Dr. Debnath is a Lecturer in Civil Engineering at Victoria University. His research interests include work zones, advanced statistical methods, bicyclist and motorcyclist safety, and surrogate measures of safety. He is a member on the TRB ANF 30 Standing Committee on Motorcycles and Mopeds, as well as a member on the TRB AHB 55 Committee on Work Zone Traffic Control.

Paul Degges, Tennessee Department of Transportation, Nashville, Tennessee, United States

Mr. Degges is a Deputy Commissioner and Chief Engineer at the Tennessee Department of Transportation. He is responsible for overseeing all engineering projects and divisions. He is an author on the FHWA *Infrastructure Countermeasures to Mitigate Motorcyclist Crashes in Europe* report.

Joseph Elliott, National Motorcycle Institute, Springfield, Oregon, United States

Mr. Elliott is the founder of the National Motorcycle Institute. He is an avid motorcycle rider who has ridden since 1975. His career focuses on data, training, and behaviors relating to motorcycle fatalities. He is also interested in riding gear, road engineering, vehicle engineering, and intelligent vehicles.

Eric Emery, Ph.D., D-ABFA, National Transportation Safety Board, Washington, D.C., United States

Dr. Emery is a Transportation Analyst with the National Transportation Safety Board. He has been involved in victim search and recovery work since 1993.

David Ennis, National Highway Traffic Safety Administration, Washington, D.C., United States

Mr. Ennis is a Highway Safety Specialist at the National Highway Traffic Safety Administration where he is currently involved with motorcycle safety initiatives. Mr. Ennis has over 35 years of law enforcement experience. Of those years, 24 years were spent as a motorcycle officer.

James Evans, P.E., Evans Accident Reconstruction, College Station, Texas, United States

Mr. Evans is a mechanical engineer who owns Evans Accident Reconstruction. He has been involved in more than 1,000 accident reconstructions and is certified by the Accreditation Commission for Traffic Accident Reconstructors (ACTAR). Mr. Evans possesses extensive experience in motorcycle crash reconstruction involving fatalities with infrastructure-based safety systems. He is also an avid motorcycle rider with more than 100,000 miles' experience.

Michael Fitzharris, Ph.D., Monash University, Melbourne, Victoria, Australia

Dr. Fitzharris is an Associate Professor and Associate Director of regulation and in-depth crash investigations in the Accident Research Centre and the Injury Outcomes Research Unit at Monash University. He has several peer-reviewed motorcycle safety publications focusing on rider behavior, injuries, crash risk factors, autonomous emergency braking, and safety clothing.

Joseph Foglietta, P.E., HVEA Engineers, Beacon, New York, United States

Mr. Foglietta is a Senior Project Manager at HVEA Engineers. He was formerly the acting Director of Engineering at New York State Department of Transportation. He helped prepared the American Association of State Highway and Transportation Officials *Scan 09-04 Leading Practices for Motorcyclist Safety*.

Michael Fox, National Transportation Safety Board, Washington, D.C., United States

Mr. Fox is a Highway Accident Investigator at the National Transportation Safety Board. Mr. Fox is an avid motorcycle safety advocate who has authored several blogs and other short news articles relative to motorcycle safety issues.

Clay Gabler, Ph.D., Virginia Tech, Blacksburg, Virginia, United States

Dr. Gabler is a Professor and Chair for Biomedical Engineering Graduate Studies in the Department of Biomedical Engineering and Mechanics at Virginia Tech. He is the Associate Director of the Virginia Tech-Wake Forest Center for Injury Biomechanics. His research interests include injury biomechanics, vehicle crash safety, crash injury epidemiology, crash modeling, crash avoidance methodologies, and protection of vulnerable road users. He has several peer-review motorcycle safety publications. He is on the TRB AFB20 Committee on Roadside Safety Design and was the session chair at for the "Motorcycle Crash Compatibility with Roadside Barriers" 2007 TRB summer meeting.

Srinivas Geedipally, Ph.D., Texas A&M Transportation Institute, College Station, Texas, United States

Dr. Geedipally is an Associate Research Engineer on the Crash Analysis Team at the Texas A&M Transportation Institute. He is a member of the TRB ANB20-(3) Subcommittee on Surrogate Measures of Safety and a friend of TRB ANB20 Committee on Safety Data, Analysis and Evaluation and TRB ABJ80 Statistical Methodology Committee. He is also a former young member of the TRB ANF30 Standing Committee on Motorcycles and Mopeds. He has several peer-reviewed journal articles, including one examining a process to determine locations for motorcycle crashes.

Konstantina Gkritza, Ph.D., Purdue University, West Lafayette, Indiana, United States

Dr. Gkritza is an Associate Professor of Civil Engineer and Agricultural and Biological Engineering at Purdue University. She has several peer-reviewed motorcycle safety publications. She is also a member of the TRB ANF30 Standing Committee on Motorcycles and Mopeds. Her research interests focus on the economic analysis of highway investments and modeling, transportation and energy interdependencies, highway safety, and sustainability.

Lois Goldman, North Jersey Transportation Planning Authority, Newark, New Jersey, United States

Ms. Goldman is the Director of Regional Planning at the North Jersey Transportation Planning Authority. Ms. Goldman is trained in transportation and urban planning and is member of the TRB ANF30 Standing Committee on Motorcycles and Mopeds.

Raphael Grezbieta, Ph.D., University of New South Wales, Sydney, New South Wales, Australia

Dr. Grezbieta is a Professor in the Transport and Road Safety (TARS) research unit at the University of New South Wales Sydney. His research expertise is in crashworthiness and road safety, including occupant protection, roadside barriers, and impact loading. He has several peer-reviewed motorcycle safety publications.

Patricia Groeber, New York State Police, Albany, New York, United States

Ms. Groeber is a Deputy Superintendent for the New York State Police. Ms. Groeber codified motorcycle safety in the New York State Police's annual Traffic Safety Detail Orders which is a document that specified motorcycle enforcement plans. Ms. Groeber has extensive experience with motorcycle safety law enforcement.

Jeremy Gunderson, National Highway Traffic Safety Administration, Washington, D.C., United States

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Shaun Lennard, Australian Motorcycle Council, Brunswick, Victoria, Australia

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Dr. Manser has been involved in human factors transportation safety research for more than 20 years and is an active rider. Currently, he leads the statewide Texas Motorcycle Safety Coalition project and is a member of the TRB ANF30 Standing Committee on Motorcycles and Mopeds. He has conducted research on rider's gear use motivations and currently is the Principal Investigator for the FHWA sponsored project "Identifying Infrastructure-Based Motorcycle Crash Countermeasures" project.

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APPENDIX A. COUNTERMEASURE SUMMARIES

Countermeasure Quick References, Terms, and Symbols

Infrastructure-based crash countermeasures to improve motorcyclist's safety are listed within the Quick Reference Countermeasures table. The table is intended to provide an overview of key information relative to each countermeasure including the countermeasure's approximate effectiveness and cost relative to rider safety. The terms and symbols used in the table and summaries are described below.

Countermeasure Name: Countermeasure name refers to the generally accepted engineering term to describe an infrastructure-based motorcycle crash countermeasure.

Vehicle Type: Vehicle type refers to whether a countermeasure is intended to improve the safety of motor vehicles (MV), motorcycles (MC), or both (MV/MC).

Crash Type: Crash type refers to the assigned crash classification (e.g., single vehicle roadway departure). Crash types include:

- Failure to Yield Right of Way (FYRoW)
- Loss of Control (LoC)
- Rear End (RE)
- Sideswipe (SDSW)
- Single Vehicle Roadway Departure (SVRD)

Injury Type: Injury type refers to the whether an infrastructure-based motorcycle crash countermeasure is primarily intended to reduce the incidence of injuries (RI), reduce injury severity (RS), or both (RI/RS).

Road Segment (Road Sgmt): Road segment refers to the common infrastructure-based motorcycle crash countermeasure installation location. The three road segments that represent the majority of motorcycle-related crashes include:

- Curves (C)
- Intersections (I)
- Straight sections (S)

Motorcycle Crash Modification Factor (MC CMF): A multiplicative factor that indicates the number of crashes expected after a countermeasure is implemented. A CMF below 1 indicates a safety benefit while a CMF over 1 represents a safety impediment. Not Est indicates a crash modification factor score has not been established yet through research.

Motorcycle Effectiveness (MC Effect): Effectiveness refers to the ability or inability of an infrastructure-based motorcycle crash countermeasure to influence motorcycle-related crash rates (not motor vehicle crash rates), injury/fatality rates, and injury severity. Effectiveness levels are represented by the following:

- Not Est: No effectiveness level established or identified through research.
- Effec +: Countermeasure was shown in research to have a safety benefit in terms of reducing crash rates, injury or fatality rates, or injury severity.
- Effec -: Countermeaure was shown in research to not have a safety benefit in terms of reducing crash rates, injury or fatality rates, or injury severity.
- Effec ~: Countermeasure was shown in research to not have a safety benefit or to impede safety in terms of reducing crash rates, injury or fatality rates, or injury severity.

Motor Vehicle Crash Modification Factor (MV CMF): A multiplicative factor that indicates the number of crashes expected after a countermeasure is implemented. A CMF below 1 indicates a safety benefit while a CMF over 1 represents a safety impediment. Not Est indicates a crash modification factor score has not been established yet through research. NA indicates not applicable.

Motor Vehicle Effectiveness (MV Effect): Effectiveness refers to the ability or inability of an infrastructure-based crash countermeasure to influence motor vehicle-related crash rates, injury/fatality rates, and injury severity. Effectiveness levels are represented by the following:

- Not Est: No effectiveness level established or identified through research.
- Effec +: Countermeasure was shown in research to have a safety benefit in terms of reducing crash rates, injury or fatality rates, or injury severity.
- Effec -: Countermeaure was shown in research to not have a safety benefit in terms of reducing crash rates, injury or fatality rates, or injury severity.
- Effec ~: Countermeasure was shown in research to not have a safety benefit or to impede safety in terms of reducing crash rates, injury or fatality rates, or injury severity.
- NA: Not Applicable

Cost: Cost refers to the approximate funding level required to build and install a countermeasure. Varying cost levels are represented by the following:

- No cost information available (NA)
- $: $0 - $50,000
- $$: $50,001 – $200,000
- $$$: $200,001 - $1,000,000

Countermeasure Quick Reference

Each infrastructure-based motorcycle crash countermeasure identified within the review of literature activity is presented in the following tables categorized by the primary crash type to be addressed and then grouped by similar functions.

Ref.	Countermeasure	Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
1.1	Red Light Violation Warning	MV/MC	FYRoW	RI	I	Not Est	Not Est	Not Est	Not Est	$
1.2	Limited Sight Distance Warning Signs	MV/MC	FYRoW	RI	C	Not Est	Not Est	1.07	Effec ~	$
1.3	Prohibitive Signs	MV/MC	FYRoW	RI	S	Not Est	Not Est	.55-.80	Effec +	$
1.4	Signals	MV/MC	FYRoW	RI	I	Not Est	Not Est	.01-1.0	Effec +	
1.5	Intersection/Merging Traffic Warning Signs	MV/MC	FYRoW	RI	C, S	Not Est	Not Est	.60-.70	Effec +	$
1.6	Lighting	MV/MC	FYRoW	RI	C, I, S	.61-.63	Effec +	.71-.79	Effec +	
2.1	High Friction Surface Treatment	MV/MC	LoC	RI/RS	C, S	Not Est	Not Est	.15-.80	Effec +	$$-$$$
2.2	Textured Pavement Markings	MC	LoC	RI/RS	C, I, S	Not Est	Not Est	Not Est	Not Est	$$
2.3	Pavement Condition Repair	MV/MC	LoC	RI/RS	C, I, S	Not Est	Not Est	.65-.95	Effec +	$$-$$$
2.4	Pavement Shoulder/Edge Drop-Off Treatment	MV/MC	LoC	RS/RI	S	Not Est	Not Est	.94	Effec +	$
2.5	Steel Plate Danger Mitigation	MC	LoC	RI/RS	C, I, S	Not Est	Not Est	NA	NA	$
2.6	Pavement Change Warning Signs	MC	LoC	RI	S	Not Est	Not Est	NA	NA	$
3.1	Design for Motorcycle Sight Distance	MC	RE	RI	C, I, S	Not Est	Not Est	NA	NA	$$$
3.2	Lane Splitting	MC	RE	RI	S, I	Not Est	Effec ~	NA	NA	$
4.1	Roadway Vehicle Parking	MC	SDSW	RI	C, S	Not Est	Not Est	NA	NA	$
5.1	Guardrail Continuous Protection System	MC	SVRD	RI/RS	C	Not Est	Not Est	NA	NA	$
5.2	Retrofit Concrete Barrier	MC	SVRD	RS	C, S	Not Est	Not Est	NA	NA	$$
5.3	Punctual Energy Absorber	MC	SVRD	RS	C	Not Est	Not Est	NA	NA	$

5.4	Ensure Proper Cross Slope (Superelevation)	MV/MC	SVRD	RI	C	Not Est	Not Est	.85-.98	Effec +	$$
5.5	Curve Speed Warning	MV/MC	SVRD	RI	C	Not Est	Not Est	.93-.95	Effec +	$
5.6	Advanced Curve Warning Signs	MV/MC	SVRD	RI	C	Not Est	Not Est	.45-.92	Effec +	$
5.7	In-Curve Warning Signs	MV/MC	SVRD	RI	C	Not Est	Not Est	.73-.82	Effec +	$
5.8	Pavement Markings	MV/MC	SVRD	RI	C, S	Not Est	Not Est	.71-.92	Effec +	$
5.9	Rumble Strips	MV/MC	SVRD	RI/RS	C, S	Not Est	Not Est	.30-.93	Effec +	$-$$
5.10	Remove Roadside Trees	MC	SVRD	RS	C, S	Not Est	Not Est	Not Est	Not Est	$
5.11	Positive Guidance in a Work Zone	MV/MC	SVRD	RI	C, I, S	Not Est	Not Est	Not Est	Not Est	$

Countermeasure Summaries, Terms, and Symbols

The Countermeasure Summaries section presents a more detailed description of each infrastructure-based crash countermeasure within a short format. Each summary includes the information from the Countermeasure Quick Reference table and includes additional information such as a full description, potential applications, and assessed effectiveness in terms of safety. It is noted that the Project Team included infrastructure-based crash countermeasures designed explicitly to improve rider safety and several countermeasures designed to improve general safety, which may also have an impact on rider safety. Terms and symbols used in the Countermeasure Summaries, beyond those included in the Quick Reference table, are described below.

Description: Provides an overview of the countermeasure design and variations of the original design when applicable.

Applications: Refers to the locations at which the countermeasure is intended for use.

Vehicle and Rider Safety Effectiveness: Crash Data provides an overview of key studies that examined the effectiveness of the infrastructure-based crash countermeasure and provides an overview of whether the countermeasure is designed specifically for rider safety, specifically for vehicle occupant safety, or both.

Design Considerations: Includes items that are related to the infrastructure-based countermeasure that may need to be addressed during design or build or are factors that should be considered before, during, or after installation.

Cost and Timeframe: Provides an estimate of the countermeasure cost, including purchase and installation when known, as well as the amount of time required for installation.

Maintenance Needs: Includes information regarding the various efforts to maintain the countermeasure over the duration of the countermeasure application.

Limitations and Concerns: Summarizes concerns or limitations from engineers, constituents, or riders relative to a wide range of topics including countermeasure installation, continued safety benefit, political obstacles, etc.

References: Presents a listing of key references cited in the summary or related to the countermeasure.

1.1 Red Light Violation Warning

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	FYRoW	RI	I	Not Est	Not Est	Not Est	Not Est	$

Description

Failure to yield right of way violations by riders and motorists at signalized intersections represents an obvious safety problem for riders. The red light violation warning system is a connected vehicles (CV) application that can inform motorists and riders who are at or passing through an intersection of an impending red light running vehicle or motorcycle. This system would employ dedicated short-range communications (DSRC) to distribute information about the signal timing, geometry of the intersection, and vehicle-related (and motorcycle) information (e.g., speed, acceleration, location). The Connected Vehicle Reference Implementation Architecture (USDOT, 2016) presents one example of the RLVW application in which a vehicle-based (or motorcycle-based) application would use the information delivered by DSRC to determine if a vehicle is likely to enter an intersection illegally. If a violation is likely, a warning could be issued to drivers and/or riders via displays (e.g., heads up display), auditory alerts, or haptics (e.g., vibrating handlebars in direction of oncoming threat).

A depiction of a red light violation warning system (USDOT, 2017).

Applications

This system would be applicable at signalized intersections, particularly those that exhibit a high rate of motorcycle crashes due to red light violations by motorists or riders.

Vehicle and Motorcycle Safety Effectiveness

The Texas Department of Transportation reported that in 2016 “disregard stop sign or light” was considered a contributing factor in 11,292 crashes statewide; 83 of which were fatal and 373 of which were incapacitating (TxDOT, 2017). Of these fatal and incapacitating crashes, 12 percent and 9 percent, respectively, involved a motorcycle. Furthermore, red light running could be attributed to 137,000 injuries and 771 fatalities nationwide in 2015 (IIHS, 2017). No crash reduction factors have been established for this countermeasure relative to motor vehicles.

No literature was found examining the effect of this potential countermeasure on motorcycle-related crashes.

Design Considerations

Connected vehicle equipment effectiveness varies based on the number of vehicles running the application.

Connected vehicle equipment installed at a location can be used to support applications beyond red light running violations potentially creating benefit of the deployment beyond the RLVW system.

Cost and Timeframe

Unit costs for DSRC infrastructure equipment and installation is on average about $18,000 in 2014 (Wright et al., 2014). Consumers will need DSRC equipment on their vehicles to support the application. Although an agency would not need to pay to retrofit the vehicles, consumers would need to pay about $4000 to support DSRC (Wright et al., 2014).

Maintenance Needs

DSRC roadside units will need to be replaced as the technology improves and as the equipment wears out from weather exposure.

Limitations and Concerns

The effectiveness of the deployment depends on the market penetration of the connected vehicle systems.

Other communication mediums, like cellular communication, are competing for vehicle applications like RLVW but their transmission latency may limit their application.

Key References

Insurance Institute for Highway Safety (2017, December 9). *Red Light Running*. Washington, DC. Retrieved from http://www.iihs.org/iihs/topics/t/red-light-running/topicoverview

USDOT (2016, December 8). *Connected Vehicle Reference Implementation Architecture. Red Light Violation Warning*. Retrieved from http://local.iteris.com/cvria/html/applications/app57.html#tab-3

Texas Department of Transportation. (2017, December 1). *Crash Contributing Factors 2016*. [Data file], Austin, Texas. Retrieved from http://ftp.dot.state.tx.us/pub/txdot-info/trf/crash_statistics/2016/20.pdf

Wright, J., Garrett, K. J., Hill, C. J., Krueger, G. D., Evans, J. H., Andrews, S., Wilson, C. K., Rajbhandari, R., Burkhard, B. (2014). *National Connected Vehicle Field Infrastructure Footprint Analysis (AASHTO*. Report No. FHWA-JPO-14-125). Washington, DC: U.S. Government Printing Office.

1.2 Limited Sight Distance Warning Signs

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	FYRoW	RI	C	Not Est	Not Est	1.07	Effec~	$

Description
Sometimes stopping sight distance is not available at a vertical or horizontal curve. In these cases, agencies could install signage to warn motorists. A limited sight distance warning sign is a low cost alternative to the redesign and construction required to provide more sight distance.

Limited Sight Distance Sign (USA Traffic Signs, 2017).

Applications
A limited sight distance warning sign is used on a vertical curve, horizontal curve, or any obstruction blocking a motorist's ability to see a hazard that would require them to stop.

Vehicle and Rider Safety Effectiveness
Nine matched pairs of sites on paved two-lane roads in Michigan were considered in a study on the effectiveness of installing a "Limited Sight Distance" sign on reducing crashes (Forbes, 2003). The study used a before-and after analysis method which considered 3.6 to 5 years before and after treatment installation. The study found that both treatment and control sites experienced an increase in the number of crashes, with a less severe increase in the control. This indicates that there may be no safety benefit. However, the number of crashes observed were statistically small and may not reflect the true efficacy of the sign (Forbes, 2003).

There have been no studies to date that have measured the effects of limited sight distance on motorcycle-related crash rates.

Design Considerations
This signage needs to be placed far enough from the curve that motorists can take appropriate action. It would be best to install the signage with an advisory speed plaque.

Cost and Timeframe
The installation of a single sign would only take a few hours and would be low cost.

Maintenance Needs

Signage needs to be replaced periodically based on retroreflectivity degradation, color degradation, age, or MUTCD standard inspection failures. Degradation varies based on sunlight exposure and the color of the sign, but signs generally last 15 years (Tayse et al., 2017).

Limitations and Concerns

Sight Distance is an engineering term that is likely not understood by the average driver. Use of another phrase such as “Hidden Driveway” or some other phrase to translate that the ability to see a hazard is limited.

Roadways where inadequate signs distance are allowed are typically low speed and low volume.

Key References

Forbes, G. (2003). *Synthesis of Safety for Traffic Operations* (*Transport Canada*. Contract No. T8056-010057/001/SS). Ottawa, Canada.

Tayse, J., Mullins, M., Linsenmayer, M., Warzala, D., Johnson, S. M., & Misgen, S. (2017). *Sign Life-Cycle Policies and Practices.* (Minnesota Department of Transportation. Transportation Research Synthesis 1707). St. Paul, MN: Research Services Library.

1.3 Prohibitive Signs

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	FYRoW	RI	I	Not Est	Not Est	.55-.80	Effec+	$

Description

One option to improve safety at an intersection is to prohibit left turns and/or U-turns which reduces potential for vehicle conflicts. This can be accomplished at the onset of designing an intersection or retrofitting a change in traffic control. Note, another method to protect riders prior to performing a left turn would be to create a dedicated and/or offset turn lane; however, the primary left-turn crash scenario occurs during the left turn maneuver.

Movement Prohibition Signs (MUTCD, 2009).

Applications

This countermeasure is used to indicate a movement restriction to motorists for left turns or U-turns. Brich and Cottrell (1994) note that a restriction to the movement causing the problem or the opposing left turn movement (if the visibility of on-coming traffic is the cause) could be prohibited.

Vehicle and Rider Safety Effectiveness

Brich and Cottrell (1994) studied eight signalized intersections in Virginia where prohibitive signs were installed to determine the effects of the signs on left-turn and U-turn related crashes. Their study found that the restricted movement resulted in an average crash rate reduction of 63 percent and the total intersection experienced an average crash rate reduction of 66 percent. A state of the practice survey of state departments of transportation by Florida DOT found that prohibition of left turns was associated with a 45% reduction in overall crashes (ranging from a 30% reduction in rear-end crashes to a 90% reduction in left-turn crashes); prohibiting right-turn-on-red at signalized intersections was associated with crash reductions of 20-30% (Gan, Shen, & Rodriguez, 2005).

There have been no studies to date that have measured the effects of prohibitive movement signs on motorcycle-related crash rates.

Design Considerations

A turn prohibition could be implemented for part of a day or an entire day, depending on the congestion and alternate route availability on a site (Brich & Cottrell, 1994). The authors also composed several design considerations from their study that included:

- A right-turn overlap phase from a side street during a protected left-turn phase could warrant a no U-turn sign.
- U-turns could be restricted when the receiving pavement width is 24 feet or less since an average automobile could cannot complete a U-turn maneuver in a continuous motion with that amount of space.
- AASHTO's minimum design standards for U-turns should be considered as a basis for restricting the maneuver.
- The absence of a left-turning bay could warrant a left-turn restriction. An alternate turn location within one block of the turn restriction should be available to avoid driver disregard of the restriction.
- A crash study is necessary to avoid driver apathy toward unwarranted traffic control devices when determining whether to employ a turn restriction.

Cost and Timeframe

The installation of a prohibitive sign would only take a few hours and would be low cost.

Maintenance Needs

Signage needs to be replaced periodically based on retroreflectivity degradation, color degradation, age, or MUTCD standard inspection failures. Degradation varies based on sunlight exposure and the color of the sign, but signs generally last 15 years (Tayse et al., 2017).

Limitations and Concerns

If the prohibition of left or U-turns is implemented at a site where the turns were formerly allowed, there may be some resistance to the signage by drivers and/or drivers may ignore it without proper enforcement.

Additionally, the problem could be shifted either upstream or downstream of the installation as drivers try to reroute to their destination. In some cases, the relocated problem is more troublesome than the problem at the original site (Brich & Cottrell, 1994). Motorists could even revert to using residential streets to reach their destination.

Key References

Brich, S. C., & Cottrell, B. H. Jr. (1994). *Guidelines for the Use of No U-turn and No-left Turn Signs.* (*Virginia Transportation Research Council*. Report No. VTRC 95-R5). Charlottesville, Virginia.

Gan, A., Shen, J., & Rodriguez, J. (2005). *Update of Florida Crash Reduction Factors and Countermeasures to Improve the Development of District Safety Improvement Projects.* State of Florida Department of Transportation, Tallahassee, FL.

Tayse, J., Mullins, M., Linsenmayer, M., Warzala, D., Johnson, S. M., & Misgen, S. (2017). *Sign Life-Cycle Policies and Practices.* (Minnesota Department of Transportation. Transportation Research Synthesis 1707). St. Paul, MN: Research Services Library.

1.4 Signals

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	FYRoW	RI	I	Not Est	Not Est	.01-1.0	Effec+	$-$$$

Description

Intersections represent one of the highest risk scenarios for motorcycle riders, particularly left-turns where a driver or rider fails to yield the right of way. A potential countermeasure to improve rider safety in this scenario is the addition of a traffic signal to a previously un-signalized intersection. Specifically, this would entail adding a signal that converts a permissive left-turn phase to a left-turn protective. A protective left-turn phase stops opposing traffic from proceeding through an intersection while traffic completes a left turn. Protected left-turn signals may be used alone (i.e., no left turns permitted except during the protected-left phase) or may precede or follow a permissive left turn phase (FHWA, 2013).

Applications

High traffic volumes often are the primary reason for adding a traffic signal to a previously unsignalized intersection, though intersection crash rates may also influence that decision. (FHWA, 2013).

Adding a left-turn protected phase to an existing signalized intersection is identified as a low-cost countermeasure for reducing left-turn crashes (FHWA, 2009).

Vehicle and Rider Safety Effectiveness

Generally, adding a signal to a previously un-signalized intersection is associated with reductions in right-angle crashes; the extent of the reductions depends on other factors including traffic volumes and intersection geometries (Bahar et al., 2008). Adding a left-turn phase to an existing signal, or changing a permissive left-turn phase to a protective or permissive-protective phase, is associated with a reduction in left-turn crashes at intersections (Bahar et al, 2008; Rice & Datta, 2010). However, the effects of left-turn phase additions or changes on *overall crashes* are mixed because of the possibility of an increase in other crash types (Bahar et al, 2008). Because of the variety of signalization countermeasure types and contexts, crash reduction factors for signal-related improvements range from 0 to 99 percent.

There have been no studies to date in the United States that have measured the effects of new signals or the addition of a left-turn phase on motorcycle-related crash rates. The *Guide to Traffic Management Part 6: Intersections, Interchanges, and Crossings* produced by Austroads in Australia provides motorcycle-specific recommendations for intersection treatments, including traffic signals (Austroads, 2017).

Design Considerations

A separate left-turn lane is recommended for signalized intersections with a separate left-turn signal phase (FHWA, 2013).

Cost and Timeframe

The installation of a new traffic signal is a relatively high-cost countermeasure, ranging from $50,000 to $500,00 in 2015 (ITE, 2004; WYDOT, 2012). Implementation can take several months.

The addition of a left-turn phase to an existing traffic signal is generally considered a low to medium cost countermeasure. Costs for adding left-turn phasing to signalized intersections were estimated at $25,000 per intersection in case studies conducted in 2000, with the implementation taking one week (Rice & Datta, 2010). Changing a permissive left-turn phase to a permissive-protective or protective-only is less expensive, estimated at $5000-$10,000 (FHWA, 2014).

Maintenance Needs

Traffic signals require continual maintenance and monitoring to function properly, including replacement of aging equipment and components and periodic timing adjustments to respond to changes in traffic flow and safety performance (FHWA, 2013).

Limitations and Concerns

Adding a protected left-turn phase to a signalized intersection can create delays and increase rear-end crashes at intersections with a high volume of through traffic (WYDOT, 2012).

Key References

Austroads (2017). Guide to Traffic Management Part 6: Intersections, Interchanges and Crossings (Austroads, Publication No. AGTM06-17). Sydney, Australia.

Bahar, G., Masliah, M., Wolff, R., Park, P. (2008). Desktop Reference for Crash Reduction Factors (Federal Highway Administration, Report No. FHWA-SA-08-011). Washington, DC: U.S. Government Printing Office.

Federal Highway Administration (2009). Low-Cost Safety Enhancements for Stop-Controlled and Signalized Intersections. (Federal Highway Administration, Report No. FHWA-SA-09-020). Washington, DC: U.S., Government Printing Office.

Federal Highway Administration (2013). Signalized Intersections: An Informational Guide. (Federal Highway Administration). Retrieved from https://safety.fhwa.dot.gov/intersection/conventional/signalized/fhwasa13027/.

Institute of Transportation Engineers (2004). Traffic Signals. Issue Briefs, Federal Highway Administration, Department of Transportation, Washington, D.C. Retrieved from http://library.ite.org/pub/e26c7ce7-2354-d714-51f1-3bf5311d7c2a.

Rice, E. and Datta, T.K. (2010). Permissive/Protected Left-Turn Phasing. Intersection Safety Case Study (Federal Highway Administration, Report No. FHWA-SA-09-015 Washington, DC: U.S. Government Printing Office.

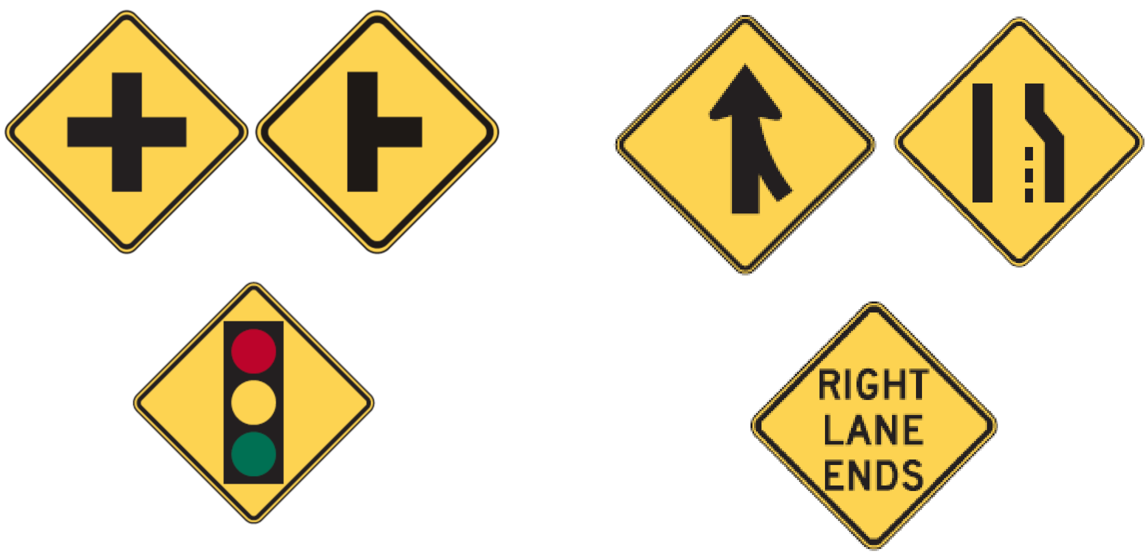
WYDOT (2012). WYDOT Quick Facts: Traffic Signals. Retrieved from http://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Traffic%20data/Traffic%20Signals.pdf.

1.5 Intersection (Ahead)/Merging Traffic Warning Sign

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	FYRoW	RI	I	Not Est	Not Est	.60-.70	Effec+	$

Description

Drivers tend to build expectation based on the latest miles driven on a roadway. If there is a long stretch without any signalized intersections, a motorist might not be as responsive to a signal as desired. Similarly, motorists might not notice an un-signalized intersection or merging area if they did not know to look for it. A low-cost solution is to install static signage to warn motorists about an upcoming intersection.



(a) (b)

Intersection Signs (a) and Merging Traffic Signs (b) (MUTCD, 2009)

Applications

Intersection and merging traffic signs are installed when there is not adequate sight distance to see the traffic control ahead and when a motorist is not expecting an intersection or potential vehicle conflict. Intersection signs are often used on rural roads where signalized and un-signalized intersections are not expected.

Merging traffic signs are useful in both urban and rural environments where there is a lane drop or another stream of traffic merging onto the same facility.

Vehicle and Rider Safety Effectiveness

Advance warning signs for intersections are associated with intersection-related crash reduction factors ranging from 22 to 40 percent (Bahar et al, 2008). There have been no studies to date that have measured the effects of intersection or merging traffic signs on motorcycle-related crash rates.

Design Considerations

This warning sign needs to be placed far enough from the traffic control that motorists can take appropriate action. The warning sign also needs to be placed apart from other signage so that it demands an appropriate amount of attention.

Cost and Timeframe

The installation of a single sign would only take a few hours and would be low cost.

Maintenance Needs

Signage needs to be replaced periodically based on retroreflectivity degradation, color degradation, age, or MUTCD standard inspection failures. Degradation varies based on sunlight exposure and the color of the sign, but signs generally last 15 years (Tayse et al., 2017).

Limitations and Concerns

Motorists might not pay these signs the attention they deserve. One option to raise awareness of intersection or merging signs is to install them with flashing beacons. Adding beacons will increase the cost of the countermeasure, but they will also increase attention given to the signs.

Key References

Bahar, G., Masliah, M., Wolff, R., Park, P. (2008). *Desktop Reference for Crash Reduction Factors* (*Federal Highway Administration*, Report No. FHWA-SA-08-011). Washington, DC: U.S. Government Printing Office.

Tayse, J., Mullins, M., Linsenmayer, M., Warzala, D., Johnson, S. M., & Misgen, S. (2017). *Sign Life-Cycle Policies and Practices.* (*Minnesota Department of Transportation*. Transportation Research Synthesis 1707). St. Paul, MN: Research Services Library.

1.6 Lighting

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	FYRoW	RI	C, I, S	Not Est	Effec+	.71-.79	Effec+	$

Description

Roadway lighting provides increased visibility of the roadway environment, including infrastructure features, pedestrians and other road users, and foreign objects or animals. Appropriate levels of lighting at intersections can increase the conspicuity of the intersection, aid drivers and motorcycle riders in recognizing intersection geometry and features and avoiding potential hazards such as medians and curbs (Milling et al., 2016).

Applications

Lighting can be installed at intersections and along roadways to enhance nighttime visibility of the roadway infrastructure as well as other hazards.

Vehicle and Rider Safety Effectiveness

The Florida DOT collected and synthesized crash reduction factors developed by multiple state DOTs for infrastructure-based countermeasures (Gan, Shen, & Rodriguez, 2005; FHWA, 2009). Lighting installation and improvements along roadway segments and interchanges are associated with average crash reductions ranging from 23% to 25% for all crashes and 37% to 50% for nighttime crashes. Installing lighting at intersections was associated with a 33% average reduction in all crashes and a 56% average reduction in nighttime crashes. Lighting at railroad crossings averaged a 46% reduction in all crashes and a 60% reduction in nighttime crashes (Gan, Shen, & Rodriguez, 2005; FHWA, 2009).

A meta-analysis of 38 studies determined a CMF of 0.79 for all nighttime crashes and 0.71 for injury crashes for lighting installed at intersections (Harkey et al, 2008). A study in Hunan, China found that improved lighting conditions at intersections was associated with a 37% reduction in fatalities and a 39% reduction in serious injuries associated with nighttime motorcycle crashes (Chang, 2016).

Design Considerations

Light poles need to be positioned away from the roadside edge or curb, to minimize the chances of a rider colliding with one. LED lighting provides better illumination than high-pressure sodium or mercury vapor lighting (Milling et al., 2016).

Cost and Timeframe

Adding lighting to an intersection is a low-cost countermeasure, estimated by a 2009 FHWA report at $5000-$15000 per intersection (FHWA, 2009). The city of Portland, Oregon estimates a total replacement cost of $170 million for its system of 11,000 roadway light fixtures, or an average cost of $15,454 per fixture, including the control systems; the city's lighting system includes a variety of fixture types and ages (Portland Bureau of Transportation, 2017). LED lighting systems require less annual maintenance and less power to operate than older high-pressure sodium lamps, which significantly reduces overall operation and maintenance costs (EERE, 2014).

Maintenance Needs

Street lights can last 20 years of more with proper maintenance. High-pressure sodium lights must be “re-lamped” approximately every 4-5 years; LED lights do not need to re-lamped. Other lighting parts may need to be upgraded periodically, or replaced due to wear or damage.

Limitations and Concerns

Roadway lighting should be evaluated to ensure that the intensity, spectrum, and direction of the light do not create unsafe levels of nighttime glare (EERE, 2017).

Key References

Chang, F., Li, M., Xu, P., Zhou, H., Haque, M. M., & Huang, H. (2016). Injury Severity of Motorcycle Riders Involved in Traffic Crashes in Hunan, China: A Mixed Ordered Logit Approach. *International Journal of Environmental Research and Public Health*, 13(7), 714.

EERE (2017). Get the Facts: LED Street Lighting. Solid State Lighting Program, Office of Energy Efficiency & Renewable Energy (EERE), U.S. Department of Energy, Washington, D.C. Retrieved from https://energy.gov/eere/ssl/articles/get-facts-led-street-lighting.

EERE (2014). Maintenance Practices for LED Streetlights. Webinar sponsored by the Office of Energy Efficiency & Renewable Energy (EERE), U.S. Department of Energy, Washington, D.C. Retrieved from https://energy.gov/eere/ssl/maintenance-practices-led-streetlights.

Federal Highway Administration (2009). *Low-Cost Safety Enhancements for Stop-Controlled and Signalized Intersections (Federal Highway Administration,* Report No. FHWA-SA-09-020). Washington, DC: U.S. Government Printing Office

Gan, A., Shen, J., Rodriguez, A. (2005). *Update of Florida Crash Reduction Factors and Countermeasures to Improve the Development of District Safety improvement Projects (Florida Department of Transportation*). Tallahassee, Florida. Retrieved from http://www.fdot.gov/research/Completed_Proj/Summary_SF/FDOT_BD015_04_rpt.pdf.

Harkey, D. L., Srinivasan, R., Baek, J., Council, F. M., Eccles, K., Lefler, N., Gross, F., Persaud, B., Lyon, C., Hauer, E., & Bonneson, J. (2008). *Accident Modification Factors for Traffic Engineering and ITS Improvements (National Cooperative Highway Research Program.* Report 617). Washington, DC: The National Academies press. Doi.org/10.17226/13899

Milling, D., Affum, J., Chong, L., & Taylor, S. (2016) *Infrastructure Improvements to Reduce Motorcycle Casualties (Austroads,* Publication No. AP-R515-16). Sydney, Australia.

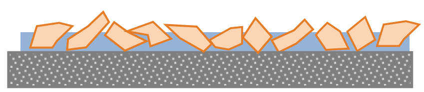
Portland Bureau of Transportation (2017, December 11). Street Light Maintenance. Online document, retrieved from https://www.portlandoregon.gov/transportation/article/192895.

2.1 High Friction Surface Treatment

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	LoC, RoR	RI/RS	C, S	Not Est	Not Est	.15-.80	Effec+	$$-$$$

Description

As roadways age due to motor vehicle traffic their surfaces tend to become smooth and, as a result, can become slippery, particularly in wet weather conditions. The smooth pavement can increase the frequency of loss of traction situations and subsequent crashes. To address this situation high friction survey treatments have been developed. A high friction surface treatment consists of a thin layer of high-quality polish resistant aggregate bonded to a pavement surface with polymer resin. The typical treatment uses calcined bauxite crushed to a fine gravel. The total thickness is less than ¼-inch. An alternative option is to use light-weight aggregate (expanded clay/shale) or another polish resistant aggregate in a standard bituminous seal coat.



An example of aggregate bonded to existing pavement.

A depiction of a high surface friction treatment application.

Applications

High friction surface treatments can be applied to many different types of pavements and are intended to reduce the rate of loss-of-friction related crashes (i.e. run-off-the-road and wet-weather crashes.) High friction surface treatments are commonly applied to rural horizontal curves where drivers tend to take turns too fast and super-elevations are inadequate, on tight radius freeway loop ramps, and at downhill signal approaches.

Vehicle and Rider Safety Effectiveness

Road departure crashes tend to occur at tighter horizontal curves with an increase in crash rates beginning at an approximate radius of 2,000 feet (Pratt et al., 2014). Several studies have examined the effectiveness of HFST at reducing crashes. In a study of curves with radii less than 1,000 feet HFSTs reduced the rate of total crashes by 32% and wet-weather crashes by 75% (Wilson & Mukhopadhyay, 2016) In another study, wet-weather crashes on horizontal curves and ramps decreased by 86% and 85%, respectively (Federal Highway Administration, 2015). Total crashes on horizontal curves and ramps were reduced by 73% and 78%, respectively (Federal Highway Administration, 2015). Also, 24% and 57% reductions for total and wet weather crashes. (Harkey et al., 2008). These results were confirmed in recent work that found a decrease of 20 to 30% for total crashes and 50% for wet weather crashes (Brimley

& Carlson, 2012). However, it is noted that the effectiveness of HFSTs at intersections is inconclusive (Wilson & Mukhopadhyay, 2016).

No literature was found examining the effect of this countermeasure on motorcycle-related crashes.

Design Considerations

The treatment should extend through the exit tangent of the curve so drivers and riders can complete their cornering maneuver before transitioning off the high friction surface treatment.

The treatment should be placed on structurally sound pavements requiring minimal surface repair. The treatment service life is between 5 and 10 years, 7-years on average.

Cost and Timeframe

The installation costs can range from $100,000-$250,000 for a typical curve. Direct material costs range between $20 and $35 per square yard of aggregate (Wilson & Mukhopadhyay, 2016). The application speed can be approximately 1,500 – 2,000 cubic yard per hour using a fully-automated set-up. A typical curve application can be completed in as little as a single day.

Maintenance Needs

Repeated sweeping of loose aggregate may be required shortly after installation.

Limitations and Concerns

High fiction surface treatments are not a preventative maintenance treatment.

Application over open-graded asphalt is not advisable.

Some users (e.g., riders) have concerns about road rash if a crash were to occur but there is no documented evidence that this is an issue.

References

Brimley, B., & Carlson, P. (2012). *Using High Friction Surface Treatments to Improve Safety at Horizontal Curves (Texas Transportation Institue). College Station, Texas*.

Harkey, D. L., Srinivasan, R., Baek, J., Council, F. M., Eccles, K., Lefler, N., Gross, F., Persaud, B., Lyon, C., Hauer, E., & Bonneson, J. (2008). *Accident Modification Factors for Traffic Engineering and ITS Improvements (National Cooperative Highway Research Program.* Report 617). Washington, DC: The National Academies press. Doi.org/10.17226/13899

Federal Highways Administration (2015, May/June). *High-Friction Surface Treatments Yield Positive Results* (Federal Highway Administration), *Innovator, 8*.

Pratt, M. P., Geedipally, S. R., Pike, A. M., Carlson, P. J., Celoza, A. M., & Lord, D. (2014). *Evaluating the Need for Surface Treatments to Reduce Crash Frequency on Horizontal Curves (Texas Transportation Institute/Federal Highway Administration.* Report No. FHWA/TX-14/0-6714-1). College Station, Texas.

Wilson, B. T., & Mukhopadhyay, A. K. (2016). *Alternative Aggregates and Materials for High Friction Surface Treatments* (*Texas Transportation Institute*. Report project BRT74-977-05). College Station, Texas.

2.2 Textured Pavement Markings

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MC	LoC	RI/RS	C, I, S	Not Est	Not Est	Not Est	Not Est	$$

Description

A significant concern of riders is the capacity of pavement markings to become slippery, particularly in wet weather conditions, and cause a crash (Department of Transport and Main Roads, 2016; Harlow, 2005; Richards, 1991). In response to this situation, engineers have developed pavement markings that can incorporate finely-graded aggregate or crushed glass to improve friction properties. The material can be mixed into paint or two-part resin systems or can be embedded into the surface of thermoplastics. Friction improvements may also be achieved with glass beads; however, the performance is generally lower than the recommended friction for motorcycle safety. Marking systems with raised texture patterns do not significantly improve friction but do improve wet-weather visibility and do serve as a lane-departure audible alert.


Example of textured pavement markings: crushed colored glass (Ruby Lake, 2017) and racetrack marking (Advanced Pavement Marking, 2017).

Applications

Textured markings can be used in lieu of any traditional pavement marking at any location, including both curves and straights. They should be used when the markings are within the travel path, where vehicles make directional changes, where vehicles accelerate and/or decelerate. Examples include cross walk lines, stop bars, turning arrows, and lane markers.

Vehicle and Rider Safety Effectiveness

Research conducted by Harlow (2005) and Richards (1991) directly support the contention that pavement markings in the travel-way can be slippery. This situation can lead to reduced levels of safety for riders. In allied work, research within the domain of direct friction measurements (made with a British Pendulum Tester) indicated that baseline friction values for standard paint and thermoplastics were relatively low (Richards, 1991; Richards, 1992) and could decrease with wear. Glass beads increased friction (Richards, 1991) from baseline while the addition of aggregate increased friction further (Richards, 1992; Siyahi, 2016). Research conducted by Harlow (2005) suggested a motorcycle requires friction slightly higher than glass beads; however, no research has been conducted to support this contention.

There is no research on crash reduction effectiveness, likely because for passenger vehicles the percent area with pavement markings is so small that it is not considered a significant safety risk (Richard, 1975). There is no research on their effectiveness for rider safety.

Design Considerations

Aggregate types that have been used in the past include granite, quartz, silica, glass, corundum, and alumina oxide. The aggregate should be crushed to a fine sand.

Based on a laboratory abrasion test, textured pavement markings may have lower life expectancy than traditional markings. Results of a study conducted by Siyahi (2016) indicated decreased durability of 15 to 25 percent for select materials compared to a traditional marking. It is unknown whether this is an actual concern in field performance.

Cost and Timeframe

Additional aggregate will increase the cost of the pavement marking. No information regarding cost could be found. Little to no additional time is required for applying texture.

Maintenance Needs

The pavement markings will require routine reapplication similar, if not slightly more often, than traditional pavement markings.

Limitations and Concerns

None

References

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2.3 Pavement Condition Repair

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	LoC	RI/RS	C, I, S	Not Est	Not Est	.65-.95	Effec+	$$-$$$

Description

It is not unusual over the lifespan of a roadway for sections of pavement to be in need of repair due to a variety of issues (e.g., potholes, cracks). Pavement deterioration initially affects the ride-ability and safety of a pavement. Rough pavement, characterized by a bumpy, undulating ride, generates considerable discomfort and could even unbalance a rider driver. Potholes, concrete punch-outs, and similar severe distress can easily destabilize a motorcyclist and high and low speeds. Flushed and bleeding surfaces and old polished aggregate surfaces are slick and dangerous under braking and evasive maneuvering.

To address these issues it is common to employ a variety of techniques in pavement maintenance to improve ride quality and safety. These have included:

- Pothole patch repair.
- Removal of road debris (e.g., sweeping).
- Diamond grinding on concrete.
- Overlay or mill and overlay of flushed/bleeding surface.
- Overlay or mill and overlay of rutting surface.
- Seal coat over polished surface.
- Warning signs (e.g., Rough Road) of pavement disrepair to warn drivers.

During the mill and overlay procedure, a milling machine is used to remove the upper surface of a pavement ahead of overlaying. A traditional milled surface is rough and uncomfortable for a rider to traverse. An alternative approach is micro milling, which uses a finer toothed mill drum, resulting is a finer texture.

Patch repair

Sweeping

Diamond Grinding

Examples of pavement condition repair techniques (left, City of Norfolk, 2017; center, Selbig & Bannerman, 2007; right, Roads and Bridges, 2017).

Applications

Pavement condition repair techniques can occur on any roadway.

Vehicle and Rider Safety Effectiveness

Fagnant and Kockleman (2015) conducted a survey of motorcycle enthusiasts to identify their impressions for the importance of good pavement condition for rider safety. Respondents ranked “maintaining a good pavement condition” and “clearing roadway debris” each within the top three recommendation to transportation professionals. Research examining the relationship between overall pavement condition and severity of crashes found that a decrease in pavement condition was linked with an increase in crashes (Chan et al., 2009; Elghriany, 2016; Li & Ding, 2013; Zeng et al., 2014).

In an effort to improve pavement conditions researchers have investigated several techniques to improve road pavement quality. For example, diamond grinding has been show to result in a CMF between 0.64 and 0.95 for total crashes and is particularly well-suited at addressing run off the road crashes (Merritt et al., 2015). Wu et al (2015) has shown that improving pavement friction in general will increase wet weather safety. Chip seals have shown to result in a wet-road CMF of 0.78 and 0.95 on multilane and two lane roads, respectively (Merritt, et al., 2015). Similar wet-weather improvements were identified for thin HMA overlays (Merritt et al., 2015). However, chip seals were also associated with a slight increase in dry-road crashes (Merritt et al., 2015).

It is noted that no research exists that examined the effects of pavement condition improvement techniques on motorcycle crashes.

Design Considerations

Relative to pothole repair, corrective action should consider more than just the failed pavement location. Filling in a hole is a temporary fix since the area around the hole is likely to degrade as well. Instead, an area larger than the pothole should be cut away and cleaned, and new filler material put in its place. Hot mix asphalt is ideal; though cold mix can also be used for areas with low traffic severity.

Diamond grinding addresses functional problems of concrete pavement surfaces; however, it does not correct structural deficiencies. Correa and Wong (2001) indicated the desired texture for diamond grinding grooves should be 0.08-0.16 inches wide, a depth of 0.06 to 0.14 inches, and 50-60 grooves per foot.

To correct a severely flushed/bleeding or rutted surface, the surface should first be milled and swept clean prior to an asphalt overlay. If the distress is low severity, the overlay may be placed directly on the surface. The specific design of the asphalt mix should be determined by a pavement engineer or certified technician.

Cost and Timeframe

A “throw-and-roll” technique is a common inexpensive emergency patch method, but the long term effectiveness is limited. At about 2.5 times the cost (considering materials, equipment, labor, and user delays) a semi-permanent patch can be installed. This method has much better long-term durability (Dong et al., 2014).

A diamond ground surface can last 8 to 10 years. In 2001, the cost of grinding was $2 to $7 per square yard (Correa & Wong, 2001).

A typical hot mix overlay costs $2.00-$6.00 / m^2 without milling and $6.00-$12.00/m^2 with milling. (Ploeger et al., 2015).

Seal coat costs \$1.50-\$4.00/yd^2. (Ploeger et al., 2015)

Maintenance Needs

The treatments described in this section are maintenance treatments. Some provide a long-term solution, while others are likely to degrade in a shorter timeframe. Pothole repair and removal of roadway debris should occur at least annually. Diamond grinding and asphalt overlays should last 8 to 10 years. The overlay should have some routine maintenance once or twice before this time.

Limitations and Concerns

The performance of any given treatment is largely dependent on the correct treatment for the problem and proper construction techniques. When considering any of these methods, coordinate closely with the pavement maintenance division within the department of transportation.

References

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2.4 Pavement Shoulder/Edge Drop-Off Treatment

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	LoC	RS/RI	S	Not Est	Not Est	.94	Effec+	$

Description

Pavement shoulder/edge drop-off treatments are used to reduce loss-off-control crashes for vehicles that leave the roadway or change lanes in a work zone where there are two different pavement heights. A vehicle can become unstable when tires leave the roadway and experiences a sudden vertical change. This is particularly true for motorcycles. A particularly negative response by drivers in these situations is a dangerous overcorrection at high speeds.

A pavement edge drop-off treatment is a construction technique or maintenance activity that minimizes the height difference and/or provides a slope from the pavement edge to the unpaved shoulder. A wedge-shaped edge is built into the pavement and is called a Safety Edge. A similar approach is used during staged overlay construction to minimize the drop-off between the overlay and the adjacent existing lane. This technique is called a notched wedge joint. For more severe drop-offs additional warning devices and protective barriers may be warranted.

Examples of pavement edge drop off (left, FHWA, 2017), Safety Edge (center, Carlson Paving, 2017), and notched wedge joint (right, Willow Designs, 2017) treatments.

Applications

The countermeasure should be considered during initial construction of rural roads, in overlay construction resulting in significant drop-off height, and in staged overlay construction with a drop off between the overlay and an adjacent lane.

Vehicle and Rider Safety Effectiveness

The overall safety benefit of the treatment for shoulders is very small (CMF of 0.94 and not statistically significant) for motor vehicles: however, given the very low cost of implementation, the treatment may still be cost-effective (Graham et al., 2011). The treatment is cost-effective for two-lane highways with daily traffic volumes greater than 1,000 (Graham et al., 2011).

No literature was found examining the effect of this countermeasure on motorcycle-related crashes.

Design Considerations

The danger of the drop-off is dependent on the drop-off height, the drop-off shape, the vehicle speed, vehicle type, and the vehicle departure angle (Glennon, 2005). The maximum height of a steep drop-off (greater than 1:1) is recommended between 1.5 to 2.5 inches, with lower drop-offs heights recommended for work zone scenarios (Hallmark et al., 2006). The recommended slope on the pavement edge is 30 to 35° (3:1 slope) (Hallmark et al., 2006). The recommended notched wedge joint design has up to 3/4–inch vertical notches on either side, and the sloped area is typically 12 inches wide. These drop-off recommendations, however, are based on a four-wheel vehicle and do not consider motorcycles (Mounce & Hofener, 2002). Anecdotally, even 1-inch drop-offs can cause challenges for motorcycles (FHWA, 2011).

Notched joint construction may depend on the construction specifications dictated in a region.

In work zones, where drop-offs are very common, advanced warning signs and clear delineation of the lane edge should be implemented (Mounce & Hofener, 2002).

Cost and Timeframe

Constructing safety-edge treatments and notched joints adds minimal cost. A simple, inexpensive metal jig is attached to existing paving equipment. For shoulders, a small amount of extra asphalt is used in the edge, costing between $500 and $2,000/mile (Graham et al., 2011). Using the jig does not add time to the construction process.

Maintenance Needs

None.

Limitations and Concerns

There are no concerns with constructing a safety-edge.

References

AASHTO (2011). Roadside Design Guide, 4th Edition. Washington, DC.

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Mounce, J. M., & Hofener, M. (2002). *Pavement Surface Elevation Changes in Highway Construction Work Zones as Contributing Factor to Motorcycle Crashes* (*Texas Transportation Institute*). College Station, Texas.

2.5 Steel Plate Danger Mitigation

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MC	LoC	RI/RS	C, I, S	Not Est	Not Est	NA	NA	$

Description

During construction or maintenance steel plates are often used to cover temporary holes and utility trenches. The steel plates are generally very thick so they do not bend due to the weight of a motor vehicle and are often quite large so that can completely cover the area of concern. Steel plates represent a significant concern for riders because the thickness can jar a motorcycle when driving onto or off the plate resulting in motorcycle destabilization, the plates are often difficult to see, and they can become very slippery when wet or covered in soil or debris (Federal Highway Administration, 2011).

In light of the fact that steel plates can represent a significant safety concern, several techniques have been implemented to improve the level of safety associated with their use. These include:

- Placing warning signs ahead of steel plates (Cottrell, 2006).
- Visible markings on the corners of plates (Cottrell, 2006).
- Plate Locks® which is a system for securing steel plates and improving the transition onto and off of the steel plates.
- SlipNOT® textured plates or non-proprietary skid surface (Siyahi, Kavussi & Boroujerdian, 2016).
- Plasticade® road plate which is a modular, plastic covered plate with a self-locking mechanism and rubber-edge ramps.
- Asphalt tapering to ease the transition onto and off steel plates.

Plate Locks®

Asphalt Taper

Plasticade© plate

Examples of steel plate danger mitigation techniques (left, Plate Locks, 2017; center, National Trench Safety, 2017; right, Plasticade, 2017).

Applications

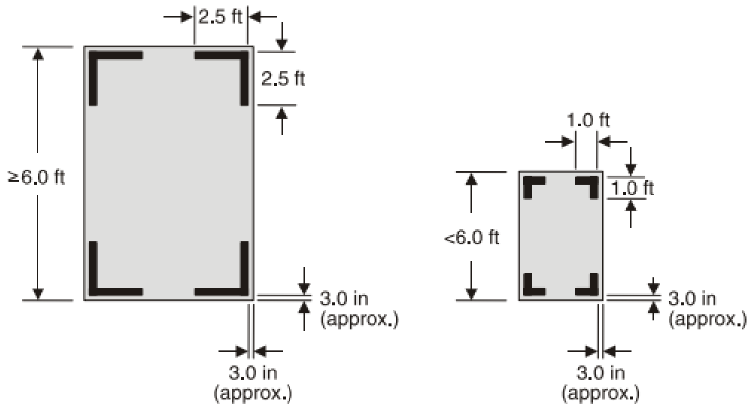
Steel plates are used in work zone environments to cover temporary utility trenches.

Vehicle and Rider Safety Effectiveness

No research exists that examined the effectiveness of steel plate danger mitigation techniques to improve rider safety.

Design Considerations

The recommended marking of steel plates to increase visibility is shown below (Cottrell, 2006).



One jurisdiction specifies that asphalt wedges should be at least 1-foot wide (City of Charleston Department of Public Service, 2013).

Other countermeasures are proprietary products that can be purchased.

Cost and Timeframe

To mark an 8-ft x 12-ft plate with 4-inch wide reflective tape on the corners costs approximately $27 (Cottrell, 2006).

Maintenance Needs

Since plates tend to move under traffic, they should be securely anchored and routinely inspected while work is ongoing.

Limitations and Concerns

Increasing steel plate visibility through the application of marking techniques does not increase surface friction.

References

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Siyahi, A., Kavussi, A., & Boroujerdian, A. M. (2016). Enhancing Skid Resistance of Two-Compontent Road Marking Paint using Mineral and Recycled Materials. *International Journal of Transportation Engineering, 3*(3), 195-206.

2.6 Pavement Change Warning Signs

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MC	SVRD LoC	RI	S	Not Est	Not Est	NA	NA	$

Description

Changes in pavement surfaces can make riding a motorcycle more difficult. For example, changing from tarmac to gravel requires significantly different riding techniques to avoid a crash and milled pavement can create motorcycle instability. Warning signs can notify a rider of a change in roadway surface conditions so they can preemptively adopt appropriate riding techniques. Many of these warning signs are located in advance of work zones.

Examples of pavement change warning signs. Note, the metal bridge deck warning sign is for permanent pavement situations versus temporary pavement changes (top left to bottom right Dairyland, 2017; DWKLAW, 2017; DWKLAW, 2017; Roadway Safety Consortium, 2017; Alberta Transportation, 2017).

Alternative designs of pavement change warning signs exist to address the various types of temporary pavement surfaces. They can include the following signs:

- Fresh Oil
- Grooved Pavement
- Loose Gravel
- Rough Road

Applications

Pavement change warning signs are typically used in advance of work zones in which temporary pavement conditions, such as milling or gravel overlays, created by roadway maintenance or other activities may create additional risk for riders. However, the warning signs can be used in advance of permanent conditions such as a metal bridge deck.

Vehicle and Rider Safety Effectiveness

Cottrell (2006) examined the state of practice of warning motorcyclists about steel plates in roadways and developed signing recommendations. Cottrell found that none of the thirteen states that use steel plates position them to improve visibility of the plate and only four states install signs to warn of their presence. Typically, the signs indicate "STEEL PLATE(S)" or "BUMP". The city of Richmond, Virginia employs a drum with a "STEEL PLATE" sign either attached to a post or directly on a drum to notify riders of the location of a steel plate in snowy conditions. Cottrell also documented the use of several retroreflective tape configurations on steel plates as a cost-effective method to improve visibility of the plates. Cottrell (2016) surveyed seven participants viewing side-by-side steel plates in nighttime conditions from 80 feet under low-beam light. The study concluded that an advanced warning "STEEP PLATE AHEAD" sign in combination with "corners only" pavement markings was the preferred method by the stakeholder group to improve the visibility of steel plates (Cottrell, 2006).

No studies examined how pavement condition warning signs have impacted rider behavior or subsequent safety.

Design Considerations

The State of Kentucky Department of Highways has a standard design drawing for pavement conditions warning signs (Kentucky Transit Cabinet, 2015) and has provided recommendations regarding the size and distance of pavement condition warning signs before roadway condition changes for both freeways and rural/urban arterials. The recommendations suggest that signs on freeways, rural or urban roads with speed limits greater than or equal to 45 mph, and urban roads with speed limits less than or equal to 40 mph be placed 750, 500, and 250 feet in advance of the pavement condition, respectively. Supplemental plaques can be used to draw attention that the information presented on these signs are meant for motorcyclists.

Cost and Timeframe

Estimated cost of a pavement condition warning sign and mount is approximately $200 to $300 (Cottrell, 2006). The portable signs and mounts would take negligible time to deploy.

Maintenance Needs

Fading of sign faces due to sun exposure over long period of time, which can make the sign difficult to read, will require sign replacement. Periodic replacement of signs may be required if drivers crash into the signs.

Limitations and Concerns

A central limitation of the pavement condition warning signs is the fact that they do not improve the ride conditions but simply provide some advanced warning of condition changes.

Key References

Cottrell, B. H. Jr. (2006). *Visibility of Steel Plates Used in Connection with Highway Repairs (Virginia Transportation Research Council.* Report No. VTRC 07-R16). Charlottesville, Virginia.

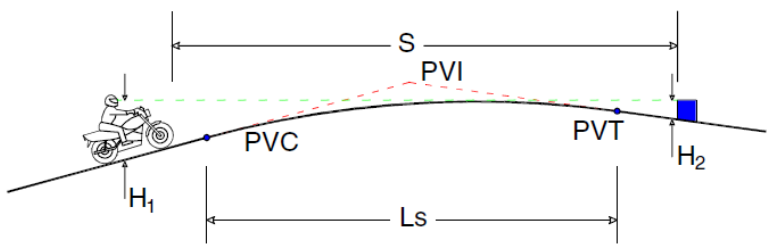
Kentucky Transport Cabinet. (2015). *Pavement Condition Warning Signs*. Standard Drawing No TTD-125-02. Retrieved from http://transportation.ky.gov/Highway-Design/Standard%20Drawings%20%20Sepias%20PDFs%202016/ttd125.pdf

3.1 Design for Motorcyclist Sight Distance

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MC	RE	RI	C, I, S	Not Est	Not Est	NA	NA	$$$

Description
A risk factors for riders is not being able to see an upcoming risk such as an intersecting roadway that may contain vehicles or objects in a road. Sight distance refers to the distance that a driver/rider can see in front of their own vehicle. Sight distance is directly related to eye height for horizontal curves and road radius for horizontal curves with "flatter" and "straighter" roads offering better sight distances. Adequate sight distances are needed to identify upcoming risk factors such as intersections, driveways, or other roadside features.

The following figure identifies key parameters of sight distance for a vertical curve. H_1 represents the height of the rider's viewpoint while H_2 represents the height above the ground that a rider can see. S represents the sight distance and Ls represents the length of the vertical curve. PVC, PVT, and PVI represent the vertical curve beginning, end, and tangential intersection, respectively. As an example, vertical sight distance can be determined by distance between the two objects when a driver able to see H_2 feet above the roadway. A description of vertical curves can be found in Davoodi et al. (2011) while a description of horizontal curves can be found in Himes and Donnell (2014).



Motorcyclist Sight Distance on a Vertical Crest Curve (Davoodi et al., 2011).

Applications
This treatment is a preventative measure intended to aid driver's and rider's ability to see roadway risk factors. When designing roadways, engineers should seek to provide sufficient sight distance for both vertical and horizontal curves. An example warning sign contains the message "HIDDEN DRIVE AHEAD."

Vehicle and Rider Safety Effectiveness
Harwood and Bauer (2015) studied crash data for 452 different crest vertical curves which were approximately equally distributed between stopping sight distance above and below design criteria. The proximity to other geometric factors like horizontal curves, intersections, or driveways was also considered. Analysis without considering geometric factors found statistical significance between the two stopping sight distance categories, but there was not statistical significance when the geometric features were included. The presence of these hidden geometric features was found to be statistically significant. Harwood and Bauer concluded that

priority be given to improving sight distance when these hidden features are present. Improving sight distance when these features are not present may have little effect on crash frequency or severity (Harwood & Bauer; 2015).

Davoodi et al. (2011) examined the eye height for 525 motorcyclists and found that all had a greater eye height than the minimum for passenger cars. However, passenger-car vertical curve sight distance is designed or an object height, H_2 in the figure, of two feet. A motorcyclist may need to see objects of a lower height, such as an uneven pavement surface. For example, a pothole could be avoided by a motorcyclist if they have adequate sight distance to avoid such an obstacle (Davoodi et al., 2011).

While Davoodi et al. (2011) has initiated some investigations into minimum sight distance requirements for riders there is still strong need to better understand fundamental elements of sight distance for riders, such as object height requirements.

Design Considerations

Creating adequate vertical and horizontal sight distances can require significant design efforts due to the large amount of earthwork required and the limited roadway path possibilities afforded by some areas. Extensive site redesign can increase construction costs significantly.

The use of advanced warning signs is a relative inexpensive solution but one that has not yet been tested with riders.

Cost and Timeframe

Approximate construction costs vary by site; however, significant site redesign (e.g., level out vertical curves, reduce roadway radius) will result in higher construction costs. Significant site redesign can also extend construction time.

Sign installation is relatively inexpensive.

Maintenance Needs

Not applicable.

Limitations and Concerns

Vertical and horizontal curve considerations must be addressed within the design phase. In addition, increased construction costs could make the addition of this countermeasure unreasonable.

Key References

Davoodi, S.R., Hamid, H., Arintono, S., & Muniandy, R. (2011). Motorcycle Characteristics for Sight Distance Investigation on Exclusive Motorcycle Lanes. *Journal of Transportation Engineering*, 137(7), 492-495. http://doi.org/10.1061/(ASCE)TE.1943-5436.0000226

Harwood. D. W. & Bauer, K. M. (2015). Effect of Stopping Sight Distance on Crashes at Crest Vertical Curves on Rural Two-Lane Highways. *Transportation Research Record, 2486,* 45-53. http://DOI:10.3141/2486-06

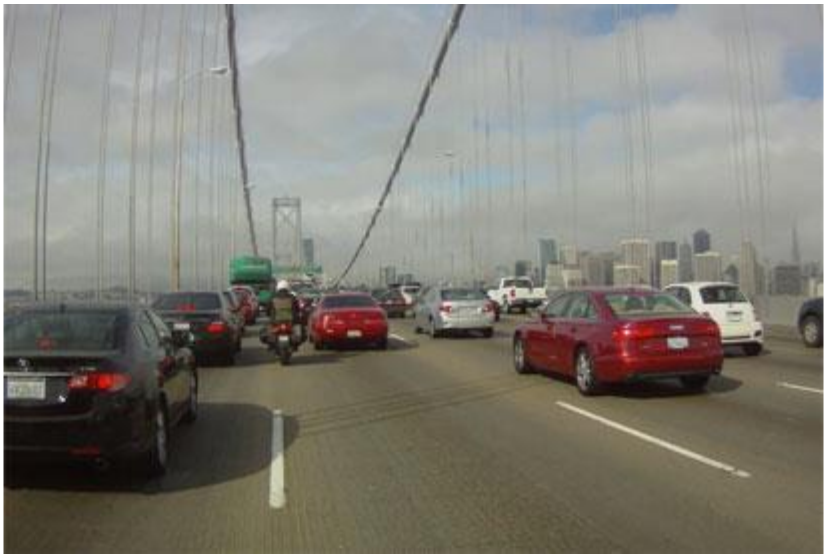
Himes, S. C. & Donnell, E. T. (2014). Reliability Approach to Horizontal Curve Design. *Transportation Research Record, 2436,* 51-59. http://DOI:10.3141/2436-06

3.2 Lane Splitting

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MC	RE	RI	I, S	Not Est	Effec ~	NA	NA	$

Description

A significant risk for motorcycle riders when waiting in traffic is being involved in a rear end crash when a following motorist does not see a leading motorcycle or fails to stop resulting the vehicle crashing into the rear of the motorcycle. A solution to this crash scenario involves lane splitting which allows a motorcyclist to travel in limited space next to vehicles. Lane splitting is currently legal in some states.



An example of motorcycle lane splitting (Yang, 2015).

Applications

Lane splitting typically includes several restrictions that limit its use to low speed situations that may occur on urban highway and freeway roads. For example, lane splitting is often only allowed when prevailing traffic is moving slower than a criteria speed (e.g., 30 mph) and when there are two or more lanes of traffic. This countermeasure should be employed when there is a prevalence of rear end crashes.

Vehicle and Rider Safety Effectiveness

Limited research on lane splitting exists. A study conducted by Rice, Troszak, and Erhardt (2015) examined the risks involved with lane splitting in California. Their work showed 17% of 5,969 motorcycle crashes involved a lane splitting motorcycle at the time of collision, found that lane splitting motorcyclists used better helmets and traveled at lower speeds, and were injured less frequently. However, lane-splitting motorists were equally likely to suffer neck injury. The study found that lane-splitting was relatively safe when traffic moved at 50 mph or less and the rider did not exceed the speed of other vehicles by more than 15 mph, as these two thresholds led to increased injury likelihood if exceeded. Rice et al. did note that a significant number of motorcyclists did lane split in fast-moving traffic or at excessive speed differentials.

A synthesis of literature on motorcycle lane sharing, conducted by Sperley and Pietz (2010) at the Oregon Department of Transportation, examined national and international reports on motorcycle crashes and lane splitting. They found that crashes involving lane splitting were generally caused by a driver of a car, in traffic that was stopped or slow-moving, did not expect to be passed by a motorcyclist traveling between the lanes. The reports claimed that lane splitting was a factor in less than 1 to 5% of motorcycle crashes.

Design Considerations

Lane splitting does not alter roadway design; however, wider lanes could facilitate road splitting.

Cost and Timeframe

Lane splitting does not add cost to design and/or build construction phases or to roadway maintenance costs.

Maintenance Needs

Not Applicable.

Limitations and Concerns

Lane splitting would allow motorcyclists to spend increased time in the blind spots of the other vehicles which could result an increased number of sideswipe crashes due to cars changing lanes.

Key References

Rice, T., Troszak, L. & Erhardt, T. (2015). *Motorcycle Lane-splitting and Safety in California*. (*Safe Transportation Research & Education Center).* Berkeley, California.

Yang, S. (2015, May 29). *Is Motorcycle Lane-Splitting Safe? New Report Saying It Can Be. Berkley News*. Retrieved from http://news.berkeley.edu/2015/05/29/motorcycle-lanesplitting-report/

Sperley, M. & Pietz, A. J. (2010). *Motorcycle Lane-Sharing Literature Review* (*Oregon Department of Transportation Research Section*. Report No. OR-RD-10-20). Salem, Oregon.

4.1 Roadway Vehicle Parking

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MC	SDSW	RI	C, S	Not Est	Not Est	NA	NA	NA

Description

Vehicles parked on the side of a street can be a significant safety risk for riders. Vehicle opening a car door can present a sudden obstacle for riders, vehicles attempting exiting a parking space may not see a rider and fail to yield as they proceed. The roadway vehicle parking countermeasure involves removing or limiting on-street parking to remove the potential conflict between parked vehicles and motorcycles. Roadway vehicle parking can be considered an infrastructure-based countermeasure due to the need to alter the infrastructure, through signing or roadway design, to remove the conflict.

An example of on-street parking in an urban area (City-Data.com, 2017).

Applications

The application of the roadway vehicle parking countermeasure can involve a variety of approaches including restricting parking on the side of a road by providing appropriate signs (e.g., no parking signs) or designing a road for single vehicle use.

Vehicle and Rider Safety Effectiveness

No literature was found examining the effect of this countermeasure on motorcycle-related crashes; however, the removal of a threat should significantly improve rider safety.

The Highway Safety Manual notes that removal of on-street parking can be used to reduce several types of sideswipe crashes and pedestrian crashes (AASHTO, 2010).

Design Considerations

Changing roadside parking through signs or roadway design can require alternations to pavement markings, geometric designs, and signs.

Crash migration is a possible result of prohibiting on-street parking (AASHTO, 2010).

Cost and Timeframe

Cost varies based on how the facility will be retrofitted for different traffic patterns.

Maintenance Needs

Not Applicable.

Limitations and Concerns

Motorcycle-vehicle crashes due to roadside parking will not result in significant fatality rates and therefore may not receive high prioritization relative to rider safety.

Local businesses would likely oppose the removal of parking near their establishments.

Key References

AASHTO (2010). *Highway Safety Manual 1st Edition*. Washington, DC.

5.1 Guardrail Continuous Protection System

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MC	SVRD	RI/RS	C	Not Est	Not Est	NA	NA	$

Description

The purpose of the Guardrail Continuous Protection System (GCPS) is to prevent a motorcycle rider from sliding under the guardrail and contacting the guardrail barrier posts, a situation which can cause significant injury to riders. The GCPS is a roadside infrastructure device that typically consists of a flat metal beam affixed under a guardrail system. Often times, an existing w-beam guardrail system will be retrofitted with the GCPS rail.

The GCPS has several variations including:

- GCPS made of plastic or other types of flexible material in place of the metal rail. This has the advantage absorbing kinetic energy during impact due to the material's flexibility Dobrovolny & Bligh, 2017).
- The GCPS can be constructed of different surface shapes including flat or w-shaped.

Examples of guardrail continuous protection systems (Department of Planning, Transport, and Infrastructure, 2017).

Applications

GCPSs are often used on roadway locations with a blind-spot corner or on roadways with successive curves. The speed for these roadway locations is typically around 60 mph (100 km/h).

Vehicle and Rider Safety Effectiveness

A study conducted by the University of New South Wales found that in 166 non-fatal collisions across New Zealand, 83.1% were located on a curve, and 73.5% were in 60 mph (100 km/h) speed zones (Grezbieta & Bambach, 2014). 78% of the collisions were with steel w-beam guardrail barriers. Although these data relate primarily to motor vehicle crashes, they do provide insight into the location of crashes, the speed of crashes, and the primary object struck by vehicles. Research examining the effectiveness of guardrail systems in general have shown a significant reduction in the probability of fatal injury. A study was conducted with a roadway departure crash severity model which demonstrated a 45% to 50% reduction in fatal injury when impacting guardrail systems versus not impacting a guardrail system (Li, Park, & Lambert, 2017).

There have been no studies to date that have measured the effectiveness of the GCPS or its variants relative to crash injury or severity rates for either motor vehicle drivers or riders. In addition, it is unknown if the GCPS reduces crash frequency when implemented on specific roadway sections.

Design Considerations

GCPSs are easy to install at existing guardrail locations and they easy to append to new guardrail systems that will be installed. Ease of construction will be similar for both options.

Harsh winter weather is not expected to reduce the lifespan of plastic GCPSs due to their durability.

Cost and Timeframe

The approximate cost for a GCPS to be constructed is approximately $20,000 per 200 feet of guardrail; however, the cost can be dependent on the length of the installed system. Construction material (e.g., metal, plastic) can influence GCPS cost.

The time to construct the GCPS will range from 1 to 2 weeks.

Maintenance Needs

The GCPS would only need maintenance if a crash occurred with the system. Depending on the location and severity of the crash this can require an entire system repair or just a repair of a small section.

Typically, a lane closure is required when repairing the guardrail system.

Limitations and Concerns

The effectiveness of this type of countermeasure is not documented.

These types of guardrail systems could be costly when installed on long lengths of roadway sections.

References

Dobrovolny, C., & Bligh, R. (2017). *Literature Review of Motorcycle Testing Standards and Motorcycle-Friendly Roadside Hardware (Texas A&M Transportation Institute*. Internal report). College Station, Texas.

Grezbieta, R., & Bambach, M. (2014). *Motorcycle Crashes into Roadside Barriers Stage 4: Protecting motorcyclists in collisions with roadside barriers* (*University of New South Wales*. TARS Research Report). Sydney, New South Wales.

Li, N., Park, B.B., & Lambert, J.H. (2017). Effect of Guardrail on Reducing Fatal and Severe Injuries on Freeways: Real-World Crash Data Analysis and Performance Assessment. *Journal of Transportation Safety and Security,* 1-16.

5.2 Retrofit Concrete Barrier

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MC	SVRD	RS	C, S	Not Est	Not Est	NA	NA	$$

Description

While a concrete barrier can prevent motor vehicles from traveling off a roadway, a significant concern for riders is that they will travel over the top of a barrier in a crash and be presented with secondary risks due to oncoming traffic or falls (e.g., overpasses). The Retrofit Concrete Barrier (RCB) is a solid concrete barrier with an added protection system, such as a chain-link fence or acrylic sheeting, mounted on top of the barrier. The RCB can help prevent the rider from falling to the other side of the barrier when impacting the concrete barrier in an upright motorcycle configuration.

Example of different types of retrofit concrete barriers (Transpo Industries, 2017).

Applications

RCB systems can be utilized on roadways with horizontal curves or in any location where there is concern for the rider to fall over the concrete barrier upon impact. An example of this would be an overpass ramp where a rider could fall to their death upon impact with a roadside concrete barrier.

Vehicle and Rider Safety Effectiveness

Research examining the effectiveness of concrete barrier systems in general have shown a significant reduction in the probability of fatal injury for motorists. A study conducted by Zou (2014) indicated that that risk of injury for vehicles departing a roadway was reduced by 39% when a concrete barrier was installed (Zou, 2014). While motorcycles accounted for only 3% of registered vehicles in the U.S. in 2005, approximately 22% of all fatalities associated with concrete barrier collisions were motorcycles (Gabler, 2007). The percentage of rider fatalities associated with concrete barriers is not large when compared to vehicles but this scenario is a growing concern (Gabler, 2007).

There have been no studies to date that have measured the effectiveness of the RCB or its variants relative to crash injury or severity rates for either motor vehicle drivers or riders.

Design Considerations

In addition to designing the RCB to contain and redirect the rider, structural loading on the RCB due to wind loads should also be taken into consideration. This is dependent on the location that the RCB is installed and the type of device that is placed on the concrete barrier.

If the RCB can also act as a pedestrian handrail, additional structural loading design is required according to ASCE Chapter 7.

Cost and Timeframe

The approximate cost for a RCB is $942 per every 4-foot section. The time to install would be about 1 week.

Maintenance Needs

A RCB would not require any maintenance but would need to be repaired anytime the system was impacted by a vehicle. Depending on the severity of the crash, only a few sections of the barrier would need to be repaired and not the entire system.

Limitations and Concerns

The effectiveness of this type of countermeasure is not well documented.

These types of guardrail systems can be costly when installed on long lengths of roadway.

References

Gabler, H.C. (2007). The Risk of Fatality in Motorcycle Crashes with Roadside Barriers. In *Proceedings of the 20th international technical conference on enhanced safety of vehicles, Lyons, France*. Paper 07-0474.

Zou Y., Tarko A.P., Chen E., & Romero M.A. (2014). Effectiveness of Cable Barriers, Guardrails, and Concrete Barrier Walls in Reducing the Risk of Injury. *Accident Analysis and Prevention,* 72, 55–65.

5.3 Punctual Energy Absorber

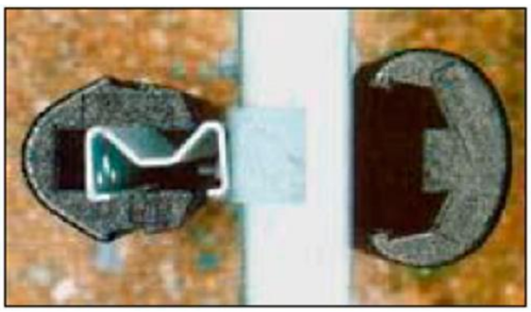
Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MC	SVRD	RS	C	Not Est	Not Est	NA	NA	$

Description

When traveling through a curve a rider can sometimes lose control of the motorcycle and slide into guardrail systems that are placed along the curve. It has been observed that some riders will impact sharp guardrail system posts resulting in serious or fatal injuries (Grezbieta & Bambach, 2014). The Punctual Energy Absorber (PEA), also called crash barrier protectors, are foam or plastic impact attenuators wrapped around barrier posts. PEAs have the dual purpose of protecting the impacting rider from the sharp edges of a barrier post and of absorbing a motorcyclist's kinetic energy upon impact (Dobrovolny & Bligh, 2017). The use of these devices is reported in various European Countries, like Germany, Austria, and Luxembourg (Federation of European Motorcyclists, 2000).

A few variations have been developed that include:

- PEA made with a metallic pipe surrounding the post and filled with sand.
- PEA made of used rubber tires surrounding the post.



Example of punctual energy absorber for a steel post (Dobrovolny & Bligh, 2017).

Applications

PEAs are often used on roadway locations with a blind-spot corner or on roadways with successive curves. The speed for these roadway locations is typically around 60 mi/h (100 km/h).

Vehicle and Rider Safety Effectiveness

A study conducted by the University of New South Wales found that in 166 non-fatal collisions across New Zealand, 83.1% were located on a curve, and 73.5% were in 60 mph (100 km/h) speed zones (Grezbieta & Bambach, 2014). 78% of the collisions were with steel w-beam guardrail barriers. Although these data relate primarily to motor vehicle crashes, they do provide insight into the location of crashes, the speed of crashes, and the primary object struck by vehicles. Research examining the effectiveness of guardrail systems in general have shown a significant reduction in the probability of fatal injury. A study was conducted with a roadway departure crash severity model which demonstrated a 45% to 50% reduction in fatal injury when impacting guardrail systems versus not impacting a guardrail system (Li, Park, & Lambert, 2017).

There have been no studies to date that have measured the effectiveness of PEAs or variants on crash injury or severity rates for either motor vehicle drivers or riders. In addition, it is unknown if the PEA reduces crash frequency when implemented on specific roadway sections.

Design Considerations

The different PEA variations are used for different types of steel posts. Special attention is required to ensure the proper type of PEA is used with the correct steel post type.

Cost and Timeframe

No literature on cost of PEAs, but it is expected that they will be relatively inexpensive.

Maintenance Needs

The maintenance for a PEA is quick and cost-effective. Depending on the location of the guardrail system in relation to the roadway, a traffic lane would not need to be closed off to repair a PEA. In addition, these systems are extremely durable and can last up to 4 years before needing to be replaced.

Limitations and Concerns

The effectiveness of this type of countermeasure is not well documented.

References

Dobrovolny, C., & Bligh, R. (2017). *Literature Review of Motorcycle Testing Standards and Motorcycle-Friendly Roadside Hardware (Texas A&M Transportation Institute*. Internal report). College Station, Texas.

Federation of European Motorcyclists (2010). *Final report of the Motorcyclists & Crash Barriers Project. Federation of European Motorcyclist's Associations*. Brussels Belgium.

Grezbieta, R., & Bambach, M. (2014). *Motorcycle Crashes into Roadside Barriers Stage 4: Protecting motorcyclists in collisions with roadside barriers* (*University of New South Wales*. TARS Research Report). Sydney, New South Wales.

Li, N., Park, B.B., & Lambert, J.H. (2017). Effect of Guardrail on Reducing Fatal and Severe Injuries on Freeways: Real-World Crash Data Analysis and Performance Assessment. *Journal of Transportation Safety and Security,* 1-16.

5.4 Ensure Proper Cross Slope

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	SVRD	RI	C	Not Est	Not Est	.85-.98	Effec +	$$

Description

Superelevation (i.e., cross slope) provides cross-slopes on horizontal curves to provide a more comfortable experience for motorists. For a motorcyclist, superelevation can make a curve easier to maneuver, thus potentially helping to improve safety. If needed, superelevation can be adjusted through wedging which is a process that adds material onto the road surface in a wedge shape to create a desired superelevation. Desired superelevation varies based on design speed and curve radii. Typical values range between 0 percent and 12 percent.

Example of superelevation on a multilane roadway (Stein & Neuman, 2007).

Applications

Superelevation is intended to alter cross-slope on horizontal curves.

Vehicle and Rider Safety Effectiveness

Research indicated that the estimated number of crashes increased for a rural two-lane highway demonstrating increased superelevation deficiency or when there was insufficient superelevation compared to the recommended amount of superelevation (Harwood et al., 2000). Research has indicated that for superelevation deficiencies of 0.02, 0.03, 0.04, and 0.05 percent resulted in CMF Scores of 1.06, 1.09, 1.12, and 1.15, respectively (Harwood et al., 2000). These values suggest, for example, that a superelevation deficiency of 0.02 leads to an estimated six percent increase in the number of crashes on a rural two-lane roadway.

It is important to note that these data relate only to the number of overall crashes and are not representative of motorcycle specific crashes. There have been no studies to date that have measured the effects of superelevation on motorcycle-related crash rates.

Design Considerations

Special attention is required to maintain proper drainage when cross-slopes are minimal.

Superelevation is largely dependent on the design speed and curve radius.

Cost and Timeframe

Approximate construction costs vary by site; however, significant site redesign (e.g., level out vertical curves, reduce roadway radius) will result in higher construction costs.

Significant site redesign can also extend construction time.

Maintenance Needs

Not Applicable.

Limitations and Concerns

There are concerns that increases in driver comfort associated with increasing superelevation may result in increased curve speeds (Federal Highways Administration, 2017). This counterproductive response by drivers may reduce or negate the level of anticipated safety benefits.

Cross-slope considerations must be addressed within the design phase.

Key References

Federal Highway Administration. (2017). *Low-Cost Treatments for Horizontal Curve Safety 2016* (FHWA. Report No. FHWA-SA-15-084). Washington, DC: U.S. Government Printing Office.

Harwood, D. W., Council, F.M., Hauer, E., Hughes, W. E., & Vogt, A. (2000). *Prediction of the Expected Safety Performance of Rural Two-Lane Highways* (*Midwest Research Institute*. Publication No. FHWA-RD-99-207). Washington, DC.

5.5 Curve Speed Warning System

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	SVRD	RI	C	Not Est	Not Est	.93-.95	Effec +	$

Description

Single vehicle roadway departures, which represent a significant crash type for riders, have excessive speed as a crash contributing factor. A Curve Speed Warning (CSW) application uses connected vehicle (CV) information from the infrastructure to issue an in-vehicle (or heads-up display for riders) warning about excessive speed for an upstream curve. The Connected Vehicle Reference Implementation Architecture (USDOT, 2016) presents one example of a CSW system in which a vehicle that is approaching a curve too fast receives a warning to slow down. Additional warnings could also be issued when the speed through the curve exceeds the recommended speed (USDOT, 2016). Similar to RLVW system, the CSW could be based on the transmission of data between the infrastructure and vehicle/motorcycle via dedicated short-range communications (DSRC) protocols.

A variation of this system would employ sensors in advance of curves to detect the approaching vehicle speed and then display a warning on an infrastructure-based warning sign.

Curve speed warning application (Electrobit, 2017).

Applications

This system can be applied to locations before and within curves that exhibit a high frequency of crashes due to excessive speed.

Vehicle and Rider Safety Effectiveness

A national field evaluation of dynamic curve speed warning signs on rural two-lane roadways found 5 to 7 percent reductions in vehicle crashes following installation of the signs (Hallmark et al, 2015).

No literature was found examining the effect of this countermeasure on motorcycle-related crashes.

Design Considerations

Connected vehicle equipment effectiveness varies based on the number of vehicles running the application.

Connected vehicle equipment installed at a location can be used to support applications beyond curve speed warnings, potentially creating benefit of the deployment beyond the discussed application.

Cost and Timeframe

Unit costs for DSRC infrastructure equipment and installation is on average about $18,000 in 2014 (Wright, 2014).

Consumers will need DSRC equipment on their vehicles to support the application. Although an agency would not need to pay to retrofit the vehicles, consumers would need to pay about $4000 to support DSRC (Wright, 2014).

An infrastructure signing solution may cost between $50,000 and $200,000 depending on the complexity of the system.

Maintenance Needs

DSRC equipment will need to be replaced as the technology improves and as the equipment wears out from the elements.

Limitations and Concerns

The effectiveness of the deployment depends on the market penetration of the connected vehicle systems.

Other communication mediums, like cellular communication, are competing for vehicle applications like CSW.

Key References

Hallmark, S.L., Qiu, Y., Hawkins, N., & Smadi, O. (2015). Crash modification factors for dynamic speed feedback signs. *Journal of Transportation Technologies*, Vol 5, pp.9-23.

USDOT (2016, December 8). *Connected Vehicle Reference Implementation Architecture. Curve Speed Warning*. Retrieved from http://local.iteris.com/cvria/html/applications/app13.html#tab-3

Wright, J., Garrett, K. J., Hill, C. J., Krueger, G. D., Evans, J. H., Andrews, S., Wilson, C. K., Rajbhandari, R., & Burkhard B. (2014). *National Connected Vehicle Field Infrastructure Footprint Analysis* (*AASHTO*. Report No. FHWA-JPO-14-125). Washington, DC: U.S. Government Printing Office.

5.6 Advanced Curve Warning Signs

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	SVRD	RI	C	Not Est	Not Est	.45-.92	Effec +	$

Description

Advanced curve warning signs advise motorists about a curve in a roadway that might not be readily visible or understood. Advanced curve warning signs are standardized in the Manual of Uniform Traffic Control Devices (MUTCD), which contains guidelines regarding the types of signs to place along specific roadway locations (Federal Highway Administration, 2009). Advanced curve warning signs can also be used to advise motorists about permanent or temporary changes in alignment in a work zone. The following figure presents examples advanced curve warning signs found in the MUTCD (Federal Highway Administration, 2009).

Examples of advanced curve warning signs (FHWA, 2009).

A variation, dynamic curve warning sign, can include a sensor to detect the presence of or the approaching speed of a vehicle and trigger a sign-based light, particularly if the speed is excessive.

Applications

These signs aid motorists in warning them that they are approaching a horizontal curve. The warning signs are intended to enable drivers to recognize that they are approaching or are on a horizontal curve and maneuver their vehicle accordingly and to warn about changes in horizontal alignment for a work zone.

Vehicle and Rider Safety Effectiveness

Hammer (1968) examined the effect of warning signs in advance of several curves on crash rates and found that crashes were reduced by 18 percent after installation and found the addition of an advisory speed plaque reduced crashes by 22 percent. Various studies cited in the FHWA Desktop Reference Guide estimate crash reductions ranging from 8 to 55 percent for advance curve warning signs (Bahar et al, 2008).

Brimley et. al., examined crashes between 2009 and 2011 on 541 sites across four states. Their findings indicated the effectiveness of advance warning signs depended on curve geometry. Only isolated curves with a radius of less than 400 feet had a significant reduction in crashes at the 95% confidence level. Brimley et al. (2009) found that curve warning signs (MUTCD designation W1-2 and W1-4) were generally more effective when the degree of curve was relatively low while curve warning signs W1-1 and W1-3 were more effective when the degree of curvature was 10 degrees or more (i.e., with a radius less than approximately 600 feet).

The Florida Department of Transportation designed and implemented a dynamic curve warning sign specifically designed to address riders who use the dynamic speed information to see if they can post a high speed on the sign. Instead of displaying the speed of an approaching vehicle the sign displays the advisory speed for the curve in a digital format and then, if radar detects a vehicle approaching at a higher speed, the sign flashes and displays "slow down." If a vehicle is approaching at more than 5 mph over the advisory speed, the sign flashes faster. A report on the sign's effectiveness is expected to be released in 2018.

There have been no studies to date that have measured the effects of curve warning signs on motorcycle-related crash rates.

Design Considerations

The Horizontal Curve Signing Handbook notes that motorists do not necessarily slow in response to a curve warning sign (Bonneson et al., 2007).

The type and location of sign will depend on the difference between the posted speed limit and the advisory speed. Including vehicle detection or speed detection sensors to the "sign system" may raise the cost but could improve effectiveness.

Work zone advanced curve warning signs are orange instead of yellow.

Cost and Timeframe

Low Cost. $500 - $700 for a sign on a wooden post. Additional cost for a more crashworthy breakaway sign (Oregon Department of Transportation, 2010). Simple curve warning signs can be installed in as little as a few hours.

Maintenance Needs

Signage needs to be replaced periodically based on retroreflectivity degradation, color degradation, age, or MUTCD standard inspection failures. Degradation varies based on sunlight exposure and the color of the sign, but signs generally last 15 years (Tavse et al., 2017).

Limitations and Concerns

Research on horizontal alignment signs (Bonneson et al., 2007) indicates that inconsistent use of the advisory speed plaque has lessened the average motorist's respect for the message the signs convey. In addition, drivers realize that they can comfortably exceed the advisor speed which can lead to excessive speeds and crashes on less familiar roads.

Key References

Bahar, G., Masliah, M., Wolff, R., Park, P. (2008). Desktop Reference for Crash Reduction Factors (Federal Highway Administration, Report No. FHWA-SA-08-011). Washington, DC: U.S. Government Printing Office.

Bonneson, J., Pratt, M., Miles, & J., Carlson, P. (2007). *Horizontal Curve Signing Handbook* (*Texas A&M Transportation Institute*. Report No. FHWA/TX-07/0-5439-P1). College Station, Texas.

Brimley, B. K., Carlson, P. J., Hawkins, Jr. H. G., Himes, S., Gross, F., & McGee, H. (2016). Guidelines for Traffic Control Devices at Changes in Horizontal Alignment. *Transportation Research Record*. http://DOI10.3141/2555-14

Federal Highway Administration (2009). *Manual of Uniform Traffic Control Devices for Streets and Highways*. 2009 Edition. Washington, DC: U.S. Government Printing Office

Hammer, Jr., C.G. (1968). Evaluation of Minor Improvements: Part 6, Signs (*California Division of Highways).* Sacramento, California.

Oregon Department of Transportation. (2010). *Updated Curve Warning Signs*. Salem, Oregon. Retrieved from http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Fact-Sheet_Curve-Warning-Signs.pdf

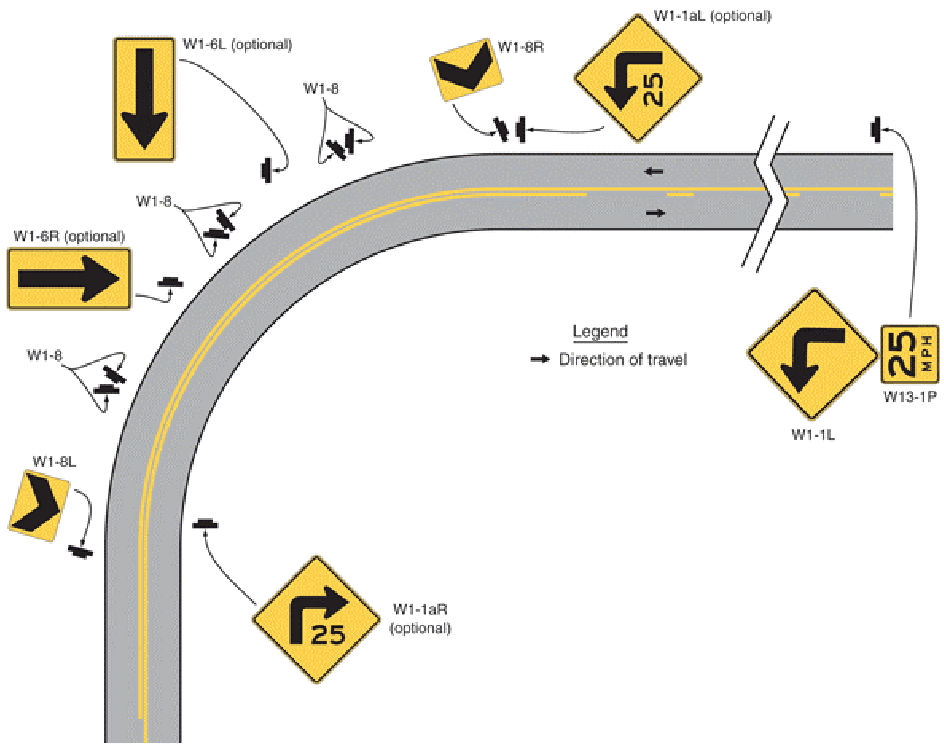
Tayse, J., Mullins, M., Linsenmayer, M., Warzala, D., Johnson, S. M., & Misgen, S. (2017). *Sign Life-Cycle Policies and Practices.* (Minnesota Department of Transportation. Transportation Research Synthesis 1707). St. Paul, MN: Research Services Library.

5.7 In-Curve Warning Signs

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	All	RI	C	Not Est	Not Est	.73-.82	Effec +	$

Description

In-curve warning signs are often installed along with advanced curve warning signs. These signs are defined in the MUTCD. The signage can consist of chevrons, arrows, and delineators such as reflectors on the top of barriers. In addition, at least one state has added reflective material to the curve sign posts to visually "anchor" the sign to the ground and has made curve chevron signs larger so that motorists perceive the curve to be closer and to subsequently brake earlier. The additional signage is intended to further raise a motorist's awareness of the curve.



Examples of in-curve warnign signs (Wemple and Colling, 2013).

Applications

This countermeasure is intended to aid navigation of horizontal curves.

Vehicle and Rider Safety Effectiveness

Geometric, traffic, and crash data were obtained from 89 curves and 139 curves in Connecticut and Washington, respectively, to determine the effect of improved curve delineation on safety (Srinivasan et al., 2009). Treatments included chevrons, horizontal arrows, and advanced warning sings as well as techniques to improve reflective sheeting on existing signs. Results indicated an 18 percent reduction in injury and fatal crashes, a 27.5 percent reduction in crashes during dark conditions, and a 25 percent reduction in lane departure crashes during dark conditions.

There have been no studies to date that have measured the effects of pavement markings on motorcycle-related crash rates.

Design Considerations

The Horizontal Curve Signing Handbook notes that motorists do not necessarily slow in response to a curve warning sign (Bonneson et al., 2007).

The type of sign employed and the location of the sign in advance of a curve depends on the difference the posted speed limit and the advisory speed. Including vehicle detection or speed detection sensors, such as flashing lights, to the "sign system" may raise the cost but could improve the effectiveness.

Cost and Timeframe

Installation of chevrons in a curve could cost approximately $300 - $500 per sign on a wooden post with additional costs associated with the additional of crashworthy breakaway signs (Oregon Department of Transportation, 2010).

Maintenance Needs

Periodic replacement of chevron signs will be required on problematic curves when driver crash into and knock down the sign.

Signage needs to be replaced periodically based on retroreflectivity degradation, color degradation, age, or MUTCD standard inspection failures. Degradation varies based on sunlight exposure and the color of the sign, but signs generally last 15 years (Tayse et al., 2017).

Limitations and Concerns

One limitation of horizontal curve signage is that motorists may not slowdown in response to signage, leading to a limited on crashes caused by excessive speeds.

Key References

Bonneson, J., Pratt, M., Miles, & J., Carlson, P. (2007). *Horizontal Curve Signing Handbook (Texas A&M Transportation Institute*. Report No. FHWA/TX-07/0-5439-P1). College Station, Texas.

Oregon Department of Transportation (2010, December 9). Updated Curve Warning Signs. Salem, Oregon. Retrieved from http://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/Fact-Sheet_Curve-Warning-Signs.pdf

Srinivasan, R., Baek, J., Carter, D., Persaud, B, Lyon, C., Eccles, K., Gross, F., & Lefler, N. (2009). *Safety Evaluation of Improved Curve Delineation (Federal Highway Administration*. Report No. FHWA-HRT-09-045). Washington, DC: U.S. Government Printing Office.

Tayse, J., Mullins, M., Linsenmayer, M., Warzala, D., Johnson, S. M., & Misgen, S. (2017). *Sign Life-Cycle Policies and Practices.* (Minnesota Department of Transportation. Transportation Research Synthesis 1707). St. Paul, MN: Research Services Library.

5.8 Pavement Markings

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	SVRD	RI	C, S	Not Est	Not Est	.71-.92	Effec +	$

Description

Pavement markings aid motorists in recognizing the edge of a roadway and the division of opposite direction traffic flows. This is especially true in nighttime driving where retroreflectivity, which is the ability to reflect light from a vehicle's headlights, is crucial for a driver to see the pavement markings. This low-cost addition to the roadway would aid all motorists as they maneuver a facility.

Yellow centerline and white edgeline pavement markings (3M, 2017).

Applications

This treatment could address crashes where motorcyclists are involved with another vehicle crossing a centerline or if the pavement edge was not visible and a motorcyclist runs off the roadway. Pavement markings can be applied to the centerline or roadside edge.

Vehicle and Rider Safety Effectiveness

An analysis of nighttime crash data for years 2003 – 2008 on rural two-lane roads in Michigan found a statistically significant relationship between pavement marking retroreflectivity and nighttime safety (Avelar & Carlson, 2014). Sites with low centerline retroreflectivity were associated with more crashes. Furthermore, research examining crash rates and pavement markings found that edgelines and centerlines could reduce crashes by 8 and 29 percent, respectively, in the United States (Bali et al., 1978). Note this study was based on the presence of a lane markings on rural two-lane highways, not the degree of retroreflectivity.

Another study analyzed the effects of adding edgelines on 5,000 miles of rural two-lane highways in Louisiana (Sun & Das, 2014). The study examined the impacts of adding edgelines to narrow roads with a pavement width of less than 22 feet, excluding shoulders using a before and after study methodology. The study claimed that, on average, implementing edge lines can reduce 17 percent of crashes, thus a CMF of 0.83. *The Handbook of Road Safety Measures* (2004) estimates crash reductions averaging 28 percent associated with the installation of edgelines and centerlines, based on a meta-analysis of previous studies (Elvik & Vaa, 2004).

There have been no studies to date that have measured the effects of pavement markings on motorcycle-related crash rates.

Design Considerations

Different pavement marking materials have varying advantages with respect to friction, visibility in inclement weather, and durability.

Cost and Timeframe

In 1992, striping with fast-drying paint costs $0.035/linear-feet in rural areas and $0.07/linear-feet in urban areas. Thermoplastic costs vary between $0.15 to $0.40/ linear-feet and average at $0.32/linear-ft. Thermoplastic tends to have a lower life-cycle costs, lasting longer in areas that do not snowplow (Miller, 1992).

Maintenance Needs

Pavement markings degrade over time and need to be replaced periodically.

Limitations and Concerns

Most sites already have adequate pavement markings.

Key References

Avelar, R.E. & Carlson, P. (2014). Link Between Pavement Marking Retroreflectivity and Night Crashes on Michigan Two-Lane Highways. *Transportation Research Record*, *2440*, 59-67. http://DOI:10.3141/2404-07

Bali, S., Potts, R., Fee, A., Taylor, J. I. & Glennon, J. (1978). *Cost Effectiveness and Safety of Alternative Roadway Delineation Treatments for Rural Two-Lane Highways* (*Federal Highways Administration*. Report FHWA-RD-78-50). Washington, DC: U.S. Government Printing Office.

Elvik, R. and Vaa, T., "Handbook of Road Safety Measures." (2004) Elsevier, Oxford, United Kingdom.

Miller, T. R. (1992). Benefit-Cost Analysis of Lane Marking. *Transportation Research Record, 1334,* 38-45.

Sun, X., & Das, S. (2012). *Safety Improvement from Edge Lines on Rural Two-Lane Highways (University of Louisiana at Lafayette*. Report No. FHWA/LA.11/487), Lafayette, Louisiana.

5.9 Rumble Strips

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	SVRD	RI/RS	C, S	Not Est	Not Est	.30-.93	Effec +	$-$$

Description

Rumble strips are considered an audible and vibratory warning device constructed in the pavement surface to mitigate lane departure incidents. A repeated pattern is milled into the shoulder next to the edge line or along the centerline of two-way undivided roads. The treatment can also be rolled in at the time of construction or using raised thermoplastic bumps.

Various rumble strip designs exist considering different widths, depths, and spacing.

Examples of rumble strip designs (left, Surface Preparations Technology, 2017; right, Crossroads, 2017).

Applications

Rumble strips are applied along the pavement in locations that are prone to lane departures. Highway shoulders and also centerlines on two-way undivided roads are most common. The treatment can be applied to several miles of pavement at a time.

Vehicle and Rider Safety Effectiveness

Research has indicated that approximately 20 percent of fatal crashes on two-lane roads were caused by lane-departure head-on collisions (Persaud, Retting & Lyon, 2003). Research examining the effectiveness of rumble strips for motor vehicles has shown positive results. For example, a study conducted in New York State found that total run off road crashes decreased by up to 70 percent after the application of continuous shoulder rumble strips (Perrillo, 1998). Khan, Abdel-Rahim and Williams (2015) found that run off road crashes on rural two-lane roadways were reduced by 14 percent due to rumble strips. The authors also found that the treatment was most effective on moderately curved roads and where shoulder widths were 3 feet and greater. Centerline cross-over crashes on rural roads were studied by Persaud et al. (2003) who found a 25 percent reduction of these due to centerline rumble strips. Depending on factors including the roadway type, rumble strip type, and the offset of the rumble strip relative to the travel lane, other studies have estimated crash reductions ranging from 7 percent to 68 percent (Donnell et al, 2009; Bahar et al, 2008; Harkey et al, 2008).

Research specific to motorcycles found through qualitative studies that proposed rumble strip designs did not make riders feel unsafe (Bucko & Khorashadi, 2001).

Design Considerations

Rumble strip designs vary from state-to-state. Typical recommendations from Federal Highway Administration (2017) for shoulder designs are given below.

Dimension	Measurement	Milled (mm)	Rolled (mm)
A	Repeat Pattern	approx. 130 (5.1 in.)	approx. 130 (5.1 in.)
B	Longitudinal Width	180 (7.1 in.)	40 (1.6 in.)
C	Transverse Width	400 (15.8 in.)	400 (15.8 in.)
D	Tire Drop	13 (0.5 in.)	0.75 (0.03 in.)
E	Depth	13 (0.5 in.)	32 (1.3 in.)

Bedsole et al (2017) suggest using a “mumble strip” design for greater motorcyclist safety, though there is no qualitative data that this is the case.

Making motorcyclists aware of centerline rumble strips is important and the MUTCD includes signage (see figure below) which may be warranted in some locations (Federal Highway Adminstration, 2011).

Cost and Timeframe

In 1996 the cost in New York was $0.12/foot (Perrillo, 1998). A subsequent report in 2001 reported the cost ranged from $0.13 to $0.35 per/foot (Corkle, Marti & Montebello, 2001).

Maintenance Needs

There is no indication that milled rumble strips decrease in performance. Even in deteriorating pavement, the rumble strip still performs as intended (Perrillo, 1998).

Limitations and Concerns

None

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5.10 Remove Roadside Trees

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MC	SVRD	RS	C, S	Not Est	Not Est	Not Est	Not Est	$

Description

A significant safety issue facing riders is leaving the roadway and striking an object such as trees or posts. The removal of roadside trees or posts can be implemented along roadways to prevent riders from impacting fixed objects and causing severe injury to a rider.

Example of tree removal (Westport News, 2017).

Applications

Removal of roadside trees should be employed at roadway locations with a blind-spot corner or on roadways with successive curves.

Vehicle and Rider Safety Effectiveness

A study in New Zealand indicated that impacts with roadside fixed objects occurred on curved roadways in 83.1% of crashes (Grezbieta & Bambach, 2014). A study of fatal motorcycle collisions with fixed roadside objects was conducted in the U.S. recently by Daniello (2011). Results of that work found that roadside trees pose the highest risk of rider fatality when compared to signs, poles, and roadside barriers. In addition, tree collisions are 15% more likely to be fatal when compared to the motorcyclist falling and impacting the ground (Daniello, 2011).

There have been no studies to date that have measured the effectiveness of the removal of trees relative to crash injury or severity rates for either motor vehicle drivers or riders. In addition, it is unknown if the removal of trees reduces crash frequency when implemented on specific roadway sections.

Design Considerations

Large trees will require significant space surrounding it in order to safely cut it down. Large trees near roadways may require additional crew members to fell the tree.

Cost and Timeframe

The approximate cost to remove a tree would $650 and would take about a day to complete.

Maintenance Needs

Once the tree has been removed, there is no required maintenance.

Limitations and Concerns

The effectiveness of this type of countermeasure is not well documented for motorcycle vehicles.

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5.11 Positive Guidance in the Work Zone

Vehicle Type	Crash Type	Injury Type	Road Sgmt	MC CMF	MC Effect	MV CMF	MV Effect	Cost
MV/MC	All	RI	C, I, S	Not Est	Not Est	Not Est	Not Est	$

Description

Positive guidance is the design concept of giving motorists information when they need it in a form that can best be used to avoid a hazard. In a work zone, this constitutes providing signage in advance of the work zone to warn motorists about upcoming ahead. More recently, states have begun to add retroreflective posts/markers along the top of construction zone jersey barriers.

Positive guidance techniques applied to a lane closure (FHWA, 2010).

Applications

Ullman and Schrock (2003) recommend that the four components of review (hazard visibility, driver expectancy violation, information load analysis, and information needs specification) be considered during a review drive-through in a work zone. Several trips may be necessary to review these components with emphasis given to locations just upstream of a decision point (exit ramps, intersections, driveways, speed reduction locations, etc.). The reviewer should account for driver perspective for each possible decision in these areas (Ullman & Schrock, 2003).

The Roadway Safety Consortium (Federal Highways Administration, 2010) recommends the following practice:

- Using arrow panels for lane closures.
- Placing signage far enough apart that the driver doesn't get overwhelmed.
- Using high quality work zone pavement markings and proper removal of misleading markings.
- Placement of critical work zone signs so they demand driver attention.

Vehicle and Rider Safety Effectiveness

Ullman and Schrock (2003) received comments from drivers on their experiences navigating a work zone. Comments from the majority of drivers indicated confusion and anxieties in traversing complex work zones could be addressed with positive guidance concepts. Ullman and Schrock warn about use of portable changeable message signs (PCMS), as they can be a major source of driver confusion in a work zone. A site reviewer should take care to ensure that PCMS messages conform to guidelines available at the state or federal level.

There have been no studies to date that have measured the effects of positive guidance in a work zone on motorcycle-related crash rates.

Design Considerations

Appropriate placement of signage in a work zone would be of negligible.

Cost and Timeframe

No literature discussing the cost of employing positive guidance in a work zone versus a work zone without considering positive guidance was found. It should be noted that positive guidance principals can be applied to any work zone with the proper placement of traffic control devices.

Maintenance Needs

Work zone signage and channelization devices are subject to a harsh environment where conditions can degrade retroreflective sheeting and make them less visible to drivers (RHWA, 2010). Additionally, work zone traffic control devices are subject to constant moving where they can be damage while loading, in-transit, or unloading.

Limitations and Concerns

Work zones remain a location where the route can be inconsistent and driver expectancy is not met, despite the use of positive guidance. This means that motorists could still be confused in a work zone that utilizes good positive guidance principals.

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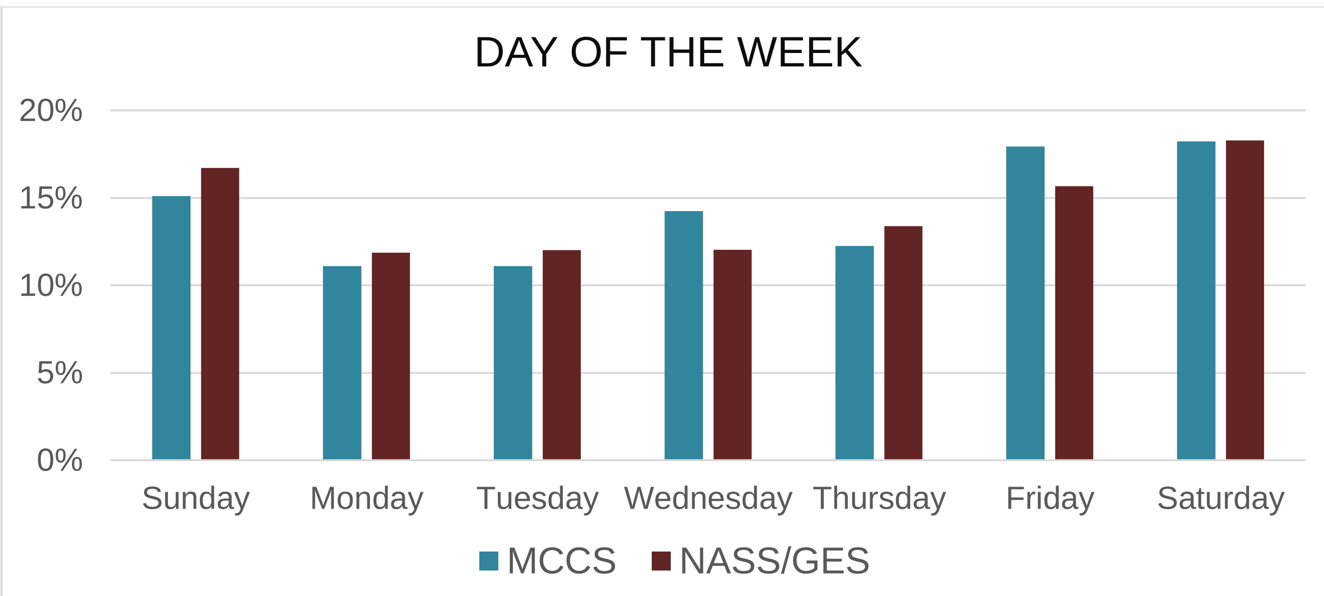
APPENDIX B. COMPARISON OF MCCS TO NASS/GES, FARS, AND FARS (CALIFORNIA ONLY)

1. Day of the Week

MCCS Crash Form (CF001_CRASHDAY)			
Code	Description	Count	%
07	Sunday	53	15.1
01	Monday	39	11.1
02	Tuesday	39	11.1
03	Wednesday	50	14.2
04	Thursday	43	12.2
05	Friday	63	17.9
06	Saturday	64	18.2
	Total	351	100.0

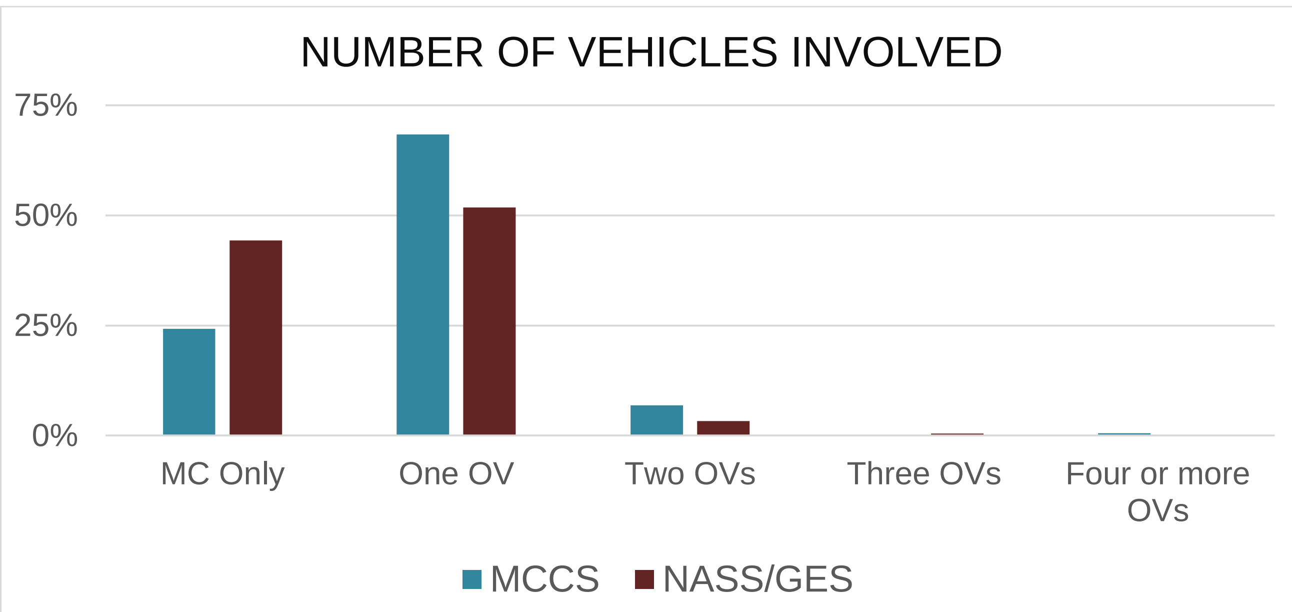
NASS/GES (2011-2015) Accident Data (DAY_WEEK)			
Code	Description	Count (weighted)	%
1	Sunday	83,560	16.7
2	Monday	59,353	11.9
3	Tuesday	60,098	12.0
4	Wednesday	60,157	12.0
5	Thursday	66,920	13.4
6	Friday	78,320	15.7
7	Saturday	91,354	18.3
	Total	499,761	100.0



2. Number of Vehicles Involved

MCCS Crash Form (CF006_OVCOUNT)			
Code	Description	Count	%
00	None	85	24.2
01	One	240	68.4
02	Two	24	6.8
03	Three	0	0.0
04	Four	2	0.6
05	Five or more	0	0.0
	Total	351	100.0

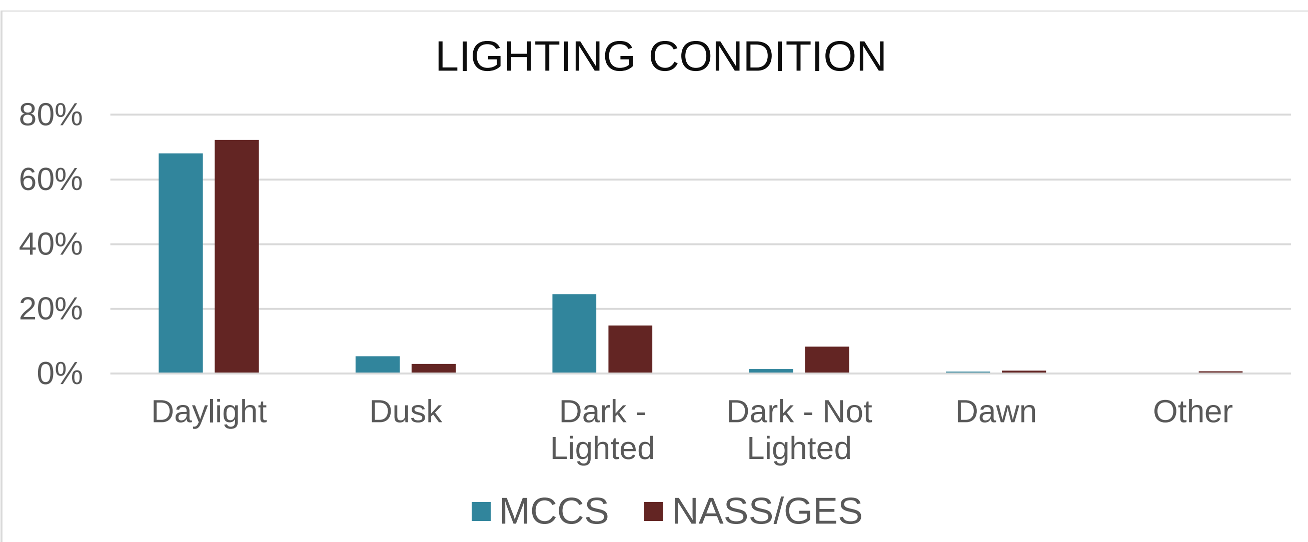
NASS/GES (2011-2015) Accident Data (VE_TOTAL)			
Code	Description	Count (weighted)	%
1	MC Only	221,581	44.3
2	One OV	258,698	51.8
3	Two OVs	16,603	3.3
4	Three OVs	2,201	0.4
5	Four OVs	626	0.1
6+	Five or More OVs	51	0.0
	Total	499,761	100.0



3. Lighting Condition

MCCS Crash Form (CF011_AMBIENTLIGHT)			
Code	Description	Count	%
01, 02	Daylight, bright; daylight, not bright	239	68.1
03	Dusk, sundown	19	5.4
04, 07, 08	Night, lighted; Night, continuous illumination; Night, spot illumination	86	24.5
05	Night, not lighted	5	1.4
06	Dawn, sunup	2	0.6
98	Other	0	0.0
99	Unknown	0	0.0
	Total	351	100.0

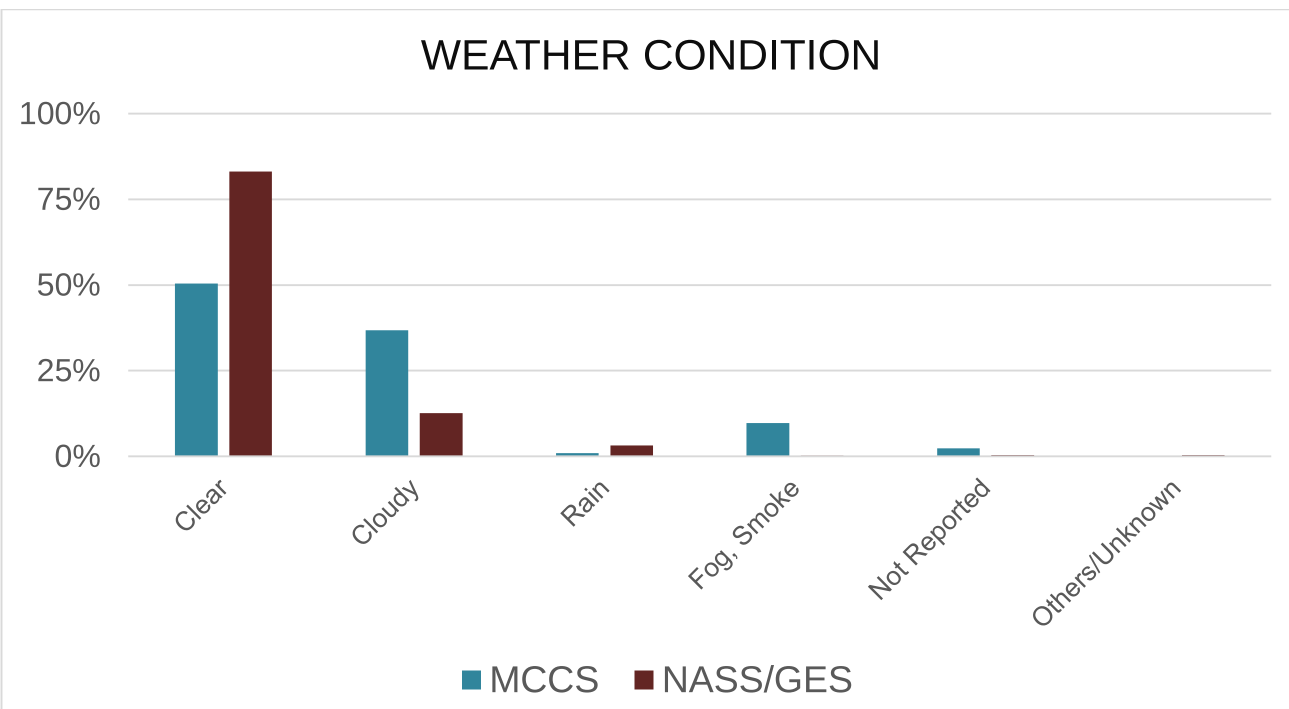
NASS/GES (2011-2015) Accident Data (LGT_COND)			
Code	Description	Count (weighted)	%
1	Daylight	360,990	72.2
5	Dusk	15,013	3.0
3	Dark - Lighted	74,670	14.9
2	Dark - Not Lighted	41,708	8.3
4	Dawn	4,266	0.9
6	Dark - Unknown Lighting	1,503	0.3
7	Not Reported	826	0.2
8	Other	32	0.0
9	Unknown	753	0.2
	Total	499,761	100.0



4. Weather Condition

MCCS Crash Form (CF013_WEATHER)			
Code	Description	Count	%
01	Clear	177	50.4
02	Cloudy, partly cloudy	129	36.8
04, 05, 07, 08	Drizzle, light rain; Moderate or heavy rain; Sleet, freezing rain; Hail	3	0.9
03	Overcast	34	9.7
	Not Reported	8	2.3
98, 99	Other and Unknown	0	0.00
	Total	351	100.0

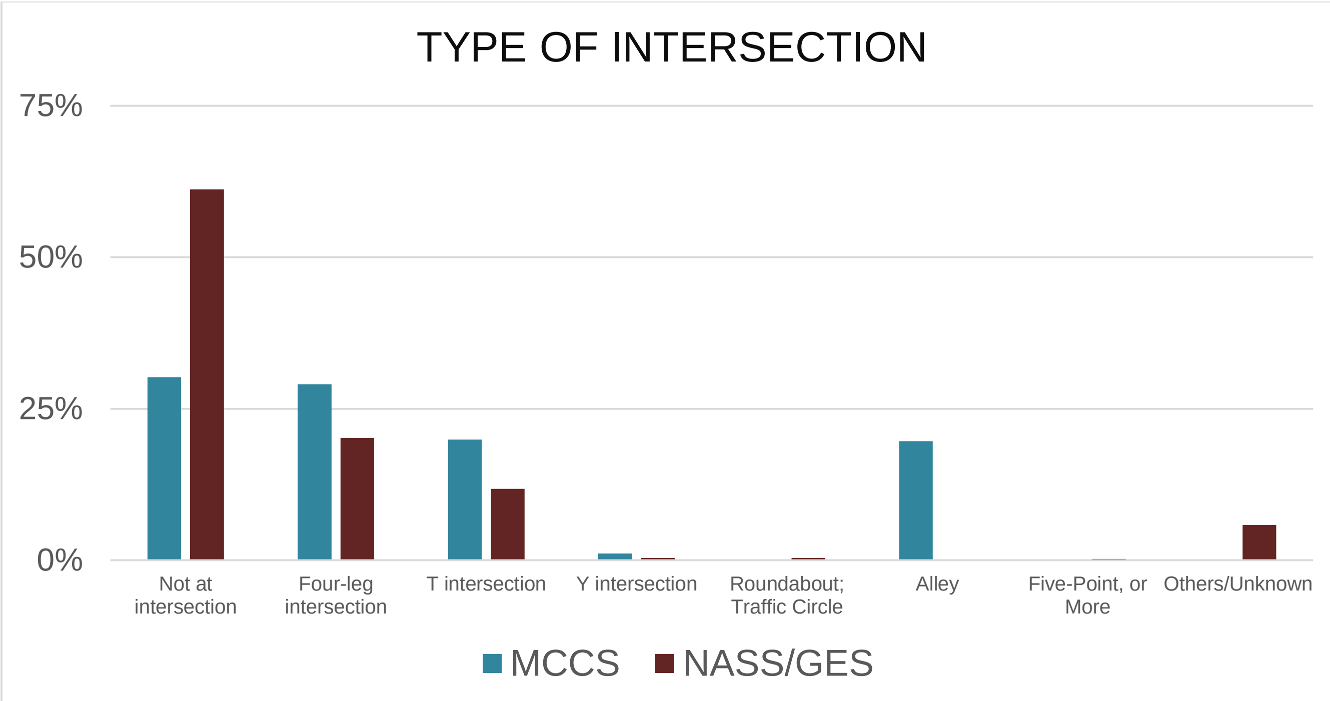
NASS/GES (2011-2015) Accident Data (WEATHER)			
Code	Description	Count (weighted)	%
1	Clear	415,257	83.1
2	Cloudy	63,210	12.6
3	Rain, Sleet or Hail (Freezing Rain or Drizzle)	16,214	3.2
4	Fog, Smog, Smoke	1,282	0.3
5	Not Reported	1,886	0.4
98, 99	Other and Unknown	1,913	0.4
	Total	499,761	100.0



5. Type of Intersection

MCCS Environment Form (EF003_INTERSECTIONCONFIG)			
Code	Description	Count	%
00	Not at intersection	106	30.2
01, 02	Four-leg intersection, not skewed; four-leg intersection, skewed	102	29.06
03	T intersection	70	19.94
04	Y intersection	4	1.14
08	Roundabout; Traffic Circle	0	0.0
05, 06, 07, 10	Alley, driveway; Offset intersection; Intersection as part of interchange; Rail/light-rail crossing	69	19.64
09	Multi-leg Intersection	0	0.0
	Total	351	100.0

NASS/GES (2011-2015) Accident Data (TYP_INT)			
Code	Description	Count (weighted)	%
1	Not at intersection	305,737	61.2
2	Four-leg intersection	101,012	20.2
3	T intersection	58,877	11.8
4	Y intersection	2,046	0.4
5, 6	Roundabout; Traffic Circle	2,030	0.4
7	Five-Point, or More	890	0.2
98	L Intersection	238	0.0
10	Not Reported	27,644	5.5
99	Unknown	1,287	0.3
	Total	499,761	100.0

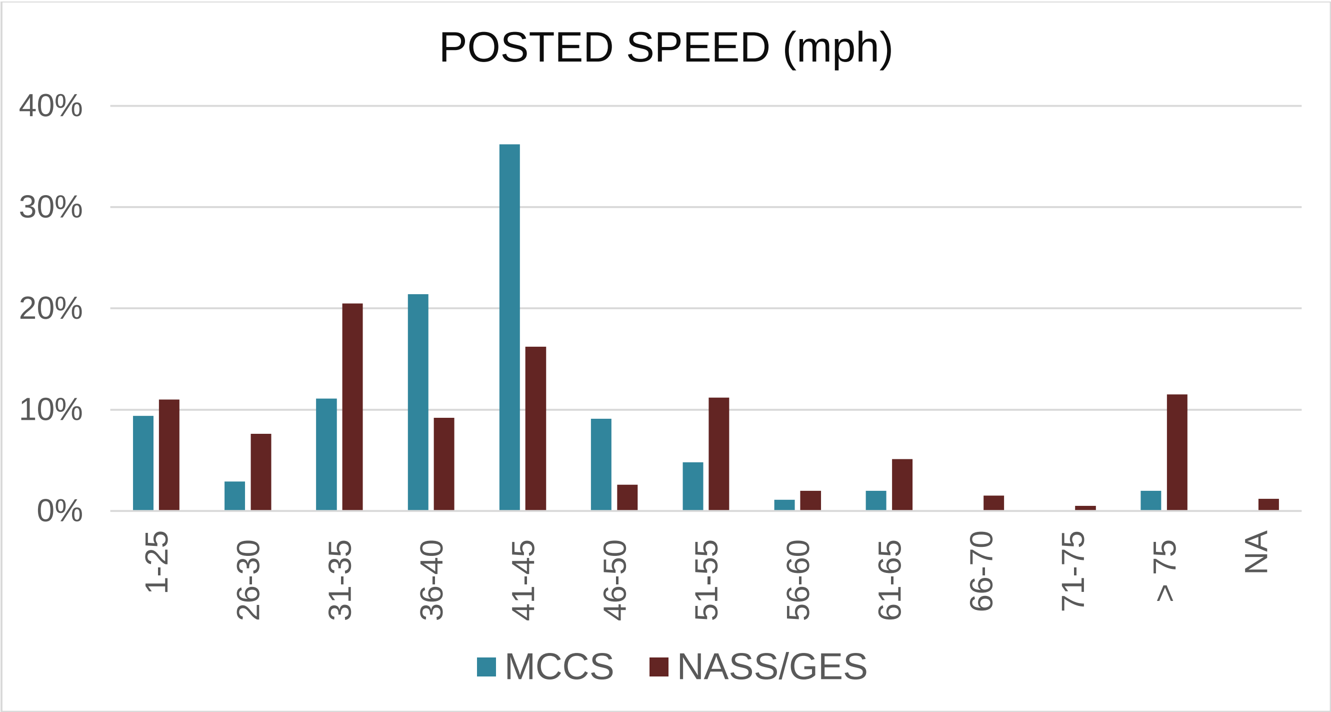


TYPE OF INTERSECTION
75%
50%
25%
0%
Not at intersection
Four-leg intersection
T intersection
Y intersection
Roundabout; Traffic Circle
Alley
Five-Point, or More
Others/Unknown
MCCS
NASS/GES

6. Posted Speed Limit

MCCS Environment Form (EF006_SPEEDLIMIT)			
Code	Description	Count	%
1- 25	1- 25 mph	33	9.4
26-30	26-30 mph	10	2.9
31-35	31-35 mph	39	11.1
36-40	36-40 mph	75	21.4
41-45	41-45 mph	127	36.2
46-50	46-50 mph	32	9.1
51-55	51-55 mph	17	4.8
56-60	56-60 mph	4	1.1
61-65	61-65 mph	7	2.0
66-70	66-70	0	0.0
71-75	71-75	0	0.0
> 75	> 75 mph	7	2.0
NA	NA	0	0.0
	Total	351	100.0

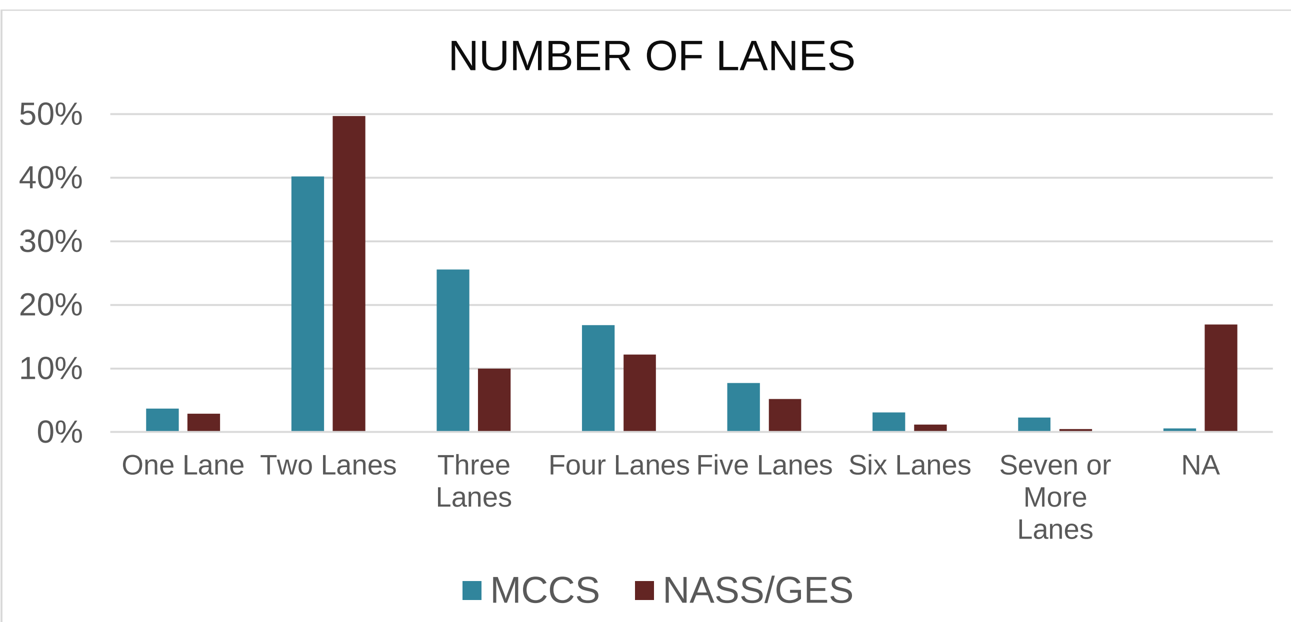
NASS/GES (2011-2015) Vehicle Data (VSPD_LIM)			
Code	Description	Count (weighted)	%
1- 25	1- 25 mph	54,738	11.0
26-30	26-30 mph	37,948	7.6
31-35	31-35 mph	102,495	20.5
36-40	36-40 mph	45,761	9.2
41-45	41-45 mph	80,802	16.2
46-50	46-50 mph	13,067	2.6
51-55	51-55 mph	55,866	11.2
56-60	56-60 mph	10,173	2.0
61-65	61-65 mph	25,388	5.1
66-70	66-70	7,365	1.5
71-75	71-75	2,358	0.5
> 75	> 75 mph	57,400	11.5
NA	NA	6,100	1.2
	Total	499,761	100.0


POSTED SPEED (mph)
40%
30%
20%
10%
0%
1-25
26-30
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
> 75
NA
MCCS
NASS/GES

7. Number of Lanes

MCCS Environment Form (EF007_NUMBERLANES)			
Code	Description	Count	%
01	One	13	3.7
02	Two	141	40.2
03	Three	90	25.6
04	Four	59	16.8
05	Five	27	7.7
06	Six	11	3.1
07, 08	Seven; Eight	8	2.3
98	NA	2	0.6
	Total	351	100.0

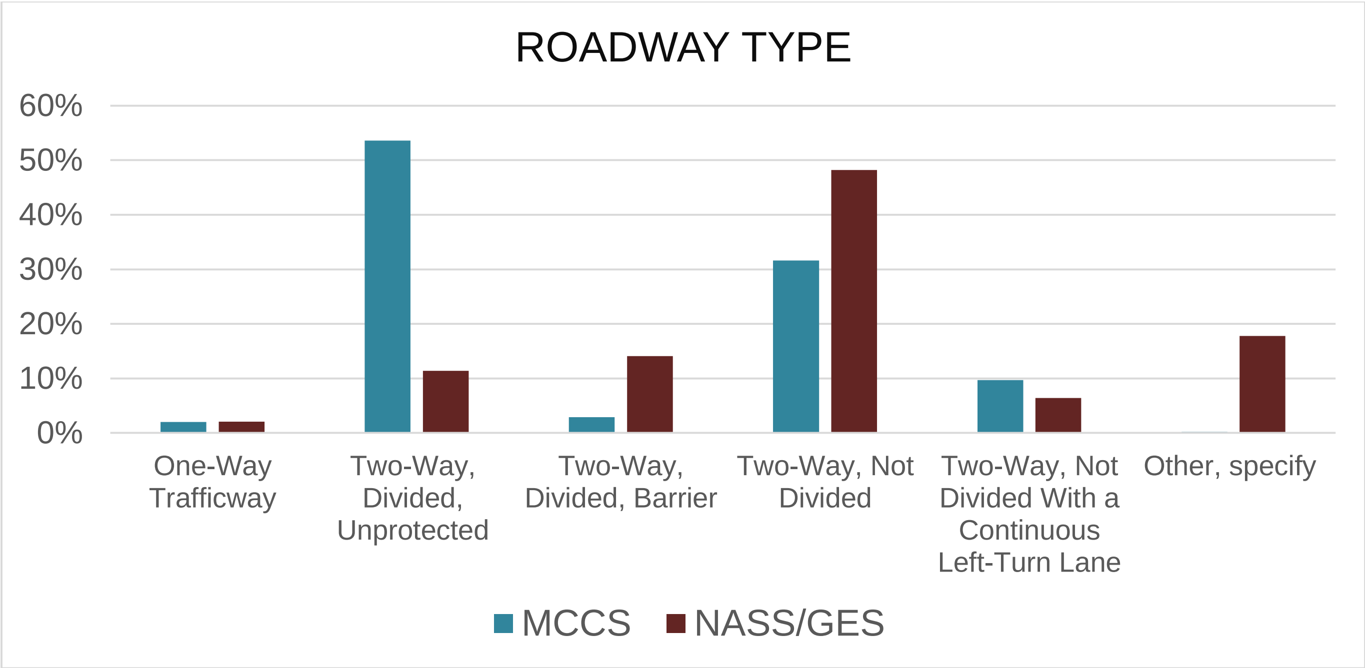
NASS/GES (2011-2015) Vehicle Data (VNUM_LAN)			
Code	Description	Count (weighted)	%
1	One Lane	14,609	2.9
2	Two Lanes	248,247	49.7
3	Three Lanes	49,758	10.0
4	Four Lanes	61,037	12.2
5	Five Lanes	25,909	5.2
6	Six Lanes	5,776	1.2
7, 8	Seven or More Lanes	2,455	0.5
	NA	84,465	16.9
	Non-Traffic way Area	5,752	1.2
	Unknown	1,453	0.3
	Total	499,761	100.0



8. Roadway Type

MCCS Environment Form (EF004_TRAFFICPATTERN)			
Code	Description	Count	%
05	One-way	7	2.0
03	Two-way, divided, no median barrier	188	53.6
04	Two-way, divided, with median barrier	10	2.9
01	Two-way, undivided	111	31.6
02	Two-way, with a continuous left-turn lane	34	9.7
98, 99	Other, specify	1	0.3
03	Unknown	0	0.0
	Total	351	100.0

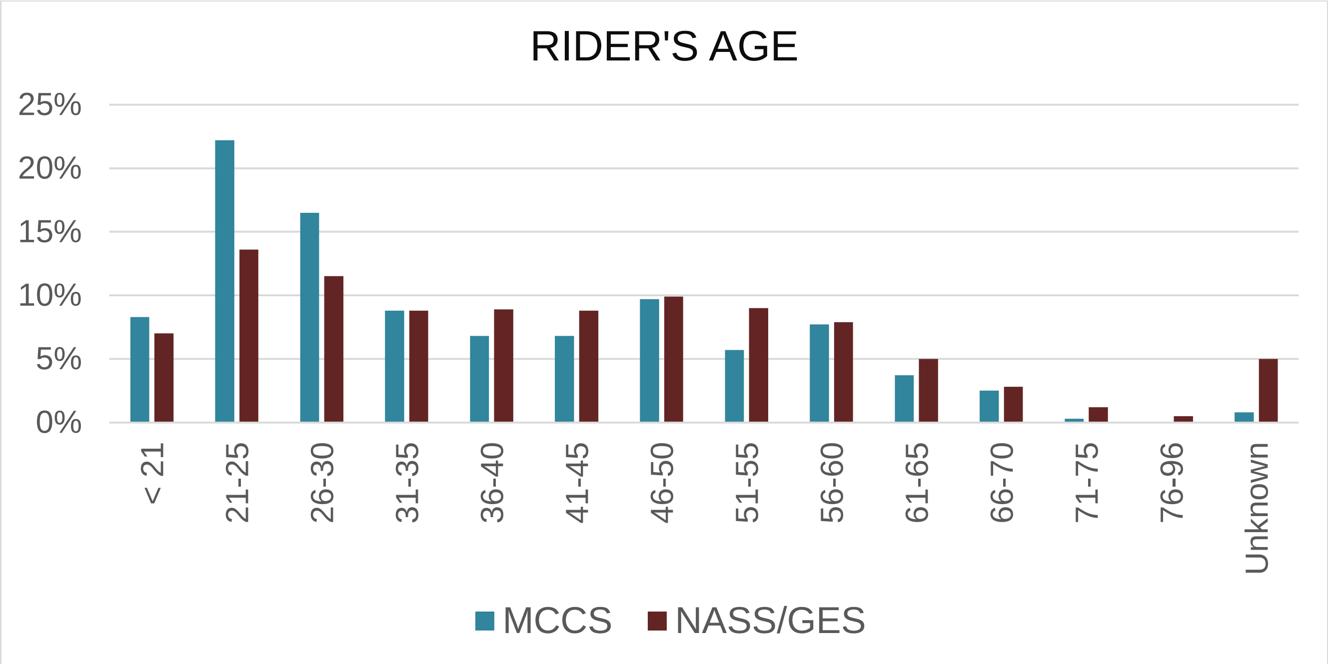
NASS/GES (2011-2015) Vehicle Data (VE_TOTAL)			
Code	Description	Count (weighted)	%
4	One-Way Traffic way	10,475	2.1
2	Two-Way, Divided, Unprotected (Painted > 4 Feet) Median	57,091	11.4
3	Two-Way, Divided, Positive Median Barrier	70,356	14.1
1	Two-Way, Not Divided	240,983	48.2
5	Two-Way, Not Divided With a Continuous Left-Turn Lane	31,840	6.4
	Other, specify	0	0.0
6	Entrance/Exit Ramp	13,265	2.7
0	Non-Traffic way Area	5,752	1.2
8	Not Reported	68,879	13.8
9	Unknown	821	0.2
	Total	499,761	100.0


ROADWAY TYPE
60%
50%
40%
30%
20%
10%
0%
One-Way Trafficway
Two-Way, Divided, Unprotected
Two-Way, Divided, Barrier
Two-Way, Not Divided
Two-Way, Not Divided With a Continuous Left-Turn Lane
Other, specify
MCCS
NASS/GES

9. Rider's Age

MCCS Motorcycle Rider Form (MR089_MCRYEARSOFAGE)			
Code	Description	Count	%
< 21	20 or under	29	8.3
21-25	21-25	78	22.2
26-30	26-30	58	16.5
31-35	31-35	31	8.8
36-40	36-40	24	6.8
41-45	41-45	24	6.8
46-50	46-50	34	9.7
51-55	51-55	20	5.7
56-60	56-60	27	7.7
61-65	61-65	13	3.7
66-70	66-70	9	2.5
71-75	71-75	1	0.3
76-96	76-96	0	0.0
	Unknown	3	0.8
	Total	351	100.0

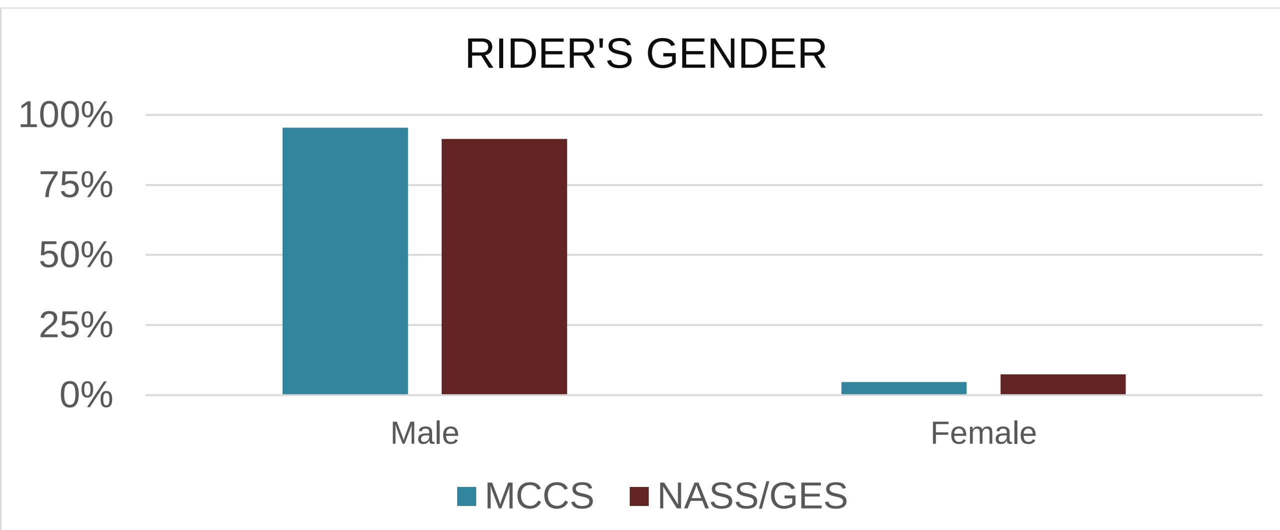
NASS/GES (2011-2015) Person Data (AGE)			
Code	Description	Count (weighted)	%
< 21	20 or under	35,002	7.0
21-25	21-25	68,110	13.6
26-30	26-30	57,342	11.5
31-35	31-35	44,112	8.8
36-40	36-40	44,581	8.9
41-45	41-45	44,062	8.8
46-50	46-50	49,501	9.9
51-55	51-55	44,810	9.0
56-60	56-60	39,661	7.9
61-65	61-65	24,953	5.0
66-70	66-70	13,824	2.8
71-75	71-75	5,824	1.2
76-96	76-96	2,482	0.5
	Unknown	25,197	5.0
	Total	499,761	100.0


RIDER'S AGE
25%
20%
15%
10%
5%
0%
< 21
21-25
26-30
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-96
Unknown
MCCS
NASS/GES

10. Rider's Gender

MCCS Motorcycle Rider Form (MR099_GENDER)			
Code	Description	Count	%
01	Male	335	95.4
02	Female	16	4.6
	Total	351	100.0

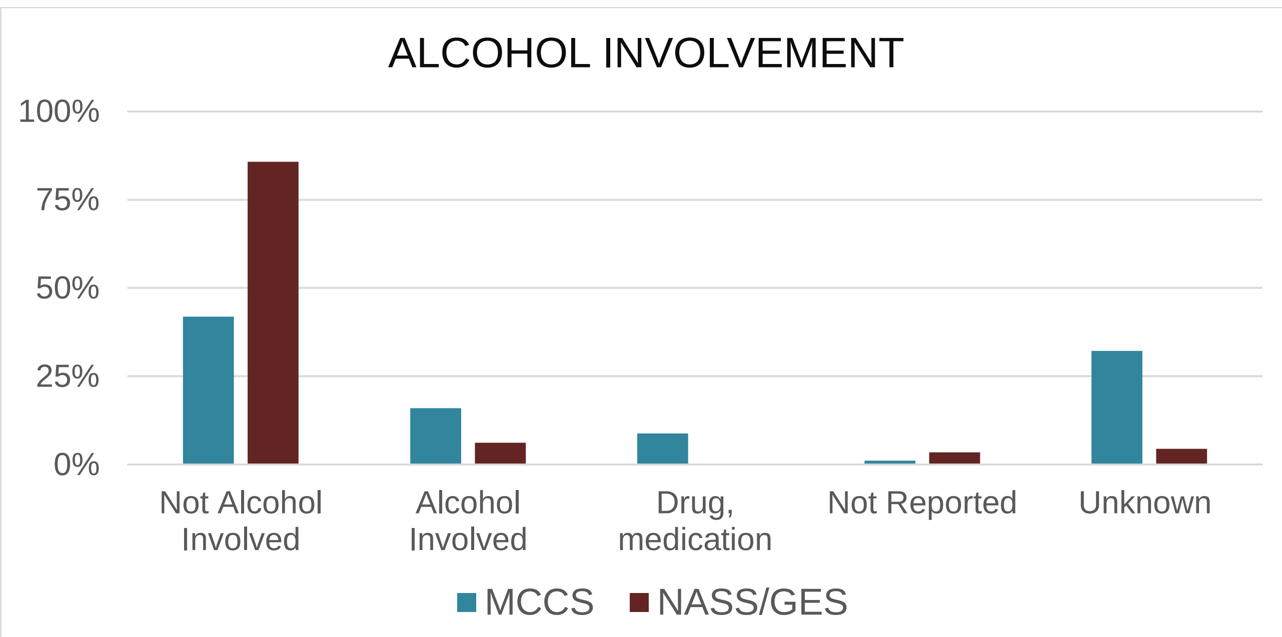
NASS/GES (2011-2015) Person Data (SEX)			
Code	Description	Count (weighted)	%
1	Male	456,354	91.4
2	Female	37,131	7.4
8	Not Reported	1,198	0.2
9	Unknown	4,778	1.0
	Total	499,761	100.0



11. Alcohol Use by the Riders

MCCS Environment Form (MR041_DRUGSLAST24HRS)			
Code	Description	Count	%
00	No	147	41.9
01; 03	Alcohol use; Combined Alcohol and Drug	56	16.0
02	Drug, medication	31	8.8
98	Other	4	1.1
99	Unknown	113	32.2
	Total	351	100.0

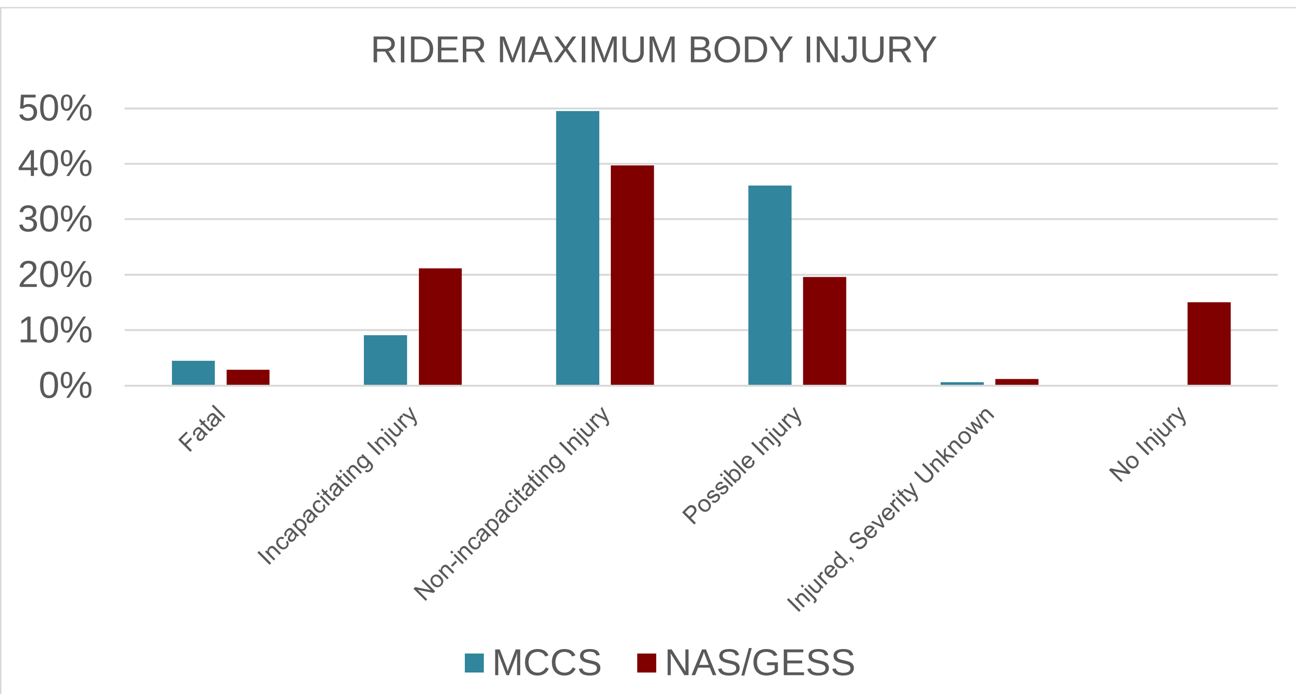
NASS/GES (2011-2015) Vehicle Data (DRINKING)			
Code	Description	Count (weighted)	%
0	No (Not Alcohol Involved)	428,470	85.7
1	Yes (Alcohol Involved)	31,119	6.2
	Drug, medication	0	0.0
8	Not Reported	17,563	3.5
9	Unknown (Police Reported)	22,608	4.5
	Total	499,761	100.0



12. Rider Maximum Body Injury

MCCS Injury Form (IF157_INJURYSEVERITYSCORE)			
Code	Description	Count	%
6	maximum (untreatable)	16	4.5
4, 5	critical injury. Severe injury	32	9.1
2, 3	serious injury; moderate injury	174	49.5
1	minor injury	127	36.1
9	injured, unknown severity	2	0.6
	Total	351	100.0

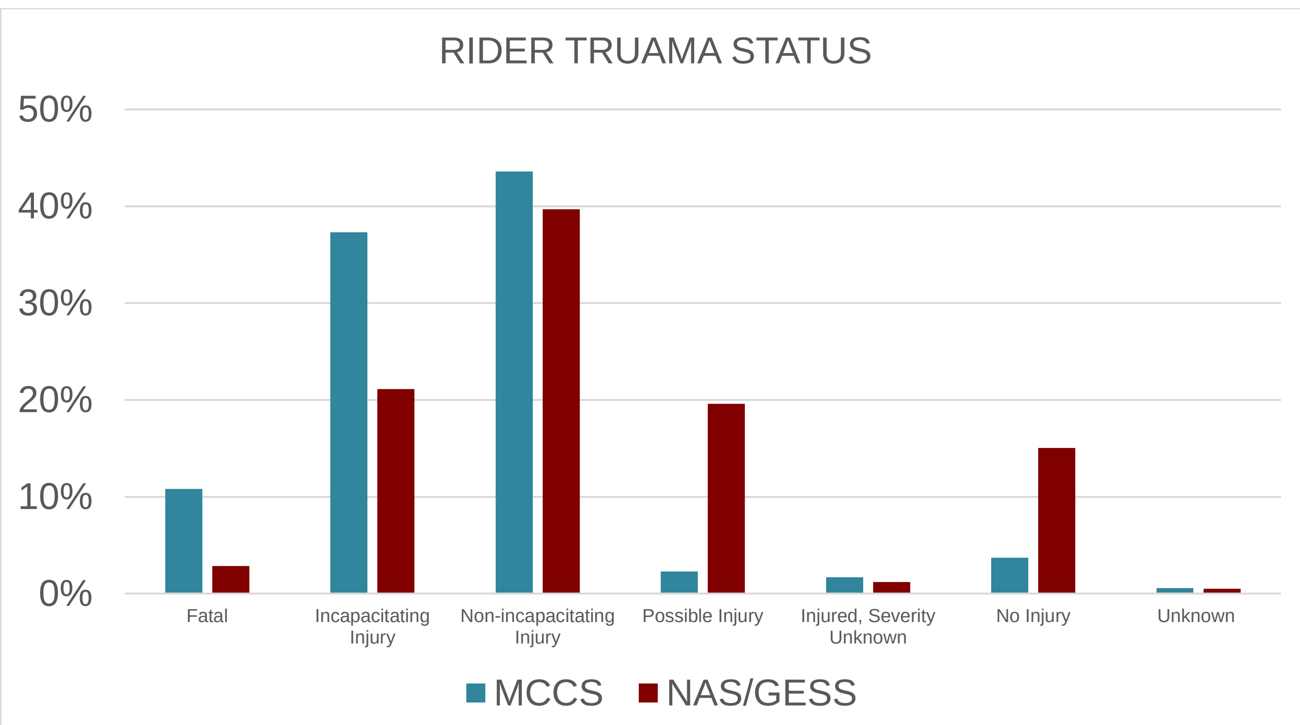
NASS/GES (2011-2015) Accident Data (MAX_SEV)			
Code	Description	Count (weighted)	%
4	Fatal	14,225	2.85
3	Incapacitating Injury	105,639	21.1
2	Non-incapacitating Injury	198,348	39.7
1	Possible Injury	97,919	19.6
5	Injured, Severity Unknown	5,949	1.2
6	No Injury	75,137	15.1
9	Unknown if Injured/Not Reported	2,542	0.4
	Total	499,761	100.0



13. Rider Trauma Status

MCCS Injury Form (IF158_TRAUMASTATUS)			
Code	Description	Count	%
5, 6 ,7	Fatal	38	10.8
3	Hospitalized	131	37.3
2, 8	Treated at scene and hospitalized; Treated at hospital and released	153	43.6
1	First Aid at Scene	8	2.3
99	Unknown	6	1.7
0	No Medical Aid	13	3.7
4, 98	Other	2	0.6
	Total	351	100.0

NASS/GES (2011-2015) Accident Data (MAX_SEV)			
Code	Description	Count (weighted)	%
4	Fatal	14,225	2.85
3	Incapacitating Injury	105,639	21.1
2	Non-incapacitating Injury	198,348	39.7
1	Possible Injury	97,919	19.6
5	Injured, Severity Unknown	5,949	1.2
6	No Injury	75,137	15.1
9	Unknown if Injured/Not Reported	2,542	0.4
	Total	499,761	100.0

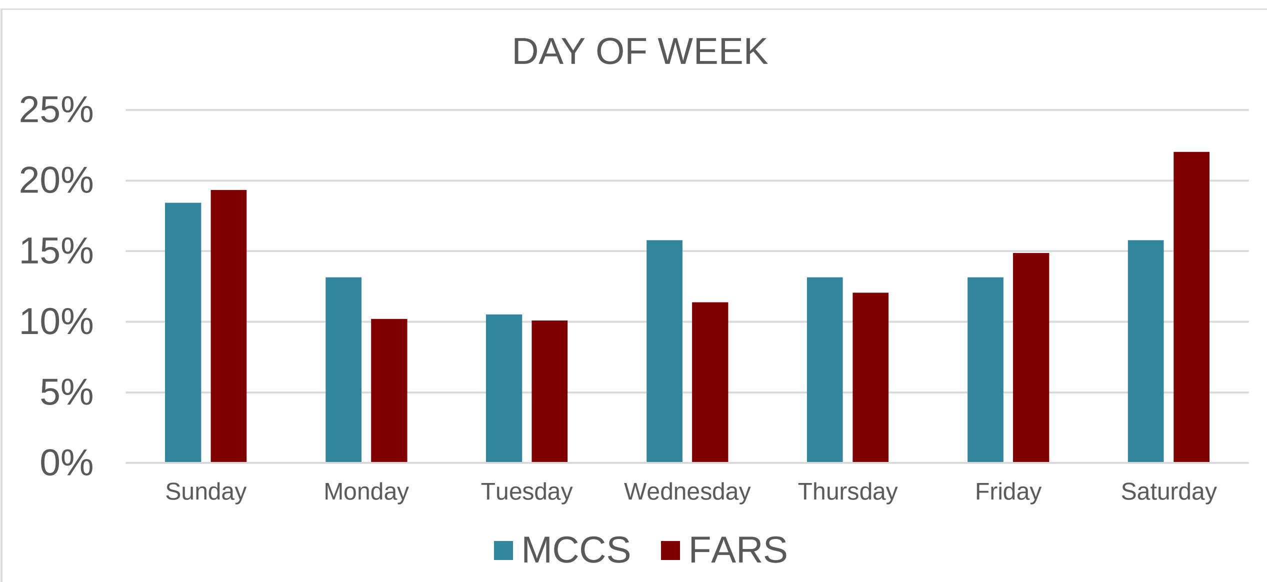


Comparison to FARS

1. Day of the Week

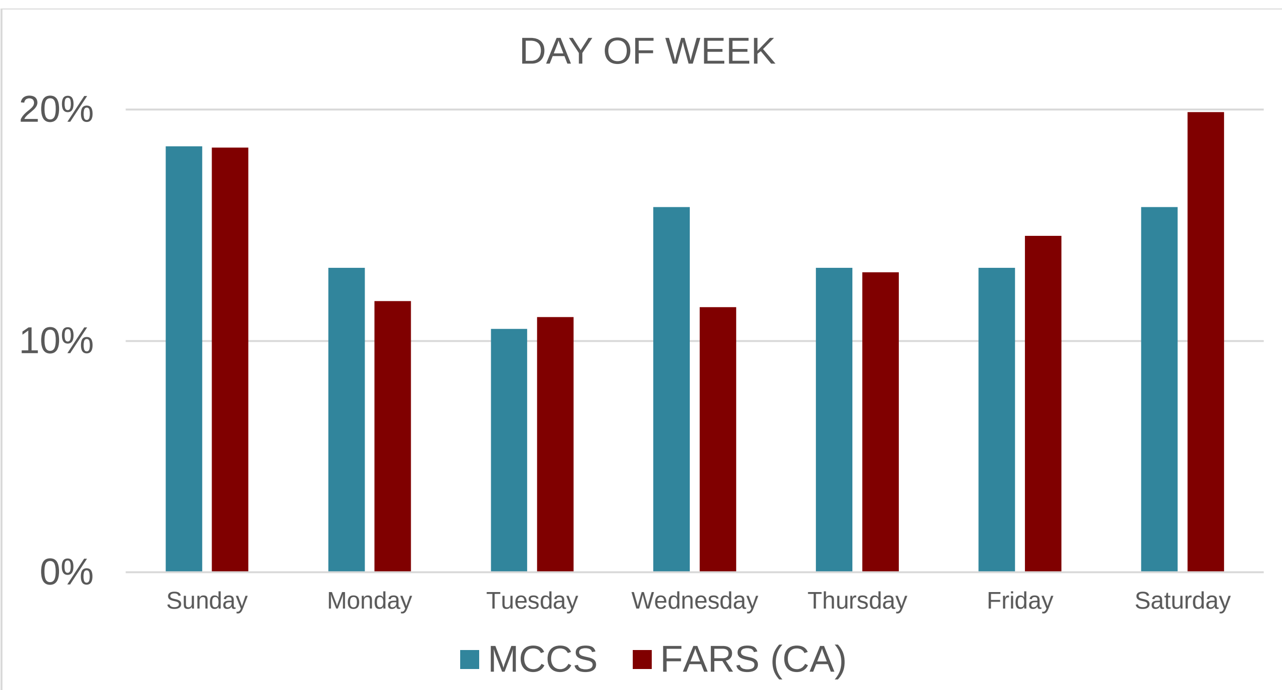
MCCS Crash Form (CF001_CRASHDAY)			
Code	Description	Count	%
07	Sunday	7	18.4
01	Monday	5	13.2
02	Tuesday	4	10.5
03	Wednesday	6	15.8
04	Thursday	5	13.2
05	Friday	5	13.2
06	Saturday	6	15.8
	Total	38	100.0

FARS (2011-2015) Accident Data (DAY_WEEK)			
Code	Description	Count (weighted)	%
1	Sunday	4550	19.3
2	Monday	2402	10.2
3	Tuesday	2372	10.1
4	Wednesday	2679	11.4
5	Thursday	2838	12.1
6	Friday	3499	14.9
7	Saturday	5185	22.0
	Total	23,525	100.0



MCCS Crash Form (CF001_CRASHDAY)			
Code	Description	Count	%
07	Sunday	7	18.4
01	Monday	5	13.2
02	Tuesday	4	10.5
03	Wednesday	6	15.8
04	Thursday	5	13.2
05	Friday	5	13.2
06	Saturday	6	15.8
	Total	38	100.0

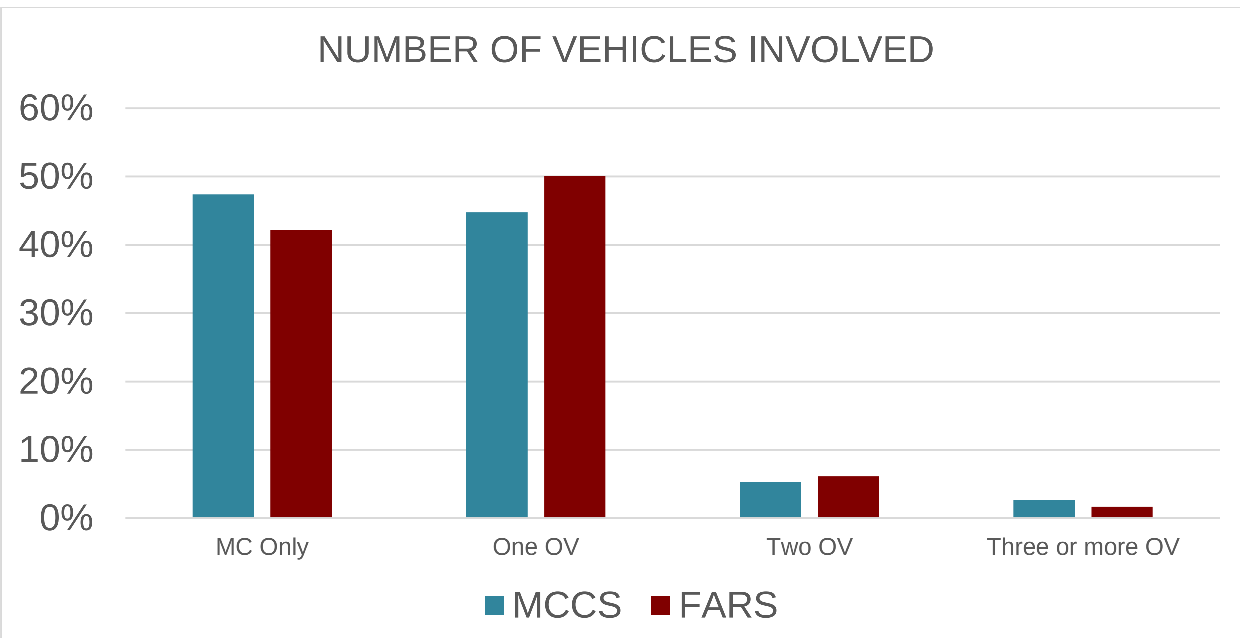
California FARS (2011-2015) Accident Data (DAY_WEEK)			
Code	Description	Count (weighted)	%
1	Sunday	429	18.4
2	Monday	274	11.7
3	Tuesday	258	11.0
4	Wednesday	268	11.5
5	Thursday	303	13.0
6	Friday	340	14.6
7	Saturday	465	19.9
	Total	2,337	100.0



2. Number of Vehicles Involved

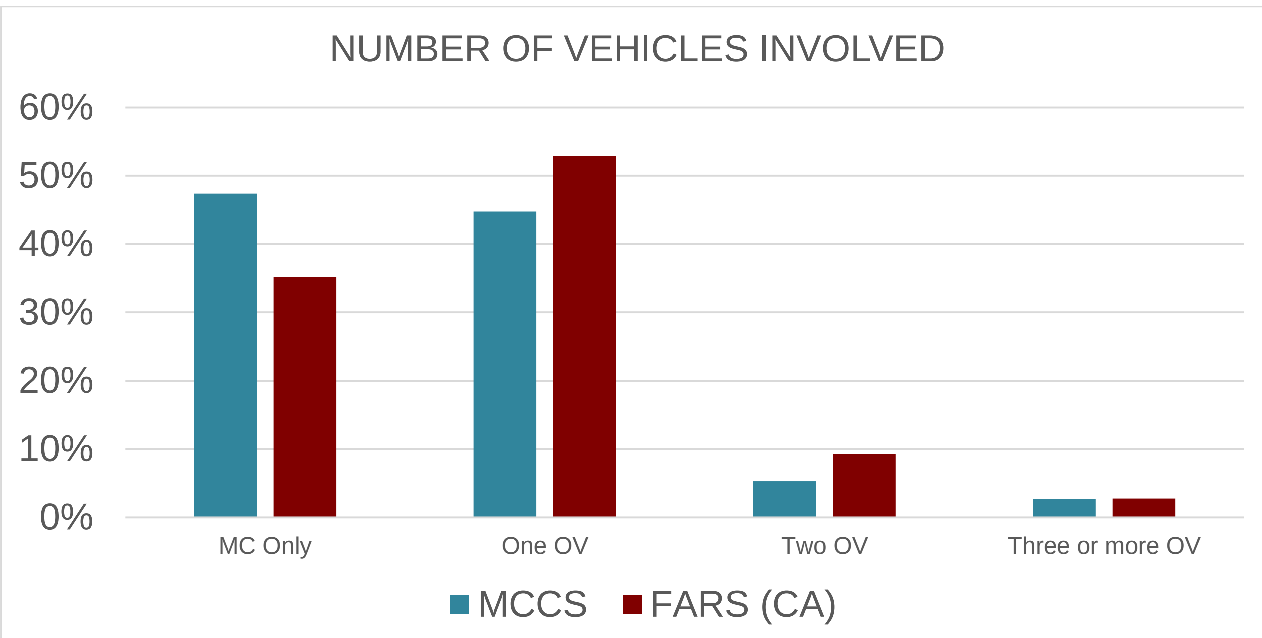
MCCS Crash Form (CF006_OVCOUNT)			
Code	Description	Count	%
00	None	18	47.4
01	One	17	44.7
02	Two	2	5.3
03 and 03+	Three or more	1	2.6
	Total	38	100.0

FARS (2011-2015) Accident Data (VE_TOTAL)			
Code	Description	Count (weighted)	%
1	MC Only	9,916	42.2
2	One OV	11,786	50.1
3	Two OVs	1,433	6.1
4	Three OVs	390	1.7
	Total	23,525	100.0



MCCS Crash Form (CF006_OVCOUNT)			
Code	Description	Count	%
00	None	18	47.4
01	One	17	44.7
02	Two	2	5.3
03 and 03+	Three or more	1	2.6
	Total	38	100.0

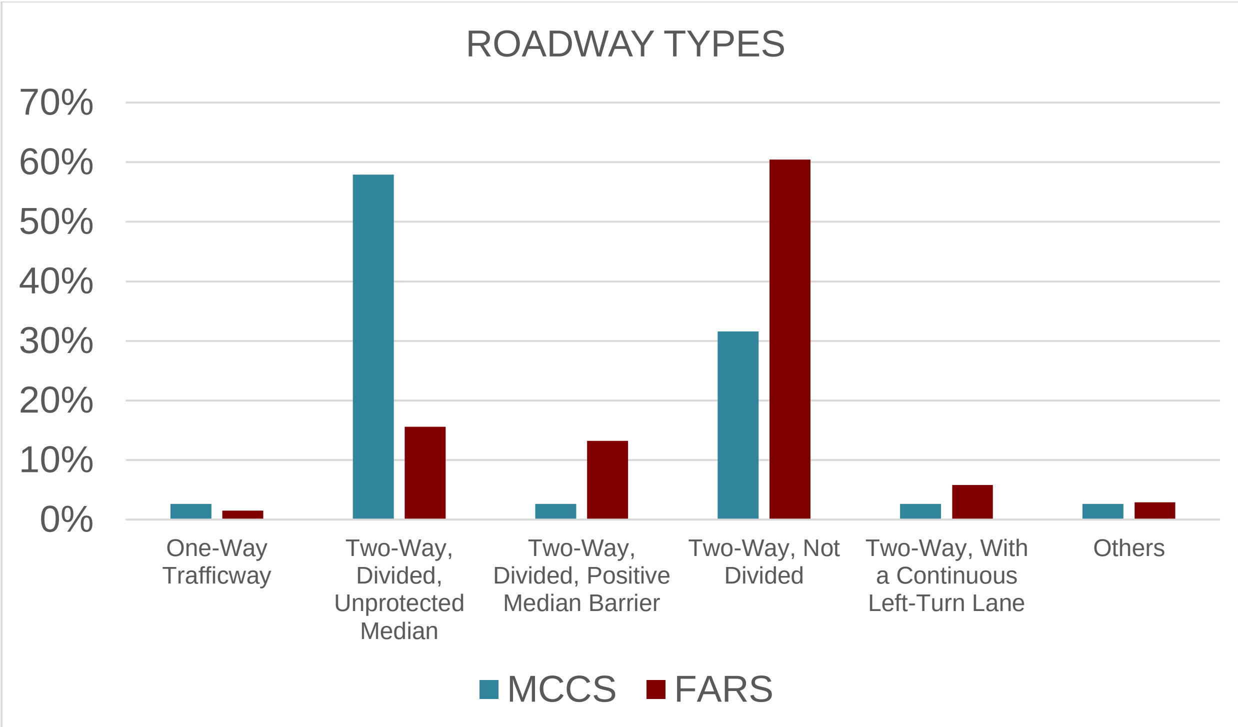
California FARS (2011-2015) Accident Data (VE_TOTAL)			
Code	Description	Count (weighted)	%
1	MC Only	822	35.2
2	One OV	1,235	52.9
3	Two OVs	216	9.2
4	Three or more OVs	64	2.7
	Total	2,337	100.0



3. Roadway Type

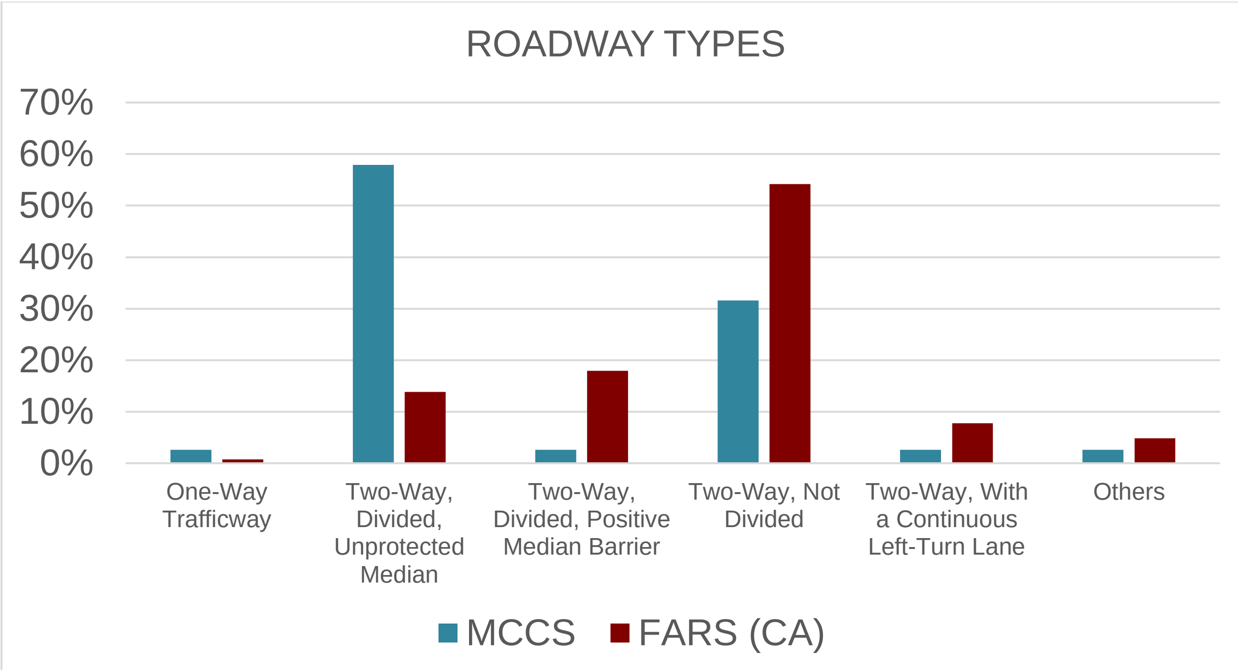
MCCS Environment Form (EF004_TRAFFICPATTERN)			
Code	Description	Count	%
05	One-way	1	2.6
03	Two-way, divided, no median barrier	22	57.9
04	Two-way, divided, with median barrier	1	2.6
01	Two-way, undivided	12	31.6
02	Two-way, with a continuous left-turn lane	1	2.6
98, 99	Other	1	2.6
	Total	38	100.0

FARS (2011-2015) Vehicle Data (VTRAFWAY)			
Code	Description	Count (weighted)	%
4	One-Way Traffic way	360	1.5
2	Two-Way, Divided, Unprotected (Painted > 4 Feet) Median	3,667	15.6
3	Two-Way, Divided, Positive Median Barrier	3,109	13.2
1	Two-Way, Not Divided	14,221	60.5
5	Two-Way, Not Divided With a Continuous Left-Turn Lane	1,364	5.8
6	Other, specify	686	2.9
8, 9	Unknown	118	0.4
	Total	23,525	100.0


ROADWAY TYPES
70%
60%
50%
40%
30%
20%
10%
0%
One-Way Trafficway
Two-Way, Divided, Unprotected Median
Two-Way, Divided, Positive Median Barrier
Two-Way, Not Divided
Two-Way, With a Continuous Left-Turn Lane
Others
MCCS
FARS

MCCS Environment Form (EF004_TRAFFICPATTERN)			
Code	Description	Count	%
05	One-way	1	2.6
03	Two-way, divided, no median barrier	22	57.9
04	Two-way, divided, with median barrier	1	2.6
01	Two-way, undivided	12	31.6
02	Two-way, with a continuous left-turn lane	1	2.6
98, 99	Other	1	2.6
	Total	38	100.0

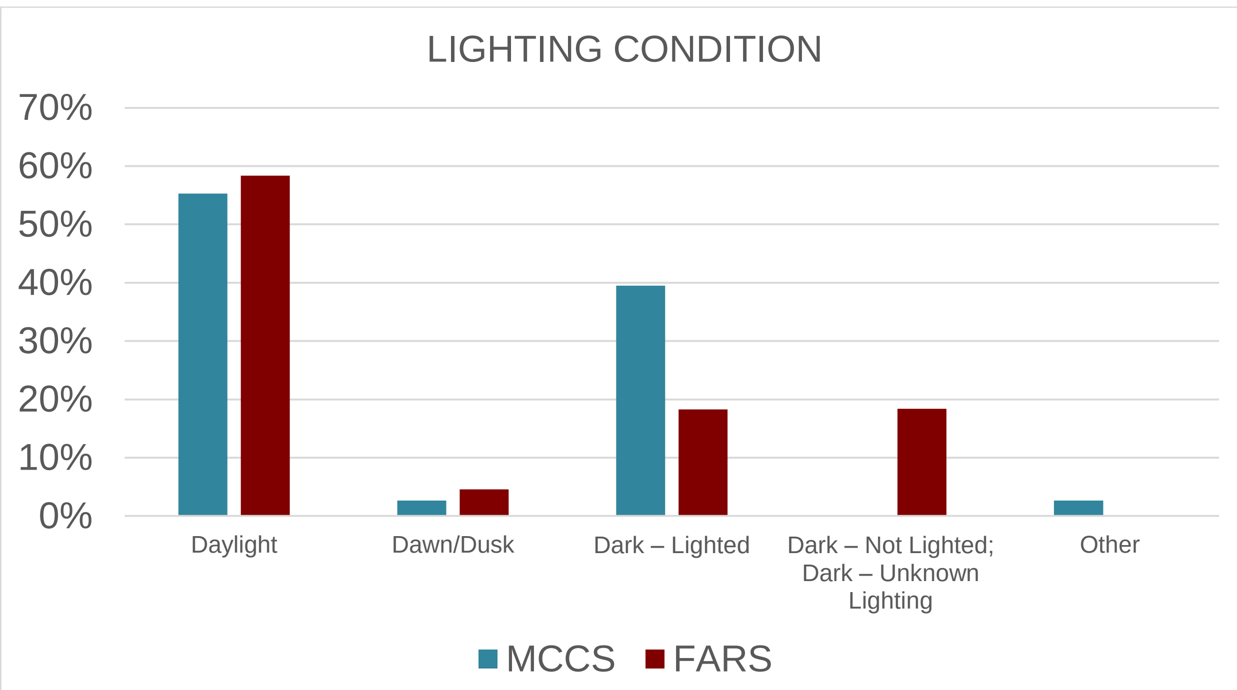
California FARS (2011-2015) Vehicle Data (VTRAFWAY)			
Code	Description	Count (weighted)	%
4	One-Way Traffic way	18	0.8
2	Two-Way, Divided, Unprotected (Painted > 4 Feet) Median	324	13.9
3	Two-Way, Divided, Positive Median Barrier	419	17.9
1	Two-Way, Not Divided	1,266	54.2
5	Two-Way, Not Divided With a Continuous Left-Turn Lane	182	7.8
6	Other, specify	114	4.9
8, 9	Unknown	14	0.6
	Total	2,337	100.0


ROADWAY TYPES
70%
60%
50%
40%
30%
20%
10%
0%
One-Way Trafficway
Two-Way, Divided, Unprotected Median
Two-Way, Divided, Positive Median Barrier
Two-Way, Not Divided
Two-Way, With a Continuous Left-Turn Lane
Others
MCCS
FARS (CA)

4. Lighting Condition

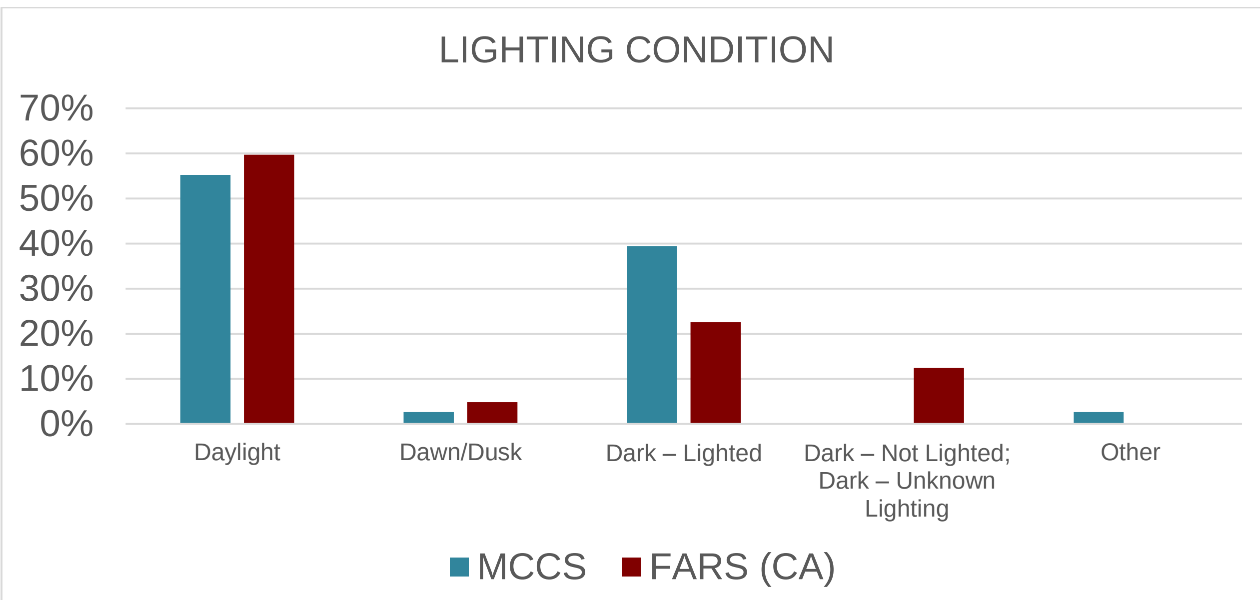
MCCS Crash Form (CF011_AMBIENTLIGHT)			
Code	Description	Count	%
01, 02	Daylight, bright; daylight, not bright	21	55.3
03, 06	Dusk, sundown; Dawn, sunup;	1	2.6
04, 07, 08	Night, lighted; Night, continuous illumination; Night, spot illumination	15	39.5
05	Night, not lighted	0	0.0
98	Other	1	2.6
	Total	38	100.0

FARS (2011-2015) Accident Data (LGT_COND)			
Code	Description	Count (weighted)	%
1	Daylight	13,721	58.3
4, 5	Dawn, Dusk	1,077	4.6
3	Dark - Lighted	4,300	18.3
2	Dark - Not Lighted	4,324	18.4
7	Other	10	0.0
9	Unknown	93	0.4
	Total	23,525	100.0



MCCS Crash Form (CF011_AMBIENTLIGHT)			
Code	Description	Count	%
01, 02	Daylight, bright; daylight, not bright	21	55.3
03, 06	Dusk, sundown; Dawn, sunup;	1	2.6
04, 07, 08	Night, lighted; Night, continuous illumination; Night, spot illumination	15	39.5
05	Night, not lighted	0	0.0
98	Other	1	2.6
	Total	38	100.0

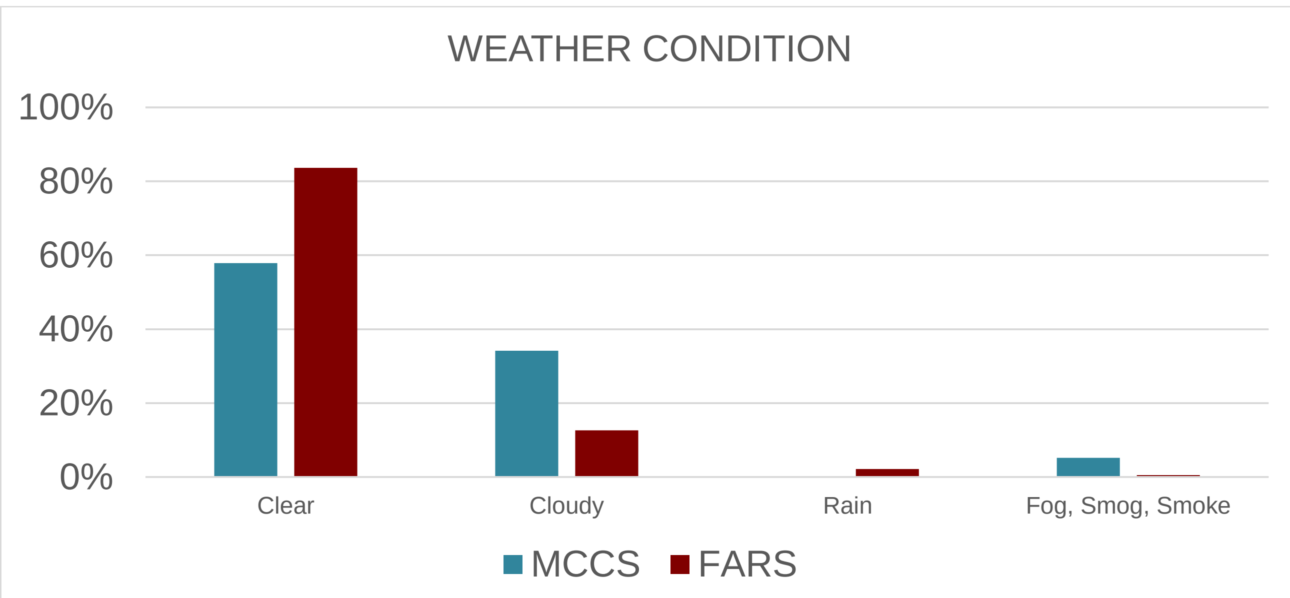
California FARS (2011-2015) Accident Data (LGT_COND)			
Code	Description	Count (weighted)	%
1	Daylight	1,396	59.7
4, 5	Dusk	112	4.8
3	Dark - Lighted	528	22.6
2	Dark - Not Lighted	290	12.4
7	Other	1	0.0
9	Unknown	10	0.4
	Total	2,337	100.0



5. Weather Condition

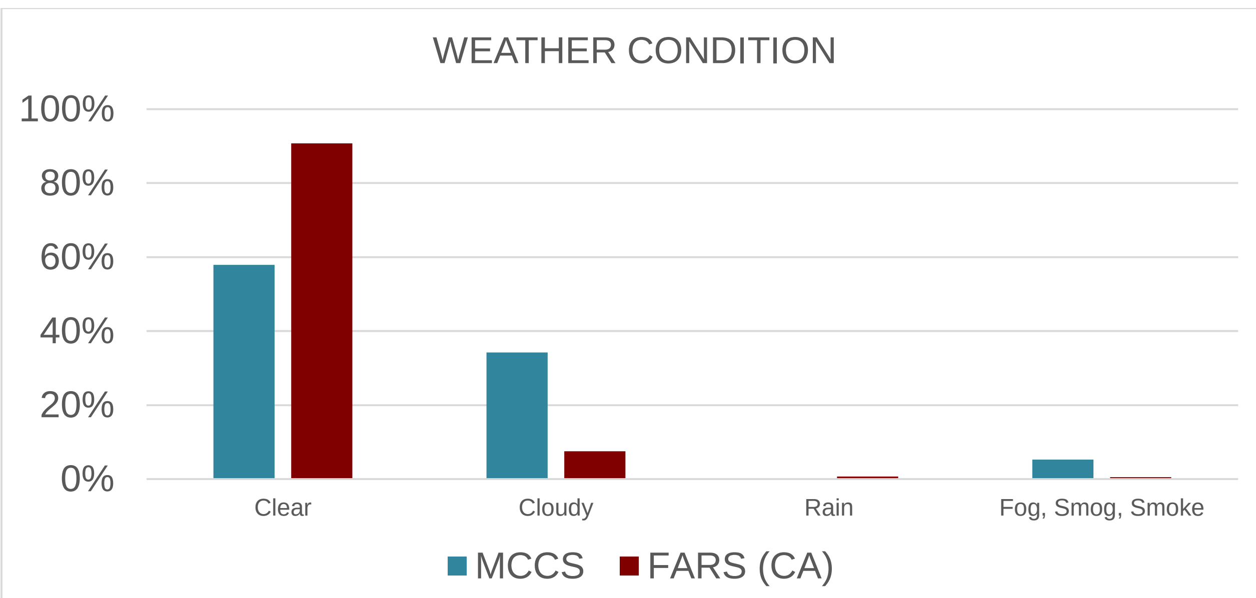
MCCS Crash Form (CF013_WEATHER)			
Code	Description	Count	%
01	Clear	22	57.9
02	Cloudy, partly cloudy	13	34.2
04, 05, 07, 08	Drizzle, light rain; Moderate or heavy rain; Sleet, freezing rain; Hail	0	0.0
03	Overcast	2	5.3
	Total	38	100.0

FARS (2011-2015) Accident Data (WEATHER)			
Code	Description	Count (weighted)	%
1	Clear	19,677	83.6
10	Cloudy	2,974	12.6
2	Rain	516	2.2
5	Fog, Smog, Smoke	134	0.6
3, 4, 11	Sleet, Hail; Snow; Blowing Snow	10	0.0
6, 7, 9, 12,	Others	68	0.3
99	Unknown	146	0.6
	Total	23,525	100.0



MCCS Crash Form (CF013_WEATHER)			
Code	Description	Count	%
01	Clear	22	57.9
02	Cloudy, partly cloudy	13	34.2
04, 05, 07, 08	Drizzle, light rain; Moderate or heavy rain; Sleet, freezing rain; Hail	0	0.0
03	Overcast	2	5.3
	Total	38	100.0

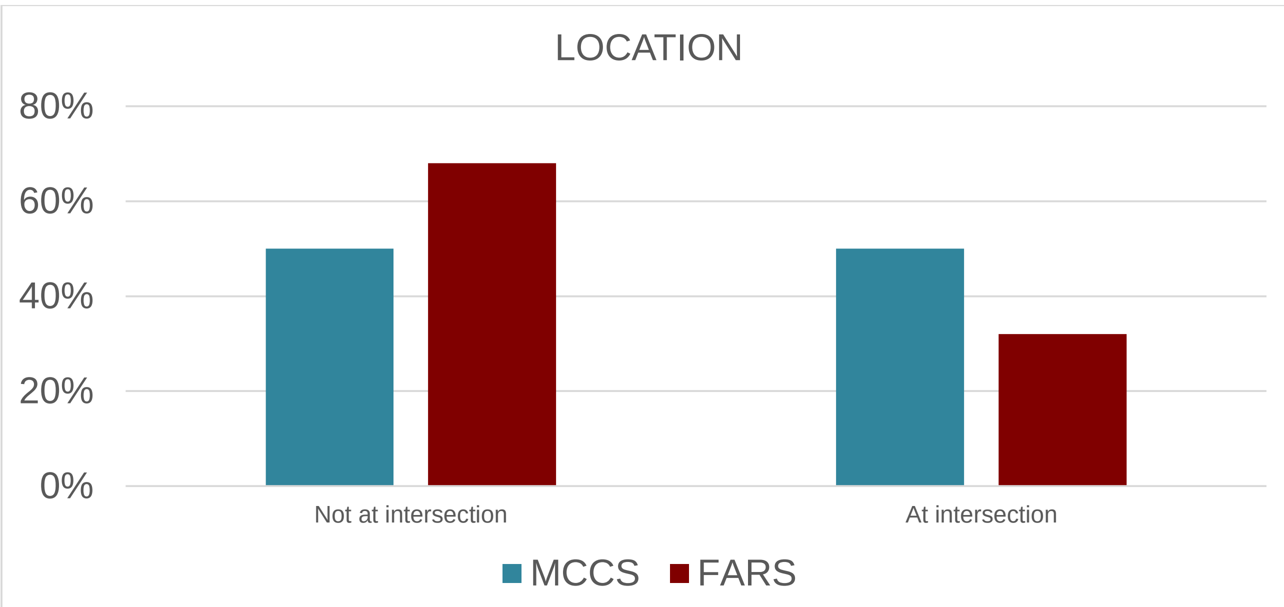
California FARS (2011-2015) Accident Data (WEATHER)			
Code	Description	Count (weighted)	%
1	Clear	2,122	90.8
10	Cloudy	175	7.5
2	Rain	17	0.7
5	Fog, Smog, Smoke	12	0.5
3, 4, 11	Others	4	0.2
6, 7, 9, 12,	Unknown	7	0.3
	Total	2,337	100.0



6. Type of Intersection

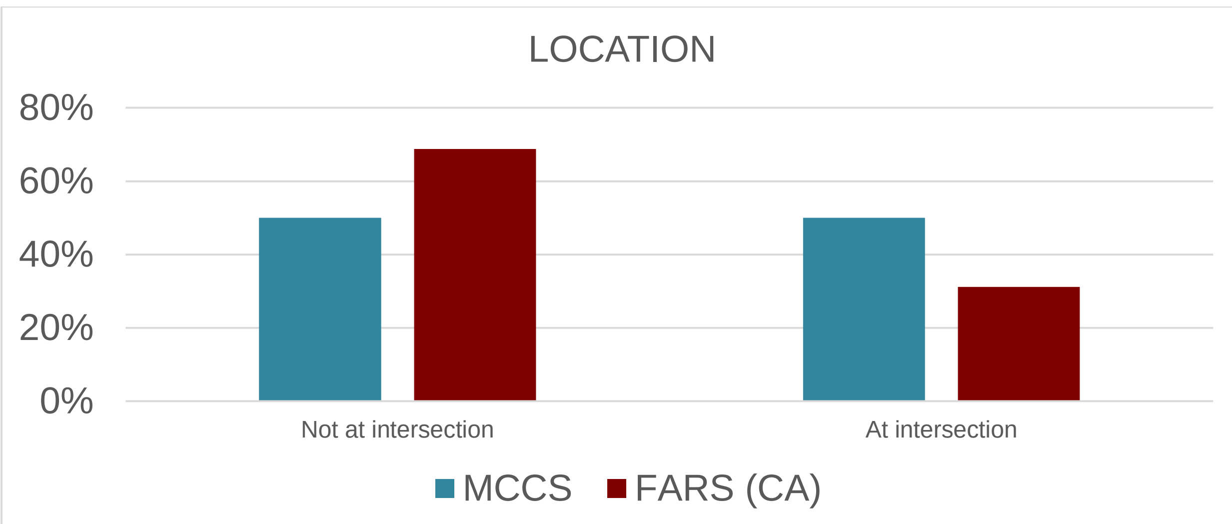
MCCS Environment Form (EF003_INTERSECTIONCONFIG)			
Code	Description	Count	%
00	Not at intersection	19	50.0
01-10	At intersection	19	50.0
	Total	38	100.0

FARS (2011-2015) Accident Data (TYP_INT)			
Code	Description	Count (weighted)	%
1	Not at intersection	15,994	68.0
2-7, 10	At intersection	7,531	32.0
	Total	23,525	100.0



MCCS Environment Form (EF003_INTERSECTIONCONFIG)			
Code	Description	Count	%
00	Not at intersection	19	50.0
01-10	At intersection	19	50.0
	Total	38	100.0

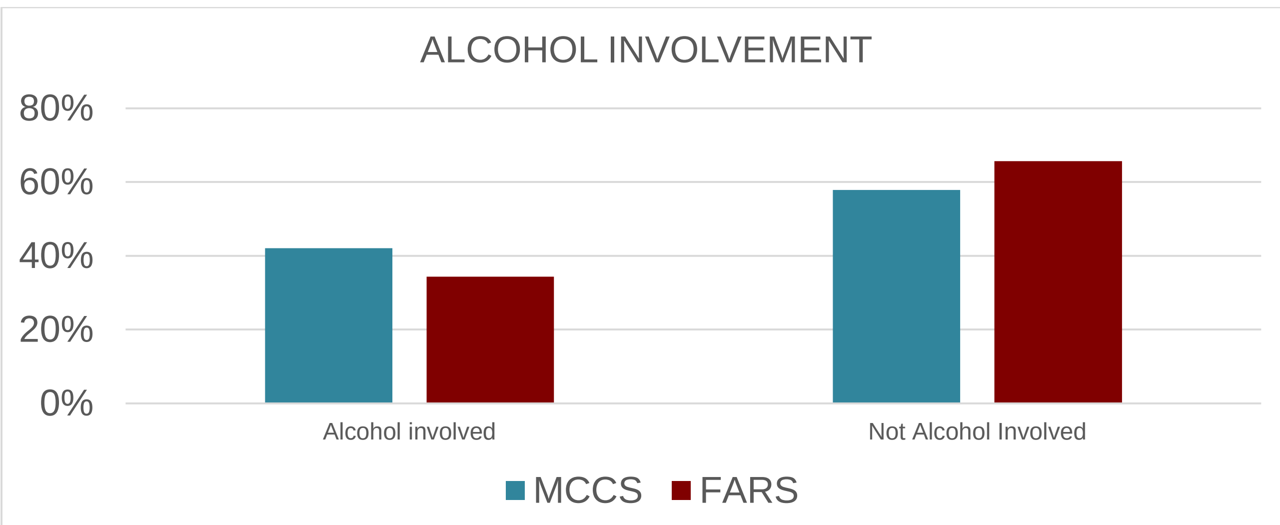
California FARS (2011-2015) Accident Data (TYP_INT)			
Code	Description	Count (weighted)	%
1	Not at intersection	1,608	68.8
2-7, 10	At intersection	729	31.2
	Total	2,337	100.0



7. Alcohol Involvement

MCCS Contributing Factor Form (FF046_MCRDRUGCONTRIBUTION, FF102_MCRDRUGCONTRIBUTION)			
Code	Description	Count	%
01	Alcohol involved	16	42.1
00	Not Alcohol Involved	22	57.9
	Total	38	100.0

FARS (2011-2015) Accident Data (DRUNK_DR)			
Code	Description	Count (weighted)	%
> 0	Alcohol involved	8,074	34.3
0	Not Alcohol Involved	15,451	65.7
	Total	23,525	100.0



MCCS Contributing Factor Form (FF046_MCRDRUGCONTRIBUTION, FF102_MCRDRUGCONTRIBUTION)			
Code	Description	Count	%
01	Alcohol involved	16	42.1
00	Not Alcohol Involved	22	57.9
	Total	38	100.0

California FARS (2011-2015) Accident Data (DRUNK_DR)			
Code	Description	Count (weighted)	%
> 0	Alcohol involved	770	33.0
0	Not Alcohol Involved	1,567	67.1
	Total	2,337	100.0