MINNESOTA DEPARTMENT OF TRANSPORTATION

Motorcycle Crashes in Minnesota

Trends 2012-2014

Katie R. Fleming, M.A.

12/31/2015

Table of Contents

List of Figures

List of Tables

Executive Summary

The findings presented here resulted from analyses of Minnesota Crash Records for 2012-2014. These analyses are exploratory; however, this study aimed to answer specific set of research questions. These questions included:

- What is the age and sex of riders involved in serious motorcycle crashes?
- What is the prevalence of helmet use?
- What are the contributing factors of motorcycle crashes?
- In what types of environments are most associated with motorcycle crashes – urban or rural?
- On what types of roads to most motorcycle crashes take place – local or state owned roads?
- What are the roadway characteristics where most motorcycle crashes occur?
    - What is the posted speed limit?
    - What is the shoulder width?
- What is the relationship with motorcycle crashes and curves in the road?
    - Among serious motorcycle crashes on curves, what is the most prevalent curve radius?
    - On curves where serious motorcycle crashes took place, what traffic safety countermeasures are available?

This study leveraged Minnesota Crash Records, roadway data extrapolated from the Minnesota County Road Safety Plans and Minnesota Department of Transportation District Safety Plans. The Minnesota Department of Transportation Video Log and Google Maps were also leveraged to determine the presence of warning signs and chevrons.

This study found that:

- Males age 21-25 and 51-60 years are over represented in motorcycle fatalities and serious injuries.
- The most prevalent driver behaviors found in fatal motorcycle crashes include: speeding, chemical impairment, and distraction.
- Forty-five percent of multivehicle, fatal and serious injury motorcycle crashes involve a passenger vehicle turning left into the path of an oncoming motorcycle.
- Significantly more motorcycle crashes happen on weekends than weekdays.
- Sixty-four percent of all fatal and serious injury, motorcycle crashes happen on local road systems.
- Fifty-three percent of all fatal and serious injury, motorcycle crashes occur at a non-intersection location.
- Half of all motorcycle fatalities and serious injuries occur in very rural areas, and 77% occur in areas with a population of 50,000 or fewer.
- Nearly half of all fatal and serious injury motorcycle crashes did not involve another motor vehicle.
- Thirty-three percent of all fatal and serious injury motorcycle crashes occur at a roadway curve.
- More than half of all curves investigated had a curve warning sign, 25% had chevrons, and 28% had an advisory speed posted.
- Thirty-eight percent of fatal motorcycle crashes happen on a gentle bend of the road rather than a hairpin turn.

Introduction

This report includes an exploratory analysis of Minnesota motorcycle crashes that occurred from 2012 through 2014. In all, 145 motorcycle riders lost their lives and another 495 sustained life-altering injuries.

Motorcycle riders are considered a vulnerable road user group. According to the American Association of State Highway and Transportation Officials, "[m]otorcycle riding is an activity with special needs and special concerns" (American Association of State Highway and Transportation Officials, 2004). In addition to the task of using the roadway, motorcycle riders must maintain balance of a two-wheeled vehicle that is vulnerable to changes in road surface conditions. Additionally, motorcycle riders do not have a protective shell or seat belts that passenger vehicles offer.

In a case-controlled study of motorcycle rider fatalities, serious injuries, and rider experiences, four areas of need were identified: need for motorcyclist conspicuity, need for optimized braking ability, need for rider control of the motorcycle (rider skill), and need for rider experience (Brown, 2015). This study found similar themes.

Methods

The findings presented here resulted from analyses of Minnesota Crash Records for 2012-2014. These analyses are exploratory; however, this study aimed to answer specific *a priori* research questions. These questions included:

- What is the age and sex of riders involved in serious motorcycle crashes?
- What is the prevalence of helmet use?
- What are the contributing factors of motorcycle crashes?
- In what types of environments are most associated with motorcycle crashes – urban or rural?
- On what types of roads to most motorcycle crashes take place – local or state owned roads?
- What are the roadway characteristics where most motorcycle crashes occur?
    - What is the posted speed limit?
    - What is the shoulder width?
- What is the relationship with motorcycle crashes and curves in the road?
    - Among serious motorcycle crashes on curves, what is the most prevalent curve radius?
    - On curves where serious motorcycle crashes took place, what traffic safety countermeasures are available?

How to Read This Report

This report includes statistical analyses and central tendency analysis. Some common symbols and abbreviations are shown below.

X^2 Indicates the Chi-square statistic associated with a Chi-square test. The Chi-square test is used to measure levels of association between two groups and two outcomes or a 2x2 crosstab comparison.

p Indicates the probability that the statistical analysis can be repeated and find different results. A lower *p* value indicates higher level of certainty in the result.
N Indicates the total number of cases reported in a graph or table.
n Indicates the total number in a given category reported in a graph or table
CI 95% confidence interval

Data Sources

This study leveraged three data sources: crash data, roadway data, and specific site observation data. Crash data used for these analyses originated from the Minnesota Department of Public Safety, crash records system. Crash record data are recorded by the responding officer. All data collected at the crash scene are based on officer observation. For the analyses of fatal crashes at curves section, roadway data were extracted from Minnesota Department of Transportation's county and district safety plan data. These data include measured observation of roadway characteristics such as curve radius, curve length, and location. Site specific observations were conducted using the Minnesota Department of Transportation Video log augmented with observations using Google Maps and Street View. Site specific observations include presence of a curve warning sign, advisory speeds, presence of chevrons, and rough shoulder width in the curve.

While data are available for locations where a fatal motorcycle crash occurred, these analyses did not include a comparison of sites with no history of a motorcycle crash. This means that the analyses are limited to observation rather than identification of causal relationships. Future studies should focus on comparisons of roadway characteristics of locations with a history of a motorcycle crash compared to locations without a motorcycle crash.

Statistical Methods

The analyses included in this report include basic frequency and central tendencies analysis and a two by two crosstabulation with a Chi-square test. Much of the crash data are categorical. The crosstabulation and Chi-square test is a useful analysis for categorical data analyzed and the research questions within this study (IBM Corporation, 2011).

Pearson's Chi-square

$$X_p^2 = \sum_{ij} \frac{(f_{ij} - E_{ij})}{E_{ij}}$$

Notations

X_p^2 Pearson's Chi-square statistic.
E_{ij} Expected cell counts
f_{ij} Sum of case weights in cell *(I,j)*

Motorcyclists and Motorcycle Crashes

Motorcycle riders are vulnerable roadway users due to their lack of a protective shell afforded by a passenger vehicle, lower mass than passenger vehicles, and the physical and cognitive demands of riding a motorcycle. As a result, motorcyclists shoulder a greater risk of injury and death than motor vehicle drivers. Nearly 4% of motorcycle crashes result in a fatality and 12% result in a life altering, serious injury; however, compared to the average distribution of all types of crashes, less than 1% of motor vehicle crashes result in a fatality and 1.3% result in a serious injury.

Table 1: Distribution of motorcycle crashes by injury severity

Injury Severity of Crash	Motorcycle Crashes *N*=3,828	Percent of Motorcycle Crashes	Average Percent of All Crash Types
Property Damage Only	498	13.0%	71.1%
Minor Injury	1162	30.4%	20.1%
Moderate Injury	1530	40.0%	7.2%
Serious Injury	493	12.9%	1.3%
Fatality	145	3.8%	0.5%

Note. All crash types include motorcycle crashes. Average distribution by injury severity includes 2012-2014 crashes.

Most motorcycle drivers involved in a crash are male, and their passengers are typically female. Additionally, 92% of all injury motorcycle crashes involve a male driver while 8% of all injury motorcycle crashes involve a female driver. This disproportionate distribution does not fully correspond to the distribution of registered motorcycle owners by sex.

Table 2: Crosstab of driver and passenger by sex

All injury severity motorcycle crashes	Male	Female
MC Driver	3,536	295
MC Passenger	45	385
χ^2=1930.4219, *p*=0.000		

Among registered motorcycle owners, 88% are males and 12% are female, yet among all injury crashes, 92% of drivers were male and 8% were female. In consideration of the proportion of motorcycles registered to females compared to males, females represent a significantly smaller proportion of drivers injured in crashes.

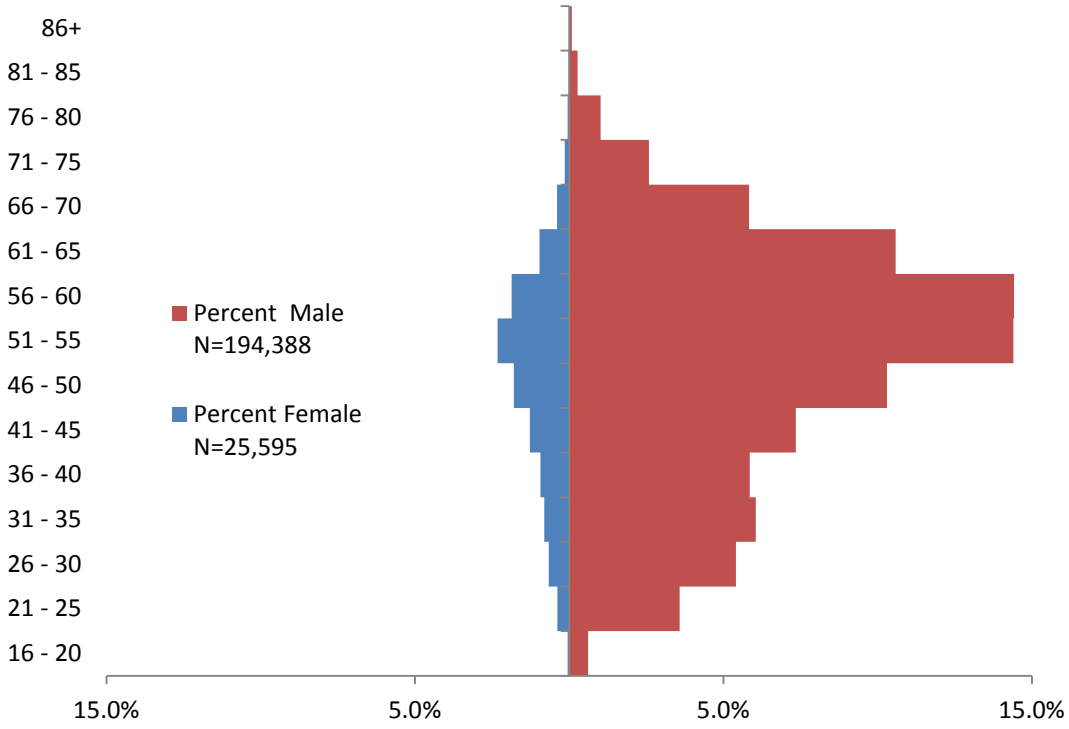
Table 3: Crosstab of registered motorcycle owners and drivers injured in a crash by sex

All injury severity motorcycle crashes	Male	Female
Registered MC Owners	194,388	25,595
MC Drivers Injured	3,536	295
χ^2=14,002,021.615, *p*=0.000		

Males represent a significantly greater percentage of motorcycle drivers killed or seriously injured. While 88% of registered motorcycle owners are male, 94% of motorcycle drivers killed or seriously

injured are male. Among the male registered owners, 29% are between 51-60 years of age and nearly half are 45-65 years of age.

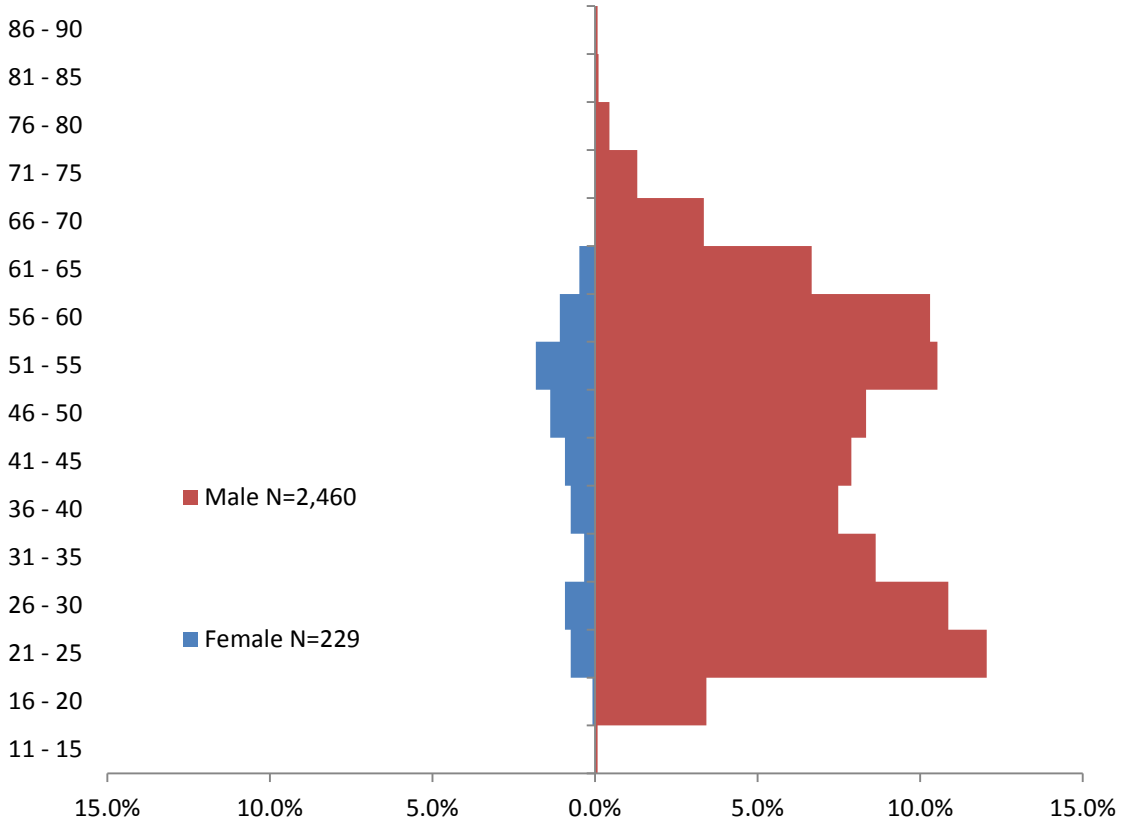
Figure 1: Registered motorcycle owners



Note. This graph shows all registrations set to expire on or before February 2016.

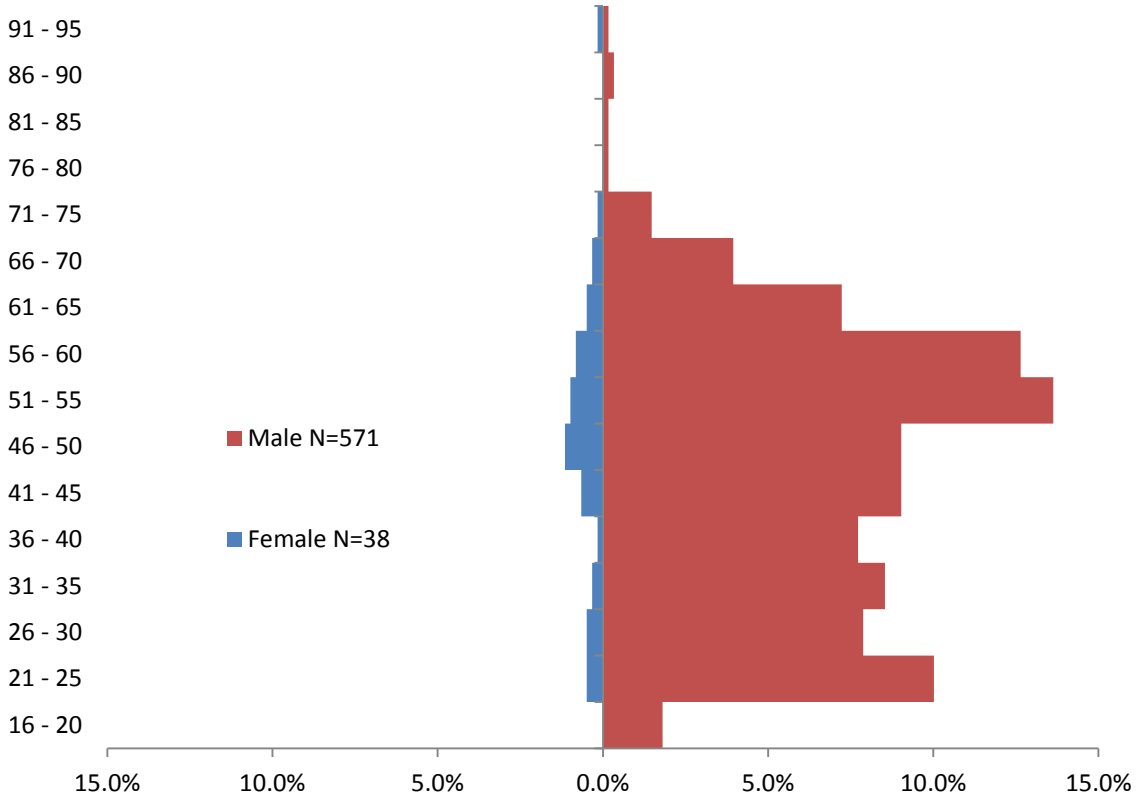
Males account for nearly all motorcycle driver and passenger injuries and fatalities. Male motorcycle drivers sustain ninety-one percent of mild to moderate injuries. Among mild to moderately injured male drivers most fall into the 26-35 and 51-60 year-old age ranges.

Figure 2: Motorcycle drivers mild to moderately injured by age and sex



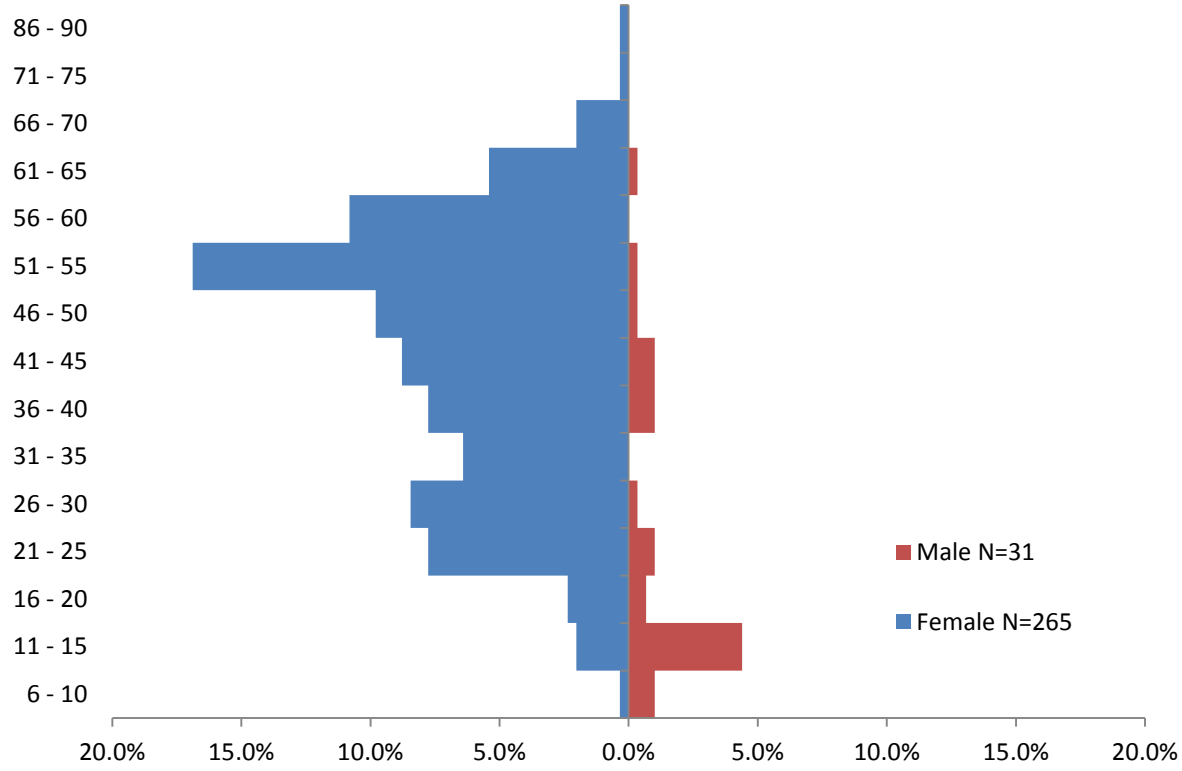
Ninety-four percent of those killed or seriously injured are male. Compared to other age groups, male drivers 21-25 years and 51-60 years old are disproportionately killed or seriously injured.

Figure 3: Motorcycle drivers killed or seriously injured by age and sex



The pattern changes dramatically for motorcycle passengers. Most passengers injured or killed are female. Women 51-55 years old account for most mild to moderate passenger injuries. However, females 21-25 years old account for most fatal and serious passenger injuries.

Figure 4: Motorcycle passengers mild to moderately injured by age and sex



Safety Equipment

Helmet use in all injury severity crashes varies significantly between the driver and the passenger. At the time of the crash, significantly more drivers involved in all injury severity crashes wore a helmet.

Table 4: Crosstab of driver and passenger by helmet use - all severity crashes

All injury severity motorcycle crashes	Known Helmet Used	Known Helmet Not Used
MC Driver	1,365	1,345
MC Passenger	141	189
χ^2=6.8721, *p*=0.008755		

Motorcycle drivers and passengers appear to be equally likely to wear a helmet. At the time of the crash, seventy-one percent of drivers and 70% of passengers involved in a fatal or serious injury crash wore a helmet.

Table 5: Crosstab of driver and passenger by helmet use - fatal and serious injury crashes

All injury severity motorcycle crashes	Known Helmet Used	Known Helmet Not Used
MC Driver	344	142
MC Passenger	47	20
χ^2=0.001, *p*=0.973		

Key Findings

Eighty-eight percent of registered motorcycle owners are male.

Ninety-two percent of motorcycle drivers killed or seriously injured are male.

Males age 21-25 and 51-60 years are over represented in motorcycle fatalities and serious injuries.

Passengers are statistically more likely to be female.

Contributing Factors to a Crash

Driver choices have a major impact on the risk of being involved in a fatal or serious injury crash and severity of injury. Among fatal and serious injury motorcycle crashes, the top five contributing factors are: unsafe or illegal speed, chemical impairment, distraction, skidding, and driver inexperience. Two items to consider when assessing Table 7, one fatal or serious injury crash may have more than one contributing factor and the contributing factor is limited to the responding officer's observations of the crash scene.

Table 6: Contributing factors of fatal and serious injury motorcycle crashes - motorcycle drivers only

Motorcycle driver	*N=660*	%
Unsafe or illegal speed	**133**	**20.2%**
Chemical impairment	**64**	**9.7%**
Distraction/inattention	**55**	**8.3%**
Skidding	**46**	**7.0%**
Driver inexperience	**35**	**5.3%**
Failure to yield right-of-way	26	3.9%
Following too closely	24	3.6%
Other human factor	23	3.5%
Improper lane use	21	3.2%
Over-correcting	21	3.2%
Improper passing	15	2.3%
Over centerline	12	1.8%
Disregard of traffic control device	10	1.5%
Weather	8	1.2%
Improper parking, starting/stopping	6	0.9%
Defective tires	4	0.6%
Vision obscured, other	3	0.5%
Other vehicle defect	3	0.5%
Improper turn	2	0.3%
Non-motorist error	2	0.3%
Defective brakes	1	0.2%

Note. Bold indicates highest frequency of crash type by injury severity group.

Table 8 shows the distribution of physical conditions of motorcycle drivers at the time of the crash. Based on observations at the crash scene, law enforcement officers determine physical condition of the driver. These analyses did not include drug or alcohol test results. Further analyses using test result data may offer a better understanding of the role of alcohol and drug impairment among motorcyclist injuries.

Table 7: Motorcycle driver by physical condition

Physical Condition	Fatal and Serious Injury	All Severity
Normal	384	3138
Under the influence of alcohol or drugs*	94	317
Under the influence	47	173
Had been drinking	45	140
Using drugs	2	4

Note. Under the influence of alcohol or drugs is based on officer's impression at the time of the crash report. This is not confirmed with blood alcohol tests or toxicology tests. The actual number of impaired drivers is expected to be higher than presented here.

Higher speed crashes increase the risk of fatal and serious injury outcomes. These data are limited in that the actual travel speed is not available; however, the documented posted speed limit offers a proxy to assess the relationship between speed and injury outcome. Most motorcycle crashes occur on roads with a posted speed limit of 55 mile per hour roads followed by 30 mile per hour roads. Crashes on roads with a 55 mile per hour posted speed limit, account for 46.6% of fatal and serious injury crashes, 33.1% of moderate to mild injury crashes, and 22.4% of non-injury crashes.

Table 8: Crash injury severity by posted speed limit

Posted Speed Limit	Fatal and Serious Injury Crash		Moderate to Mild Injury Crash		No Injury Crash	
	n=638	%	*n*=2,681	%	*n*=486	%
5mph	0	0.0%	1	0.0%	0	0.0%
10mph	1	0.2%	3	0.1%	2	0.4%
15mph	0	0.0%	9	0.3%	1	0.2%
20mph	0	0.0%	13	0.5%	4	0.8%
25mph	6	0.9%	13	0.5%	4	0.8%
30mph	**134**	21.0%	**764**	28.5%	**209**	43.0%
35mph	29	4.5%	165	6.2%	35	7.2%
40mph	38	6.0%	170	6.3%	40	8.2%
45mph	38	6.0%	174	6.5%	22	4.5%
50mph	38	6.0%	157	5.9%	17	3.5%
55mph	**297**	46.6%	**888**	33.1%	**109**	22.4%
60mph	15	2.4%	138	5.1%	21	4.3%
65mph	29	4.5%	123	4.6%	17	3.5%
70mph	13	2.0%	63	2.3%	5	1.0%

Note. Bold indicates highest frequency of crash type by injury severity group.

Table 10 shows that right angle and run-off-road to the right crashes account for 50% of all fatal and serious injury motorcycle crashes. The right angle crashes account for many of the left turn conflicts shown in Table 11.

Table 9: Crash type by injury severity

Crash Type	Fatal and Serious Injury Crash		Moderate to Mild Injury Crash		No Injury Crash	
	n=497	%	*n*=1,828	%	*n*=393	%
Right Angle	**134**	27.0%	311	17.0%	67	17.0%
ROR Right	**117**	23.5%	**405**	22.2%	26	6.6%
Rear End	69	13.9%	**380**	20.8%	**146**	37.2%
ROR Left	61	12.3%	226	12.4%	21	5.3%
Head-on	51	10.3%	122	6.7%	26	6.6%
Left Turn	35	7.0%	144	7.9%	28	7.1%
Sideswipe Passing	14	2.8%	183	10.0%	60	15.3%
Sideswipe Opposing	14	2.8%	21	1.1%	9	2.3%
Right Turn	2	0.4%	36	2.0%	10	2.5%

Note. Bold indicates highest frequency of crash type by injury severity group.

Table 11 shows the top combined preceding actions by the motorcycle driver and passenger vehicle drivers. The most salient high risk combination of actions includes the motorcycle driver traveling straight forward and the vehicle driver turning left; of these 92 took place at an intersection.

Table 10: Crosstab of motorcycle and vehicle action prior to crash - fatal and serious injury crashes

Motorcycle action	Vehicle Action			
	Traveling straight ahead	Making left turn	Slowing in traffic	Stopped in traffic
	n=84	*n*=104	*n*=10	*n*=15
Traveling straight ahead	**70**	**96**	9	14
Making left turn	10	2	1	0
Passing/overtaking	4	6	0	1

Note. Bold indicates highest frequency of crash type by injury severity group.

Day of Week and Time of Day

Most fatal and serious injury motorcycle crashes occur during the weekend. Figure 5 shows motorcycle crashes by injury severity and the day of the week. Fatal and serious injury motorcycle crashes on Friday, Saturday, and Sunday account for 53% of all fatal and serious injury crashes. This pattern is not consistent for non-motorcycle fatal crashes.

Compared to all other motor vehicle types, most fatal motorcycle crashes take place on the weekends (Saturday or Sunday). On average, fatal motorcycle crashes occur at twice the rate of the average weekday. This pattern does not exist for all other vehicle types. The increased frequency of fatal motorcycle crashes on weekend is significantly greater than weekdays at $p<0.05$.

Key Findings

The most prevalent driver behaviors found in fatal motorcycle crashes include: speeding, chemical impairment, and distraction.

Forty-seven percent of all fatal and serious injury motorcycle crashes happen on a 55 mile per hour road.

Twenty-seven percent of fatal and serious injury motorcycle crashes are right-angle crashes.

Forty-five percent of multivehicle, fatal and serious injury motorcycle crashes involve a passenger vehicle turning left into the path of an oncoming motorcycle.

Figure 5: Crashes by injury severity and day of week

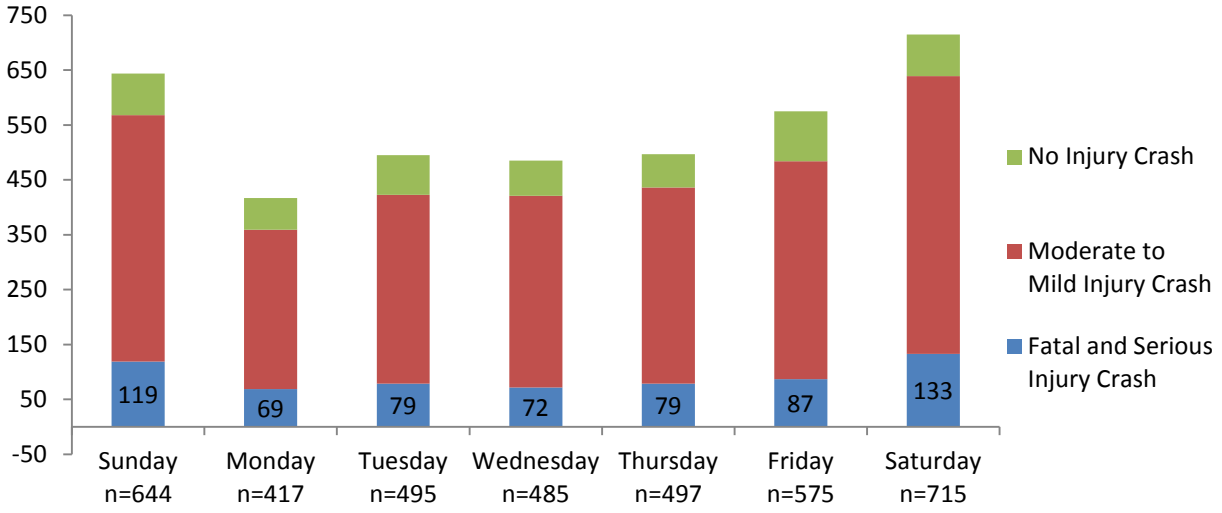
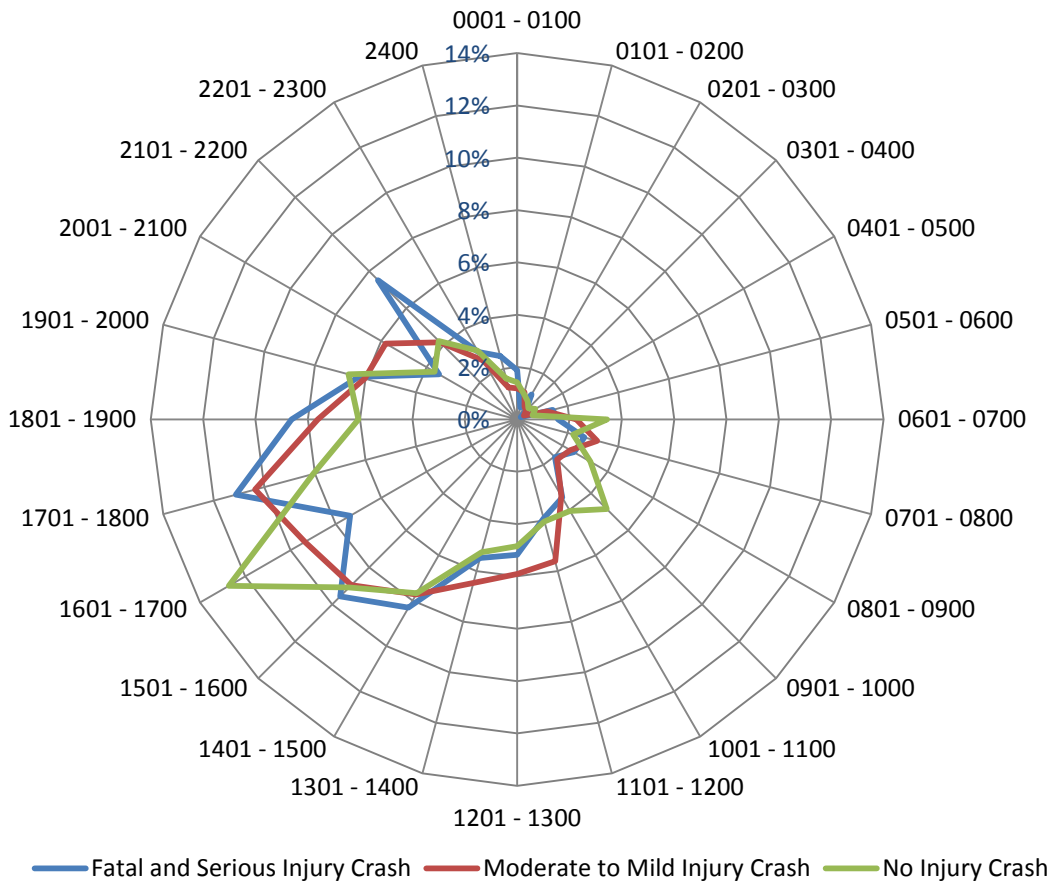


Table 11: Crosstab vehicle type by day of week crash took place

	Average Fatal Crashes Weekdays	Average Fatal Crashes Weekends
Motorcycles	16	32
All other vehicles	128	122
χ^2=5.1476, *p*=0.023279		

Fatal and serious injury crashes spike at three points during the day. The greatest spike occurs between 1701 and 1800 hours (5:01-6:00 pm); 11% of all fatal and serious injury motorcycle crashes occur during this time period. The second highest spike in fatal and serious injury crashes happens between 1501-1600 hours (3:01-4:00 pm), followed by 2101-2300 (9:00-10:00 pm).

Table 12: Crashes by injury severity and hour of the day



Key Findings

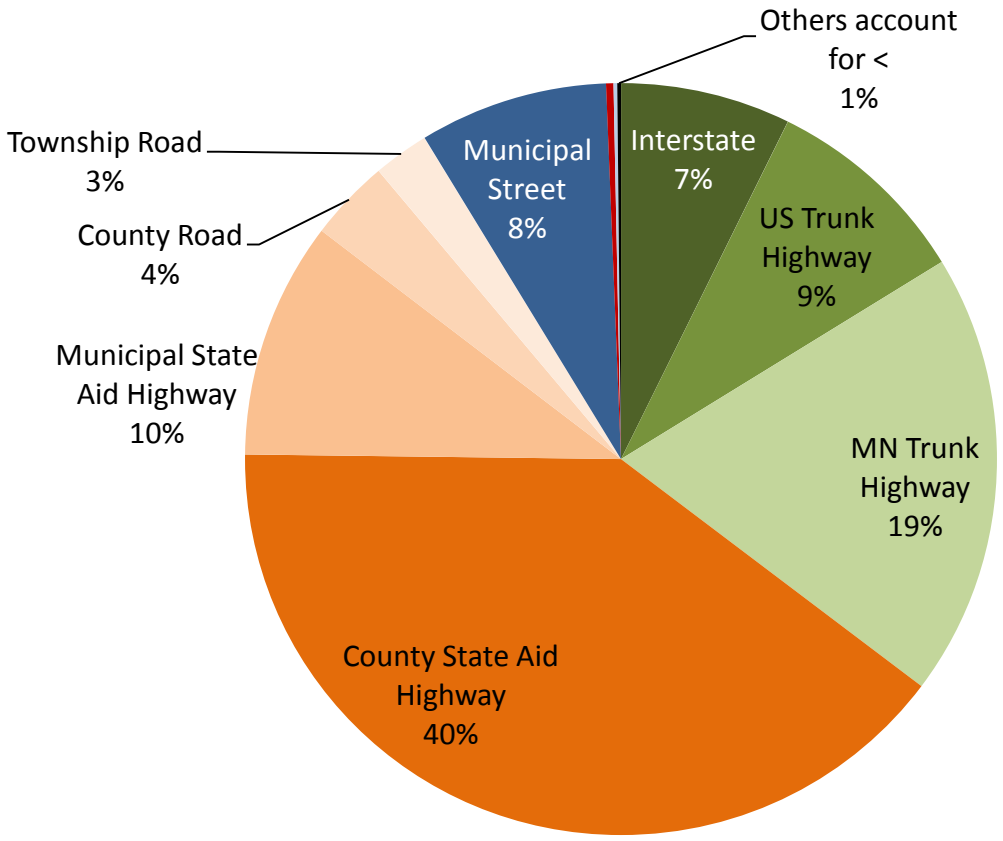
Significantly more motorcycle crashes happen on weekends than weekdays.

Fatal and serious injury motorcycle crashes typically spike from 3:00-4:00 p.m., 5:00-6:00 p.m., and 9:00-10:00 p.m.

Location of Crash

Figure 7 shows the distribution of crashes by road system.[1] Most, 64% of fatal and serious injury motorcycle crashes occur on the local roadway system and 35% of fatal and serious injury crashes occur on state roads.

Figure 6: Motorcycle fatalities and serious injuries by road system



[1] Road system is based on what government entity owns the roadway. For example interstates, US trunk highways, and Minnesota trunk highways are owned by the Minnesota Department of Transportation.

Table 13: Crashes by roadway system

Roadway system	Fatal to serious injury		Mild to moderate injury		Non-injury	
	n=629	%	*n*=2658	%	*n*=483	%
Interstate	46	7.3%	282	10.6%	46	9.5%
US Trunk Highway	56	8.9%	296	11.1%	47	9.7%
MN Trunk Highway	**120**	**19.1%**	**556**	**20.9%**	**98**	**20.3%**
County State Aid Highway	**251**	**39.9%**	**841**	**31.6%**	**131**	**27.1%**
Municipal State Aid Highway	64	10.2%	358	13.5%	83	17.2%
County Road	22	3.5%	67	2.5%	8	1.7%
Township Road	15	2.4%	43	1.6%	3	0.6%
Unorganized Township Road	0	0.0%	1	0.0%	0	0.0%
Municipal Street	51	8.1%	210	7.9%	64	13.3%
National Forest Road	0	0.0%	1	0.0%	0	0.0%
Indian Service Road	2	0.3%	1	0.0%	0	0.0%
Private Road Open	1	0.2%	0	0.0%	0	0.0%
Alleyways	1	0.2%	2	0.1%	3	0.6%

Note. Bold indicates highest frequency of crash type by injury severity group.

Intersections

Most fatal and serious injury motorcycle crashes (53%) are unrelated to an intersection. Among intersection related motorcycle crashes, however, most occur at 4-leg intersections.

Table 14: Motorcycle crashes by intersection relation and injury severity

Intersection Relationship	Fatal and Serious Injury Crash		Moderate to Mild Injury Crash		No Injury Crash	
	n=618	%	*n*=2,594	%	*n*=432	%
Non-junction	**328**	53.1%	**1313**	50.6%	**187**	43.3%
4-leg intersection	**130**	21.0%	**528**	20.4%	**116**	26.9%
T-intersection	**84**	13.6%	**312**	12.0%	**58**	13.4%
Intersection-related	35	5.7%	216	8.3%	35	8.1%
Alley driveway access	17	2.8%	59	2.3%	9	2.1%
Y-intersection	9	1.5%	29	1.1%	7	1.6%
Interchange off-ramp	6	1.0%	35	1.3%	4	0.9%
5+ leg intersection	3	0.5%	15	0.6%	5	1.2%
Interchange on-ramp	3	0.5%	53	2.0%	5	1.2%
Interchange other	3	0.5%	22	0.8%	3	0.7%
Roundabout	0	0.0%	11	0.4%	3	0.7%
RR Xing	0	0.0%	1	0.0%	0	0.0%

Note. Bold indicates highest frequency of crash type by injury severity group.

Most fatal and serious injury motorcycle crashes happen at intersections with a stop sign at the minor legs and through traffic on the major leg followed by signalized intersections. As indicated in Table 11, passenger vehicles that turn left in front of oncoming motorcyclists appear to be a serious threat to motorcyclist safety.

Table 15: Motorcycle crashes by traffic control device and injury severity

Traffic Control Device	Fatal and Serious Injury Crash		Moderate to Mild Injury Crash		No Injury Crash	
	N=196	*%*	*N=880*	*%*	*N=214*	*%*
Stop sign, not all approaches	**113**	57.7%	**379**	43.1%	74	34.6%
Traffic signals	**61**	31.1%	**395**	44.9%	**114**	53.3%
No Passing zone*	11	5.6%	29	3.3%	2	0.9%
Stop sign, all approaches	6	3.1%	28	3.2%	9	4.2%
Yield sign	4	2.0%	39	4.4%	12	5.6%
Overhead flashers	1	0.5%	4	0.5%	0	0.0%
Officer/school patrol	0	0.0%	2	0.2%	1	0.5%
RR Xing, gate	0	0.0%	2	0.2%	0	0.0%
RR Xing, overhead flashers gate	0	0.0%	1	0.1%	2	0.9%
RR Xing, cross buck	0	0.0%	1	0.1%	0	0.0%

Note. Bold indicates highest frequency of crash type by injury severity group.
*Not an intersection related crash

Very few motorcycle crashes occur on bridges. Among fatal and serious injury crashes, only 1.4% took place on a bridge.

Table 16: Crosstab crash on bridge by injury severity

On Bridge?	No	Yes	Percent Yes
	n=3,632	*n*=76	
Non-injury	428	11	2.5%
Mild to Moderate Injury	2,581	56	2.1%
Fatal or Serious Injury	623	9	1.4%

Consideration of Rural Designation

Forty-five percent of all fatal and serious injury motorcycle crashes happen in a location with a population of fewer than 1,000. The table below show motorcycle crashes by injury severity and population range for the crash location. A Chi-square test determines whether one or more group was statistically higher than the others. In this case we see that fatal and serious injury motorcycle crashes are statistically greater in areas with a population below 5,000. What is unknown is whether this is due to prevalence of motorcyclists using rural roads, accessibility and delayed access to medical assistance, or a combination of both.

Key Findings

Sixty-four percent of all fatal and serious injury, motorcycle crashes happen on local road systems.

Fifty-three percent of all fatal and serious injury, motorcycle crashes occur at a non-intersection location.

Among intersection-related fatal and serious injury, motorcycle crashes, 58% occur at a through stop intersection.

Table 17: Distribution of crashes by injury severity and population

Population	Fatal and Serious Injury		Mild to Moderate Injury	
	n=638	%	*N*=2,692	%
4,999 or fewer	**324**	**50.8%**	960	35.7%
5,000-49,999	173	27.1%	898	33.4%
50,000 or more	141	22.1%	834	31.0%
χ^2=50.7298, *p*<0.00001				

Single Vehicle Crashes

Half of all fatal and serious injury motorcycle crashes involve one vehicle – the motorcycle. When considering the complexity of riding a motorcycle with the vulnerability of the rider, this pattern is intuitive. Debris, sand, or gravel can create dangerous situations for a motorcyclist; whereas, a passenger vehicle drivers can navigate with ease. Additionally, the motorcycle rider must balance a vehicle that typically weighs more than the rider.

Table 18: Distribution of crashes by injury severity and number of vehicles

Highest level of injury in crash	Single Vehicle Crashes		Multiple Vehicle Crashes		*Two Vehicle*	*Three or More Vehicles*
	n=1,901	%	*n*=1,932	%		
Property Damage Only	126	6.6%	377	19.5%	*346*	*31*
Mild to Moderate Injury	1,454	76.5%	1,238	64.1%	*1,158*	*80*
Fatal and Serious Injury	**321**	16.9%	317	16.4%	*286*	*31*

Note. Bold indicates highest frequency of crash type by injury severity group.

The most prevalent contributing factors among single vehicle, fatal and serious injury motorcycle crashes include unsafe or illegal speed, chemical impairment, skidding, distraction, and inexperience. Table 25 lists the contributing factors to single vehicle, fatal and serious injury motorcycle crashes; each fatal or serious injury crash may have more than one contributing factor and the contributing factor is limited to the responding officer's observations of the crash scene.

Table 19: Contributing factors of fatal and serious injury, single vehicle motorcycle crashes

Motorcycle Driver	*N*=312	%
Unsafe speed	**79**	**25.3%**
Chemical impairment	**52**	**16.7%**
Skidding	**38**	**12.2%**
Distraction/inattention	**28**	**9.0%**
Driver inexperience	**28**	**9.0%**
Over-correcting	16	5.1%
Improper lane use	13	4.2%
Weather	6	1.9%
Following too closely	5	1.6%
Disregard of traffic control device	3	1.0%
Defective tires	3	1.0%
Failure to yield right-of-way	2	0.6%
Improper passing	2	0.6%
Improper parking, starting/stopping	2	0.6%
Improper turn	2	0.6%
Over centerline	1	0.3%
Vision obscured, other	1	0.3%
Defective brakes	1	0.3%

Note. Bold indicates highest frequency of crash type by injury severity group.

Most single vehicle, fatal and serious injury motorcycle crashes happen on roads with a posted speed limit of 55 miles per hour followed 30 miles per hour – 55% and 17% respectively. Precicely half of these crashes are run-off road right, one third are run-off-road left, and the remaining involve animals, debris, or skidding. Additionally, the majority of single vehicle, fatal and serious injury, motorcycle crashes occur in very rural areas. Table 30 shows that 68% of such crashes happen in areas with a population of 4,999 or fewer.

Table 20: Rural designation of single vehicle, fatal and serious injury motorcycle crashes

Population	*N*=71	%
4,900 or fewer	**48**	**67.6%**
5,000 to 49,999	15	21.1%
50,000 or more	8	11.3%

Note. Bold indicates highest frequency of crash type by injury severity group.

Horizontal curves indicate that the road turns to the left or right; vertical curves indicate that the road is either ascending or descending a grade. Horizontal curves are a known high risk area for motor vehicle crashes. Shockingly, 59.2% of single vehicle, fatal and serious injury motorcycle crashes, occur on a road with hills and/or curves. Horizontal curves account for over half of all single vehicle, fatal and serious injury motorcycle crashes.

Table 21: Curve designation of single vehicle, fatal and serious injury motorcycle crashes

Curve status	*N*=71	%
Straight and level	29	40.8%
Vertical curve	5	7.0%
Horizontal, horizontal and vertical curves	**37**	**52.1%**
Horizontal curve	22	31.0%
Horizontal and vertical curve	15	21.1%

Note[1]. Bold indicates highest frequency of crash type by injury severity group.
Note[2]. Presence of curve as determined by the responding officer

Fatalities on Curves

Curves are particularly high risk locations for motorcycle riders; 33% of fatal and serious injury crashes occur on a horizontal curve, 26% of moderate to mild injury crashes occur on a horizontal curves, and only 13% of non-injury crashes occur on a curve. Significantly more fatal and serious injury crashes occur at locations with vertical, horizontal, and horizontal and vertical curves.

Key Findings

Half of all motorcycle fatalities and serious injuries occur in very rural areas, and 77% occur in areas with a population of 50,000 or fewer.

Nearly half of all fatal and serious injury motorcycle crashes did not involve another motor vehicle

Among single vehicle, fatal and serious injury motorcycle crashes, 67% occur in areas with a population of 4,999 or fewer.

Table 22: Distribution of crashes by injury severity and curve status

Road Characteristics	Fatal and Serious Injury Crash	Moderate to Mild Injury Crash	No Injury Crash
	n=627	*n*=2,623	n=433
Straight and level	336	1,644	329
Vertical curve (hills)	84	280	46
Horizontal curve	121	412	27
Horizontal and vertical curve	86	287	31
χ^2=64.2679, *p*<0.00001			

Most fatal motorcycle crashes at curves occur on local roads; however, the distribution of crashes across curve status and road system is not statistically disproportionate.

Table 23: Distribution of fatal motorcycle crashes by curve status and road system

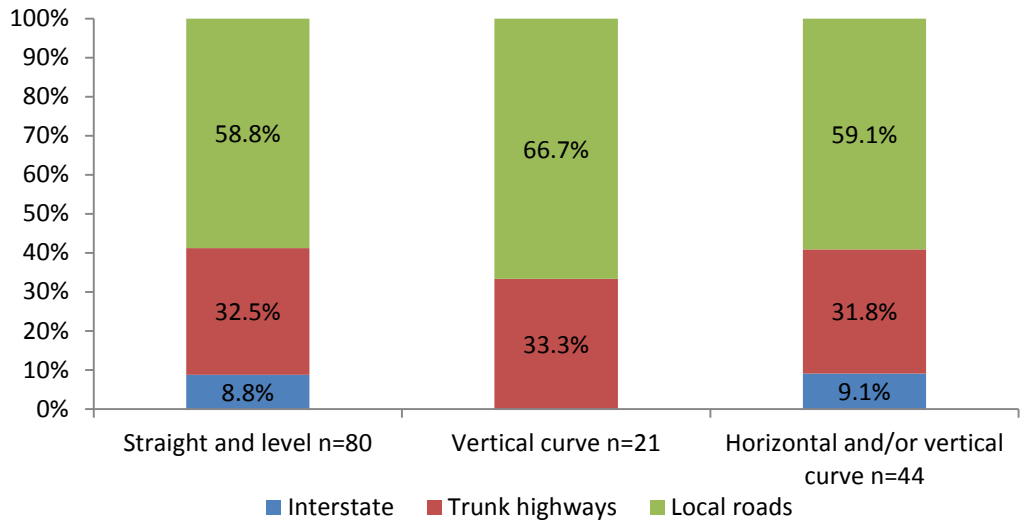


Table 24: Distribution of fatal motorcycle crashes by curve status and road system

Road system	Straight and level *N*=80	Vertical curve *N*=21	Horizontal and/or vertical curve *N*=44
Interstate	7	0	4
US Trunk Highway	9	3	4
MN Trunk Highway	17	4	10
County State Aid Highway	**39**	**8**	**18**
Municipal State Aid Highway	3	0	2
County Road	1	2	2
Township Road	0	1	1
Municipal Street	4	3	3

Note. Bold indicates highest frequency of crash type by injury severity group.

Most motorcycle crashes occur on 2-lane 2-way roads, followed by divided roads.

Table 25: Fatal motorcycle crashes by curve status by roadway type

	Straight and level *N*=78	Vertical curve *N*=20	Horizontal and/or vertical curve *N*=42
Freeway, mainline	8	1	3
Freeway, ramps	1	0	2
Divided, other	9	2	3
One-way	2	0	0
Undivided, 2-lane/2-way	**46**	**13**	**31**
Undivided, 3 lanes	1	0	1
Undivided, 2-6 lanes	11	4	2

Note. Bold indicates highest frequency of crash type by injury severity group.

Most fatal motorcycle crashes happen on roads with a 55 mile per hour speed limit. More than half of fatal motorcycle crashes on a horizontal and or vertical curve happened on roads with a 55 mile per hour speed limit.

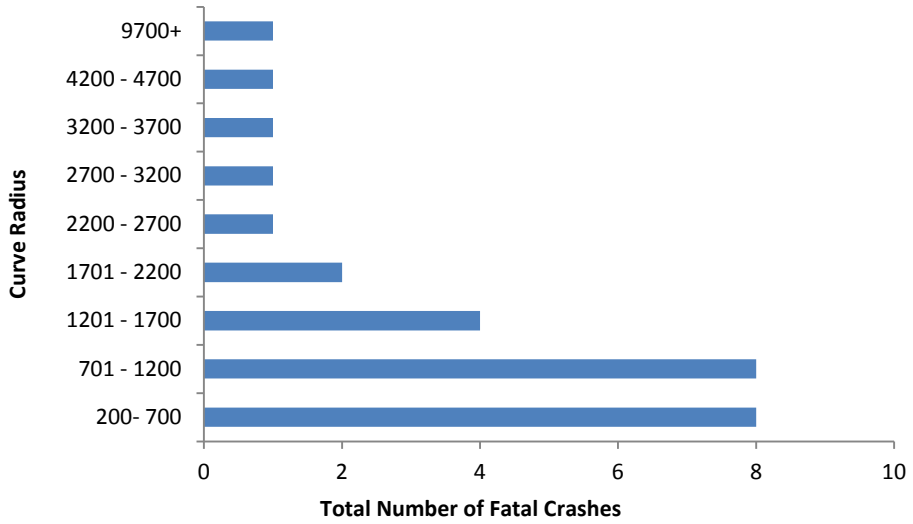
Table 26: Fatal motorcycle crashes by posted speed limit and curve status

Posted speed limit	Straight and level *N*=80	Vertical curve *N*=21	Horizontal, horizontal and/or vertical curve *N*=44
30 mph	11	4	6
35 mph	3	1	1
40 mph	8	0	2
45 mph	4	3	1
50 mph	5	2	2
55 mph	**37**	**10**	**25**
60 mph	3	0	1
65 mph	6	1	5
70 mph	3	0	1

Note. Bold indicates highest frequency of crash type by injury severity group.

Most fatal motorcycle crashes that occur on low radius curves: 30% of fatal crashes occur on a radius of 200-700 feet, 30% of fatal crashes occur on a radius of 701-1,200 feet, and 15% occur on a radius of 1,201-1,700.

Figure 7: Distribution of fatal motorcycle crashes on curve by curve radius



Among fatal motorcycle crashes most drivers were traveling forward prior to the crash. Table 25 shows the driver's action just prior to a fatal crash by the roadway environment – straight and level, vertical curves (hills), or horizontal and/or vertical curves.

Table 27: Fatal motorcycle crashes on curves, driver action prior to crash

Vehicle Action Prior to Crash	Straight and level		Vertical curve		Horizontal, and horizontal and vertical curve	
	n=81	%	*n*=23	%	*n*=42	%
Straight ahead	**61**	**75.3%**	**20**	**87.0%**	**35**	**83.3%**
Right turn	1	1.2%	1	4.3%	2	4.8%
Avoid unit/object	**7**	**8.6%**	1	4.3%	0	0.0%
Slowing in traffic	1	1.2%	0	0.0%	1	2.4%
Changing lanes	2	2.5%	0	0.0%	1	2.4%
Overtaking/passing	4	4.9%	1	4.3%	1	2.4%
Merging	1	1.2%	0	0.0%	1	2.4%

Note. Bold indicates highest frequency of crash type by injury severity group.

Among fatal motorcycle crashes on horizontal curves, 24% result in an overturn followed by collisions with other motor vehicles then an embankment or ditch. More than one third of fatal motorcycle crashes on curves involve a collision with a roadside object such as guardrail, poles, or trees.

Table 28: Most harmful event of fatal motorcycle crashes on curves

Most harmful event on a horizontal, horizontal and vertical curve	*N*=41	%
Overturn/rollover	**10**	**24.4%**
Motor vehicle in transport	**8**	**19.5%**
Embankment/ditch/curb	**7**	**17.1%**
Guardrail	4	9.8%
Sign pole	3	7.3%
Tree/shrub	3	7.3%
Utility pole	1	2.4%
Mailbox	1	2.4%
Hydrant	1	2.4%
Median safety barrier	1	2.4%
Culvert/headwall	1	2.4%

Note. Bold indicates highest frequency of crash type by injury severity group.

Table 27 shows the contributing factors associated with fatal motorcycle crashes on curves. Illegal or unsafe speed is a major contributor to all fatal motorcycle crashes. Speed, chemical impairment, skidding, distraction, and driver inattention are the most prevalent issues at horizontal curves.

Table 29: Contributing factors of fatal motorcycle crashes on curves

Contributing Factor	Straight and level		Vertical curve		Horizontal and horizontal and vertical curve	
	n=83	%	*n*=23	%	*n*=44	%
Failure to yield right-of-way	5	6.0%	0	0.0%	0	0.0%
Illegal or unsafe speed	**17**	**20.5%**	**4**	**17.4%**	**14**	**31.8%**
Over centerline	0	0.0%	2	8.7%	2	4.5%
Improper lane use	0	0.0%	0	0.0%	1	2.3%
Following too closely	3	3.6%	0	0.0%	1	2.3%
Disregard of traffic control device	4	4.8%	0	0.0%	0	0.0%
Improper passing	3	3.6%	0	0.0%	1	2.3%
Improper lane use	2	2.4%	0	0.0%	0	0.0%
Improper turn	1	1.2%	0	0.0%	0	0.0%
Over-correcting	**6**	**7.2%**	0	0.0%	2	4.5%
Distraction/inattention	3	3.6%	0	0.0%	**4**	**9.1%**
Driver inexperience	1	1.2%	**4**	**17.4%**	**4**	**9.1%**
Chemical impairment	2	2.4%	0	0.0%	**7**	**15.9%**
Vision obscured, other	1	1.2%	1	4.3%	0	0.0%
Skidding	1	1.2%	1	4.3%	**5**	**11.4%**

Characteristics of Roadway Curves

Out of 145 fatal motorcycle crashes, law enforcement officers designated 44 crashes as having occurred on a horizontal or horizontal and vertical curve. Among those crashes, roadway characteristic data were available for 47 curves. Among those data are: shoulder type, shoulder width, presence of an advisory speed limit, presence of a curve warning sign, presence of chevron signs, curve length, and curve radius.

Due to limitations within the data available, these analyses offer no conclusive causal relationship between a roadway characteristic and a fatal motorcycle crash. These analyses are limited to the roadway characteristics present for fatal motorcycle crashes on curves. These analyses do not indicate any causal relationship between one or more road characteristic with fatal motorcycle crashes. Further analyses are required to determine causal relationships and risk associated with specific road characteristics.

Road shoulders offer a safe location for a vehicle to come to a stop or serve as an emergency refuge. For these analyses, we investigated three basic road shoulder types – paved, gravel, and composite. A Composite shoulder includes gravel and paved shoulders.

Key Findings

Thirty-three percent of all fatal and serious injury motorcycle crashes occur at a roadway curve.

Fifty-three percent of all fatal and serious injury, motorcycle crashes occur at a non-intersection location.

Nearly half of all fatal and serious injury motorcycle crashes did not involve another motor vehicle

Table 30: Road shoulder type found on curves with one or more fatal motorcycle crash

Shoulder type at curve	*N*=47	%
Composite (combination of gravel and paved)	**30**	**63.8%**
Gravel	1	2.1%
Paved	13	27.7%
None	3	6.4%

Note. Bold indicates highest frequency of crash type by injury severity group.

Shoulder width was determined using visual examination of roadway video data. While this may not be a highly accurate method, we have enough information to determine whether a shoulder is available, relatively narrow, moderate, or relatively wide.

Table 31: Road shoulder width found on curves with one or more fatal motorcycle crash

Shoulder width at curve	*N*=47	%
No shoulder	3	6.4%
4 foot shoulder	3	6.4%
6 foot shoulder	11	23.4%
8 foot shoulder	**14**	**29.8%**
10 foot shoulder	10	21.3%
12 foot shoulder	6	12.8%

Note. Bold indicates highest frequency of crash type by injury severity group.

Curve warning signs, such as the one shown in Figure 9, warn drivers of a horizontal curve ahead. Within the subsample of roadway data, a curve warning sign was present at most curves where a motorcycle fatality occurred.

Table 32: Presence of curve warning signs at curves with one or more motorcycle fatality

Curve warning sign present	*N*=47	%
Yes	**26**	**55.3%**
No	21	44.7

Note. Bold indicates highest frequency of crash type by injury severity group.

Figure 8: Curve warning sign

Chevrons assist drivers as they traverse a horizontal curve. Among curve locations where a motorcycle crash occurred, only 25.5% had chevrons present.

Figure 9: Chevron sign

Table 33: Presence of chevrons at curves with one or more motorcycle fatality

Chevrons present	*N*=47	%
Yes	12	25.5%
No	**35**	**74.5%**

Note. Bold indicates highest frequency of crash type by injury severity group.

Advisory speed signs suggest the safest speed at which a driver can navigate a curve. An advisory speed is not a legal posted speed limit. Traffic engineers determine the advisory speed of a curve based on guidance found in the Minnesota Manual on Uniform Traffic Control Devices (Minnesota Department of Transportation, 2011). The criteria for an advisory speed include curve radius, side friction, and super elevation. Not all curves require an advisory speed. Most fatal motorcycle crashes occurred on curves with no advisory speed.

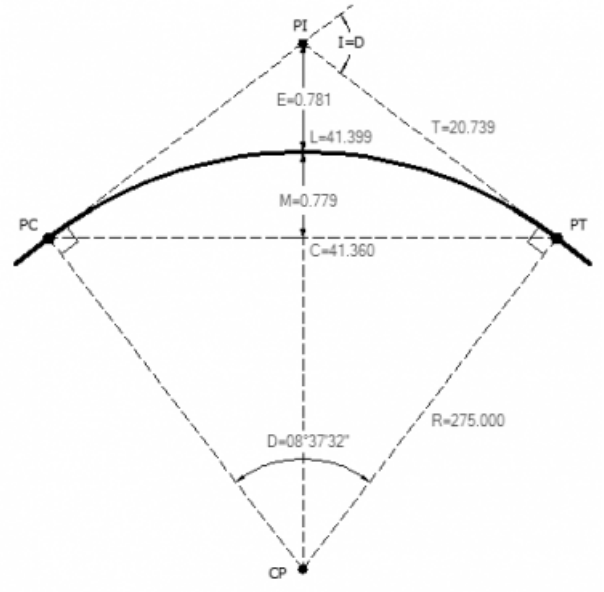
Table 34: Motorcycle fatalities by advisory speeds at curves and roadway posted speed limit

Posted Speed Limit	Advisory Speed					
	25 mph	30 mph	35 mph	45 mph	50 mph	None
	n=3	*n*=1	*n*=1	*n*=5	*n*=3	*n*=34
30 mph *n*=6	2	0	0	0	0	**4**
35 mph *n*=1	1	0	0	0	0	0
40 mph *n*=2	0	0	0	0	0	2
45 mph *n*=1	0	0	0	0	0	1
50 mph *n*=2	0	1	0	0	0	1
55 mph *n*=28	0	0	1	**4**	**3**	**20**
60 mph *n*=1	0	0	0	0	0	1
65 mph *n*=5	0	0	0	1	0	**4**
70 mph *n*=1	0	0	0	0	0	1

Note. Bold indicates highest frequency of crash type by injury severity group.

Figure 11 shows how curve radius is determined. Curve radius informs the size of the turn required by a driver, but radius alone does not tell us how long the driver is turning. For a subsample of curves both curve radius and curve length were available. In order to address feedback from motorcycle safety advocates who wanted a greater understanding of how curve radius looks in the field, we developed the percent of circle calculation.

Figure 10: How roadway curve radius is calculated



This was calculated based on a very simple calculation of percent of a full circle.

$$PoC = l/(2 \times \pi \times r)$$

PoC	Percent of circle
l	Length of curve
r	Radius of curve

The percent of circle offers a novel approach to analyses of curve characteristics. The following graph shows the amount of a circle that each of the curves analyzed account for. A curve that covers 25% of a circle indicates a full right or left turn (or a 90^0 turn) and 50% of the circle indicates a full U-turn (or a 180^0 turn).

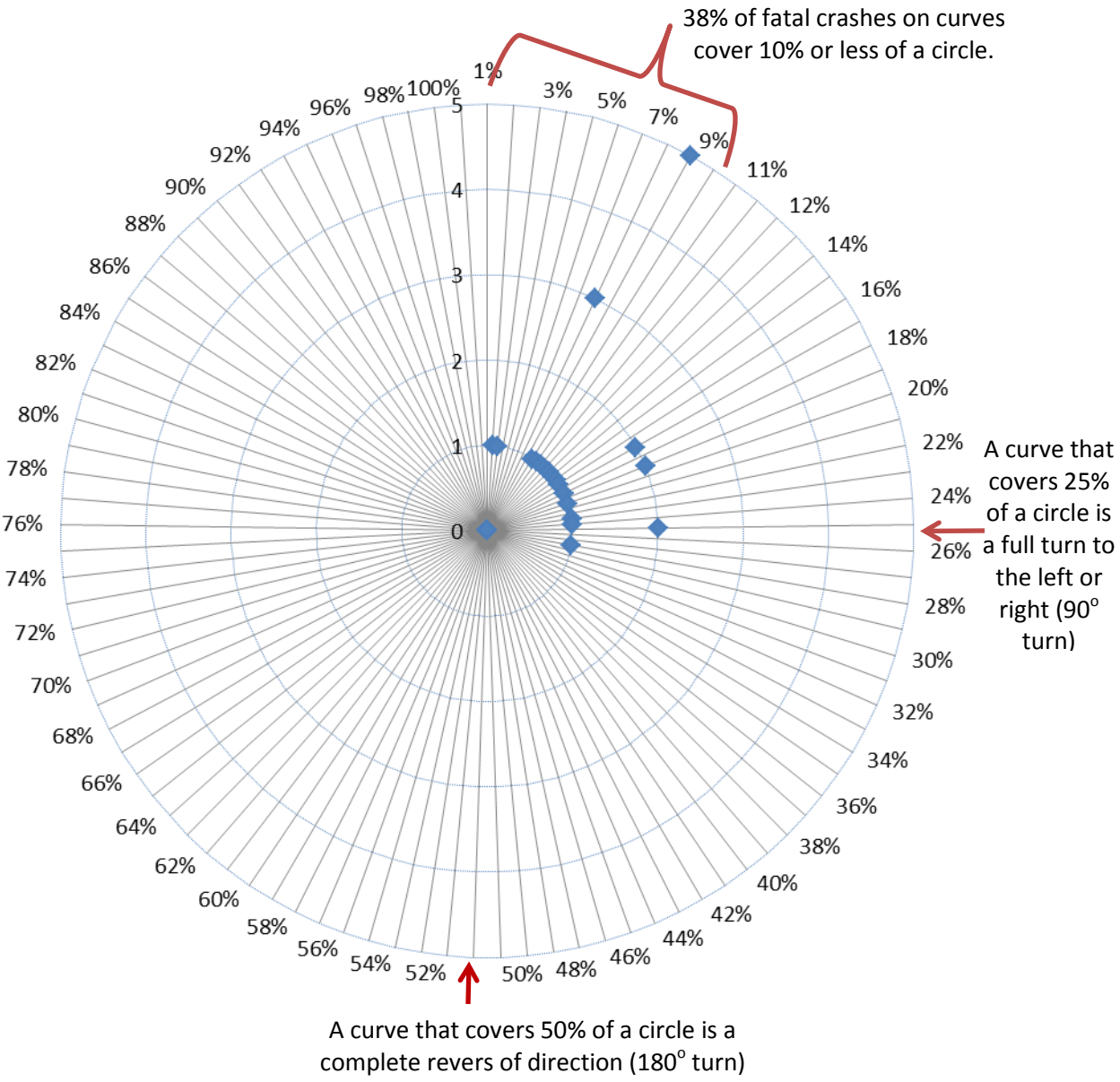


Figure 11: Percent of circle traversed in curves where a fatal motorcycle crash occurred *N*=29

Most fatal motorcycle crashes occurred on curves that account for 20% or less of a circle. This means that most of these curves are not 'hairpin' type curves commonly associated with risk. Rather the roadway gently drifts to the right or left for as much 38% of the crash locations. The remaining majority, 45% involve a curve that is less than a full turn to the right or left (or a 90° turn).

Table 35: Fatal motorcycle crashes at curves by percent of circle

Percent of Circle	*N*=29	%
1-10 percent	11	37.9%
11-20 percent	**13**	**44.8%**
21-30 percent	5	17.2%

Figure 12: A curve that accounts for eight percent of a full circle

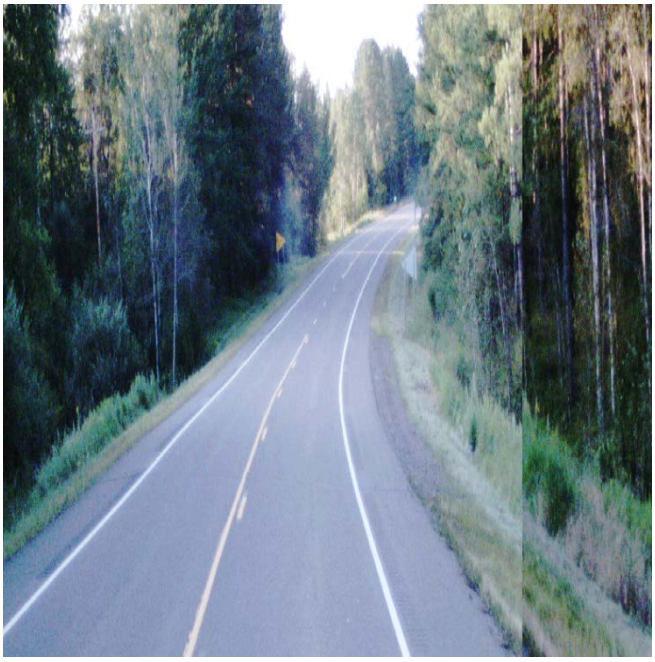


Figure 13 shows a curve that covers eight percent of a full circle. This image shows Minnesota Trunk Highway 23 in Carlton County, Minnesota. The curve radius here is 881 feet. Figure 14 shows a 20% curve found on Minnesota Trunk Highway 13 in Waseca County, MN. The curve radius here is 1,950 feet.

Curve radius alone does not offer an understanding of how a curve *feels* for the road user. While percent of circle is not a standard engineering measure to identify risk, for these purposes, it offers a better understanding of the driver's experience on a curve.

Figure 13: A curve that accounts for twenty percent of a full circle

A large percentage of fatal motorcycle crashes occurred on a relatively mild curve. Thirty-eight percent of fatal motorcycle crashes happen on a curve similar to that depicted in Figure 13. Forty-five percent of fatal motorcycle crashes happen on curves similar to that depicted in Figure

Key Findings

More than half of all curves investigated had a curve warning sign, 25% had chevrons, and 28% had an advisory speed posted.

Thirty-eight percent of fatal motorcycle crashes happen on relatively mild curves.

Conclusions and Recommendations

- Nearly 4% of motorcycle crashes result in a fatality and 12% result in a life altering, serious injury; however, compared to the average distribution of all types of crashes, less than 1% of motor vehicle crashes result in a fatality and 1.3 5 result in a serious injury.
- In consideration of the proportion of motorcycles registered to females compared to males, females represent a significantly smaller proportion of drivers injured in crashes. Males bear a greater risk of being involved in a motorcycle crash; male motorcycle drivers are 1.6 times more likely to be involved in a motorcycle crash than females
- Ninety-four percent of those killed or seriously injured are male. Compared to other age groups, male drivers 21-25 years and 51-60 years old are disproportionately killed or seriously injured.
- Crashes at higher travel speeds increase the risk of serious injury or fatality; 56% of all serious injury and fatal motorcycle crashes happen on roads with a posted speed limit of 55 miles per hour or higher
- Among fatal and serious injury, motorcycle crashes, 27% are right angle crashes and 24% are road departure to the right crashes.
- Among fatal and serious injury, motorcycle crashes, 47% occur at an intersection
    - Sixty-eight percent involve a through stop intersection (stop sign on one or more, but not all approaches).
    - Thirty-one percent involve a traffic signal.
- Among fatal and serious injury, multivehicle motorcycle crashes most passenger vehicles make a left turn into the path of an oncoming motorcycle. This warrants further investigation.
    - Do oncoming passenger vehicle drivers have difficulty judging oncoming speed and distance of a motorcycle?
    - Do passenger vehicles drivers have difficulty recognizing oncoming motorcycles?
- Seventy-eight percent of all fatal and serious injury motorcycle crashes occur in locations with a population of 50,000 or fewer.
    - Fifty-one percent occur in locations with a population of 4,999 or fewer.
    - Twenty-seven percent occur in locations with a population of 5,000 to 49,999.
- Motorcyclists face a unique challenge, maintaining balance and control on the road. Half of all fatal and serious injury motorcycle crashes involve one vehicle – the motorcycle.
    - Among single vehicle, fatal and serious injury motorcycle crashes, most involve illegal or unsafe travel speeds.
    - Sixty-eight percent of single vehicle, fatal and serious injury motorcycle crashes occur in locations with a population of 4,999 or fewer.
- Significantly more fatal and serious injury motorcycle crashes occur at locations with vertical, horizontal, and horizontal and vertical curves.
- Most fatal motorcycle crashes occurred on curves that account for 20% or less of a circle. This means that most of these curves are not ‘hairpin’ type curves commonly associated with risk. Rather the roadway gently drifts to the right or left for as much 38% of the crash locations. The remaining majority, 45% involve a curve that is less than a full turn to the right or left.

Works Cited

American Association of State Highway and Transportation Officials. (2004). *Elements of the Safety Plan*. Retrieved 2015, from Implementing the AASTO Strategic Highway Safety Plan: http://safety.transportation.org/elements.aspx?cid=6&gid=11

Brown, J. F. (2015). *Motorycle in-depth Crash Study.* Sydney: Austroads Ltd.

IBM Corporation. (n.d.). Crosstabs Statistics, Chi-square. Retrieved 2015

Minnesota Department of Transportation. (2011). 2011 Minnesota Manual on Uniform Traffic Control Devices. St. Paul, Minnesota. Retrieved from http://www.dot.state.mn.us/trafficeng/publ/mutcd/