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STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

A COMPREHENSIVE ENGINEERING ANALYSIS OF MOTORCYCLE CRASHES IN MARYLAND

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16. Abstract:
The goal of this study was to identify recurring or common road characteristics of motorcycle crashes in Maryland from 1998 to 2007. Motorcycle crash data was obtained from the National Highway Traffic Safety Administration's Crash Outcome Data Evaluation System (CODES), and road inventory data was obtained from the Maryland State Highway Administration. Both sets of data were integrated, and fault tree analysis and variable selection methods were utilized to find the highest frequency crash cases. A categorical principal component analysis was used to specify the minimum number of variables that explain most of the observed variance. In addition, ordinal logistic models were developed to estimate the number of motorcycle crashes for road segments within each road class. The results of the logistic ordinal regression analysis show that area type, median type, speed limit, average annual daily traffic (AADT), international roughness index (IRI), and the number of through lanes affect the number of motorcycle crashes on Maryland road segments. Interestingly, government control and shoulder type were shown to have no significant impact on the number of motorcycle crashes. The developed ordinal logistic model can also calculate the number of motorcycle crashes for each road characteristic. Engineers and safety officials can use this study's results to develop solutions for identified safety deficiencies.

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EXECUTIVE SUMMARY

This study identifies the recurring or common road characteristics of motorcycle crashes in Maryland from 1998 to 2007. Motorcycle crash data was obtained from the National Highway Traffic Safety Administration's Crash Outcome Data Evaluation System (CODES), and road inventory data was obtained from the Maryland State Highway Administration. Both sets of data were integrated, and fault tree analysis and variable selection methods were utilized to find the highest frequency crash cases. In order to specify the minimum number of variables that explain most of the observed variance, a categorical principal component analysis was employed. In addition, ordinal logistic models were developed to estimate the number of motorcycle crashes for road segments within each road class.

The logistic ordinal regression analysis results show that area type, median type, speed limit, average annual daily traffic (AADT), international roughness index (IRI), and number of through lanes affect the number of motorcycle crashes on Maryland's road segments. Interestingly, government control and shoulder type appear to have no significant impact on the number of motorcycle crashes. The developed ordinal logistic model can also be used to calculate the number of motorcycle crashes for each road characteristic. SHA engineers and safety officials can use this study's results to develop solutions for identified safety deficiencies.

INTRODUCTION

Commuting and recreational motorcycle use in the United States has been on the rise since the mid-1990s, with motorcycle registrations increasing 61 percent between 1996 and 2005 (NHTSA, 2006). As the number of motorcyclists increases, the safety issues associated with this mode of travel must be addressed. Motorcycle riders and passengers are more vulnerable to injury in crashes. While crash fatalities decreased from 1990 to 1997, fatalities in the U.S. have increased every year for the past 10 years (NCHRP, 2008 and III, 2008).

Similar to the national trend, motorcycle crashes are becoming more and more frequent in Maryland. Although each state's department of transportation is required to annually submit motorcycle volume data to the National Highway Traffic Safety Administration (NHTSA), there has never been a comprehensive engineering study of the nature of motorcycle crashes in Maryland. Every year, SHA engineers review automobile crash data to pinpoint problem areas. However, motorcycle crash data is not considered.

This project is an engineering analysis of Maryland's motorcycle crash data from 1998 to 2007. The crash analysis will include locations, causes, trends, increases in motorcycle volumes, registrations, and etc. The findings will help SHA engineers and safety officials to develop solutions for identified safety deficiencies.

Objectives

The objectives of this research project were threefold:

- to perform a comprehensive engineering analysis of motorcycle crashes in Maryland.
- to identify crash and injury patterns, areas with the highest motorcycle crash rates, common issues regarding crash locations, the relationship between crash rate and volume, the relationship between rural and urban areas when it comes to crashes, difficulties in reporting and collecting crash data, and the types of roadways where most crashes have occurred, etc.
- to determine any increase or trend in motorcycle registrations and volumes, and their relationship to crashes and injuries.

LITERATURE REVIEW

Although there are many studies related to motorcycle crashes in the literature, few examine the road-related factors of motorcycle crashes. Some of the related studies are summarized in this section.

According to Haque et al. (2008), motorcycles are only 19 percent of the total vehicle population in Singapore, but they are involved in 54 percent of intersection crashes. The report also showed that motorcycles are more exposed at signalized intersections than other vehicles.

A Michigan study identified three major trends in that state’s motorcycle crashes from 1997 to 2002: an increase in the number of motorcycles, motorcyclists, and motorcycle crashes and deaths; an older motorcyclist population; and a low level of motorcycle licensing (Kostyniuk, 2005). The overall number of licensed motorcyclists increased by 8 percent, while the number of licensed motorcyclists between 45 and 64 years old increased by 41 percent. Although all motor vehicle crashes decreased by 7 percent and their fatalities decreased by 8 percent, motorcycle crashes increased by 20 percent and their fatalities increased by 27 percent. The crash rate per licensed motorcyclists increased by 32 percent. During this period, 45 percent of motorcyclists (per year) who were involved in a crash did not have a motorcycle driving license. The study also showed that speeding was the most frequently recorded hazardous action followed by clear distance, reckless driving, and careless or negligent driving. The study indicated that the majority of crashes occurred on two-lane rural roads. It also found that of the motorcycle crashes in Michigan from 1997-2002, most often occurred on dry roads (89-94 percent), in good weather (73-81 percent), during the day (68-71 percent), and away from controlled intersections (70-72 percent). The study suggested increasing the knowledge and skill of motorcyclists, including licensing, and teaching other drivers how to drive near motorcycles.

To determine whether existing training programs were reducing crash probabilities, Savolanien and Mannering (2007) estimated statistical models using a sample of Indiana motorcyclists in 2005. Statistical models for speed-choice and helmet usage were also estimated. The study concluded that motorcyclists who took the training course were more likely to be involved in a crash than those who did not.

Gabler (2007) found that motorcycle crashes account for 42 percent of all guardrail collision fatalities in the U.S. The number of fatally-injured car occupants decreased 31 percent from 2000 to 2005, while this number increased by 73 percent for motorcyclists in guardrail crashes. More than two-thirds of fatally injured motorcyclists were helmeted. Around 10 percent of motorcycle riders in guardrail collisions were fatally injured, which is 100 times higher than the rate for car occupants involved in guardrail collisions.

The U.S. General Accounting Office (2003) named human factors, roadway environment, and vehicle factors as the three factors that contribute to crashes. Of the three, the human factor is the largest.

Zhang and Prevedouros (2005) conducted a web-based survey of 2,000 motorists to find how rain affects driver behavior. The findings showed that drivers’ perception of crash risk was higher in rainy weather (especially in heavy traffic), regardless of age, gender, driving experience, education, and car type. Respondents stated that they drove 4.9 percent slower on wet roads and 11.1 percent slower when it was raining.

Garber and Kassebaum (2008) utilized fault tree analysis to identify the casual factors of all crashes on 143 two-lane highways in Virginia. The dataset included approximately 10,000 crashes from 2001 to 2004. The highways—which ranged in length from five to ten miles—were classified as urban primary, urban secondary, rural primary, or rural secondary. Collisions were grouped as rear-end, angle, head-on, sideswipe, run-off-the-road (ROR), deer, or other. The majority of these crashes were ROR, and the main casual factors were curvature of the road and annual average daily traffic (AADT). The study recommended the development and implementation of a plan that would correct the high-ROR sites' geometric deficiencies.

Garber et al. (2009) extended the aforementioned study to about 40 rural and urban highways in Virginia with divided, undivided, and traversable medians. Through fault tree analysis and generalized linear modeling, the study found that most of the 34,000 crashes were rear-end collisions. It showed that the implementation of the recommended countermeasures would reduce crashes up to 40 percent, depending on the site and the level of rehabilitation. A sensitivity analysis demonstrated that the benefit/cost ratios were greater than one for all levels of countermeasure implementation.

Green et al. (2008) analyzed traffic crash data in Kentucky from 2003 to 2007. In order to identify locations with abnormal rates of crashes, the average and critical crash rates (and numbers) for different types of highways in rural and urban areas were calculated. Crash statistics by vehicle type were also examined. The study found that motorcycle crashes increased significantly in 2007 compared to the average of 2003-2006 due to replacement of the helmet requirement law.

Parham et al. (2008) evaluated road risks and road treatments (e.g., raised pavement markers, lane widening, safety treatment of fixed objects, adding flashers to warning signs, adding or paving shoulders, resurfacing, and chevrons on curve). The project was divided into three phases in order to address important increments throughout the crash research. Phase 1 described the low volume and two-lane highway crashes throughout the state of Texas. Phase 2 explained the creation of a tool that collected data for rural roads in the state. Phase 3 described Before and After Evaluation of Safety Treatments for Rural Highways. The treatments that were implemented on different crash sites—such as two left turn lanes, delineation, and barrier reflectors—helped to reduce the number of crashes at each site by 15 percent or more.

Rinde (1977) conducted a before-and-after study in California to find the relationship between shoulder width and crash rates. Three different shoulder widths were considered, and all of them showed a reduction in crash rates after widening.

Harkey (2005) summarized the current status of the crash reduction factors (CRFs) in the National Cooperative Highway Research Program (NCHRP) 17-25 report. CRFs estimate crash reductions associated with highway safety improvements. The study analyzed crash modification factors (AMFs) to predict the future safety of different alternative roadway designs or rehabilitation designs. The AMFs are currently used in safety decision making software tools such as the Interactive Highway Safety Design Model (IHSDM) and Safety Analyst.

The NCHRP 17-25 report (Harkey, 2005) was created to improve existing AMFs and to create additional AMFs that would decrease the number of crashes nationally. One hundred treatments were identified based on a literature review of existing AMFs and a survey of state DOTs that determined the applicability of the existing AMFs. An AMF knowledge matrix was also created throughout these improvements. The treatments were analyzed in three categories: intersections, roadway segments, and miscellaneous. The matrix included user priority level, level of predictive certainty, and ongoing future work for each treatment. For example, one existing treatment was "modify signal change interval," the brief yellow and all-red period that follows the green indication. The AMF for all crashes throughout 40 treated sites was 0.92. This result significantly affected the signal timing change. Another existing treatment was the "all-way stop control." In this type of treatment, traffic approaching from all directions is required to stop before proceeding through the intersection. Four regions across the U.S. were evaluated to collect data on improved sites. After the implementation of the all-way stop control, the AMF value for all crashes was 0.53. Another treatment involved the installation of a red light camera, and the study examined 132 sites where the cameras were added. The economic analysis of this treatment produced a negative percentage change in crash cost for total all-severity (i.e., there was no drastic change in crashes after the cameras were installed).

Brown et al. (1998) studied access control on high-speed urban arterials. The study developed a comprehensive procedure for evaluating access control alternatives and used negative binomial distribution to develop crash prediction models.

In an attempt to improve traffic operators, the Minnesota Department of Transportation evaluated the statistical relationship between vehicular crashes and highway access (Preston, 1998). The statistical analysis was created to collect accurate data that would show the relationship between access density and crashes. The correlation between average volume per segment and access density was tested to emphasize the traffic volume's dependency on crash rate. The statistical tests showed that the majority of roadway types have a sufficient sample size. Overall, technical analysis, benefit cost analysis, and statistical analysis affected the tested data positively. The study found a relationship between access density and crash rates in 90 percent of the highway categories. The relationship explains why there is high access density in high crash rate sites near roadways and why there is low access density in low crash rate sites. The statistical analysis found that roadway classes, not traffic volumes and traffic speeds, had an effect on the crash rates. The benefit cost analysis revealed the strategies that would decrease the number of crashes.

DATA INTEGRATION AND ANALYSIS

The research team joined two data sources, the Maryland Crash Outcome Data Evaluation System (CODES) and the SHA's road inventory, to analyze the motorcycle crashes in Maryland.

CODES is a NHTSA-funded project that studies motor vehicle crashes in conjunction with other healthcare databases. The CODES program resource center in Maryland, the National Study Center for Trauma/EMS at the University of Maryland in Baltimore, provided data on crashes for the state from 1998 to 2007. This data included 14,434 records.

The SHA's road inventory data details the characteristics of 172,000 roads in Maryland. In order to conduct the engineering analysis, the research team performed a spatial joint of the road characteristics and the motorcycle crash data.

Almost half of the crash data was lost after the two databases were joined because the road inventory data did not include road information for Baltimore City. All of the data was checked and the records for locations that did not match were removed. Data for the year 2007 was removed from the analysis because the joining resulted in a major reduction of data points. The final database included 6,736 data points.

Since the CODES data has more data points, the research team retrieved the crash and driver data from CODES and the road-related data from the joint data. The primitive data analysis is mostly based on the CODES data set; however, the statistical analysis is based on the joint data.

Crash Trends

The number of motorcycle crashes has been increasing since 1998, and they almost doubled from 1998 to 2007 (Figures 1 and 2). The consistent trend could only be because of population growth, increases in registered motorcycles, and so on. Figure 3 shows how motorcycle registrations in Maryland almost doubled from 2001 to 2008.

The research team calculated the crash rate as the number of crashes per number of registered motorcycles. As presented in Figure 4, the crash rate decreased from 2001 to 2003, slightly increased from 2003 to 2005, and decreased from 2005 to 2007. The crash rate in 2007 was the lowest since 2001. The registration data was obtained from the Maryland Motor Vehicle Administration (MVA).

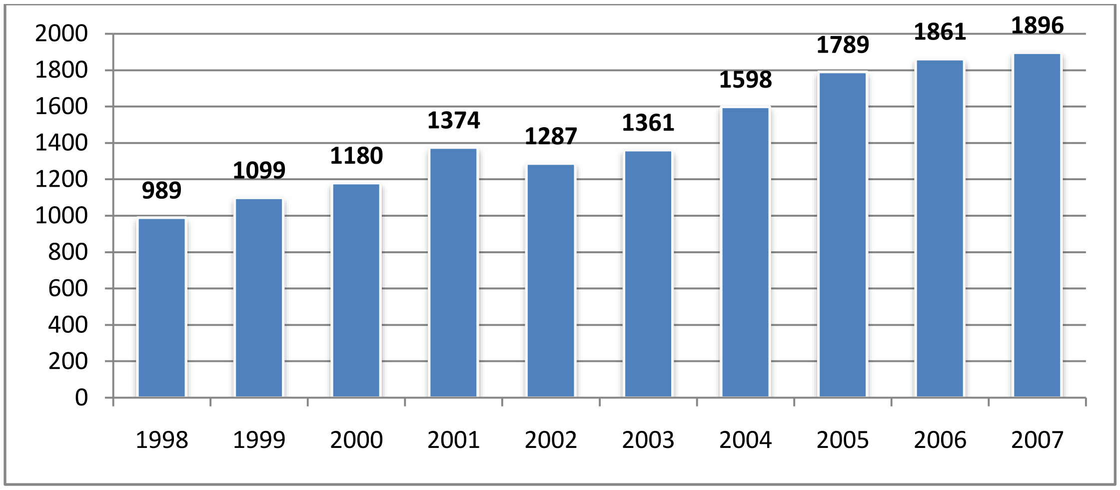


Figure 1: Motorcycle Crashes in Maryland, 1998-2007

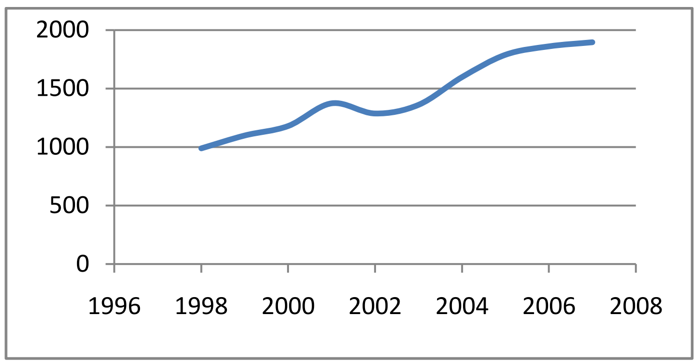


Figure 2: Motorcycle Crashes in Maryland, 1998-2007

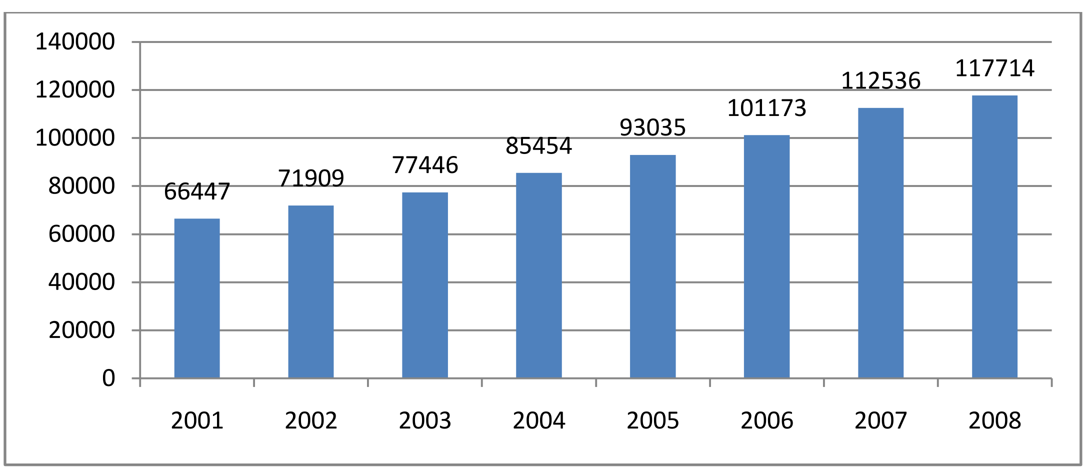


Figure 3: Motorcycle Registration Trend in Maryland, 2001-2008

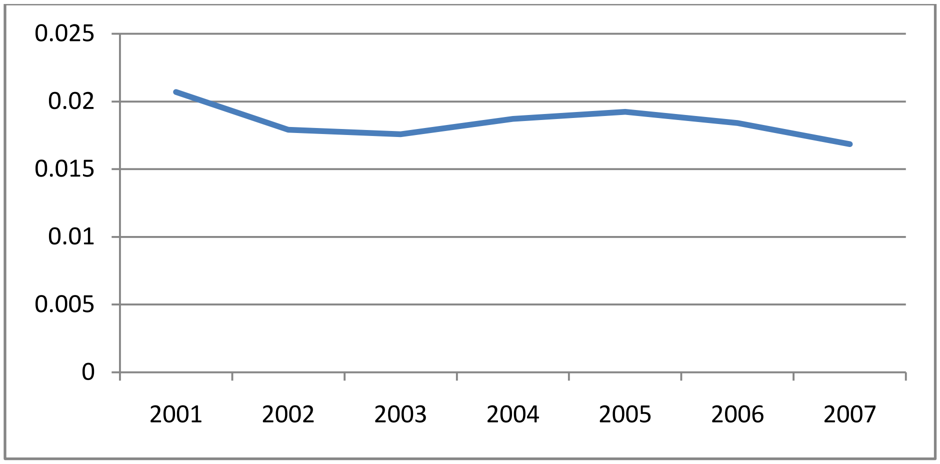


Figure 4: Motorcycle Crash Rate in Maryland, 2001-2007

Crash Locations

Prince George's County had the highest number of motorcycle crashes from 1998 to 2007, followed by Baltimore County, Baltimore City, and Anne Arundel County (Figure 5). Kent and Somerset counties recorded the lowest number of motorcycle crashes.

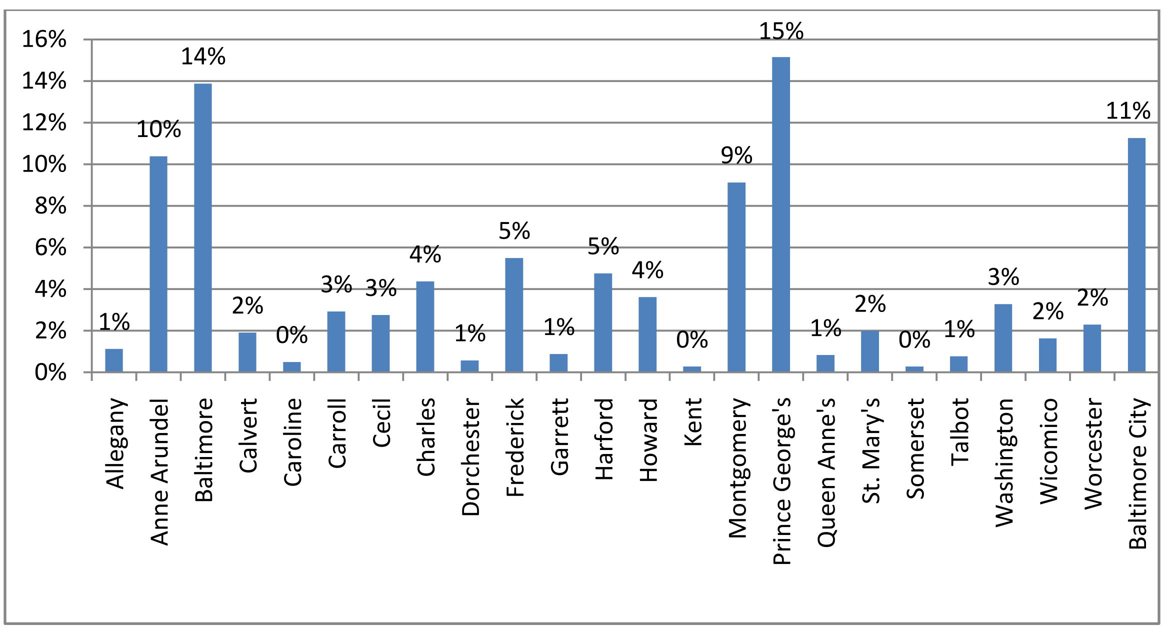


Figure 5: Motorcycle Crashes by Location in Maryland, 1998-2007

Speed Limit

As presented in Figure 6, most of the crashes occurred on roads with speed limits of 40-55 mph. As such, most of the crashes did not occur on freeways. This will be later verified by the road classification.

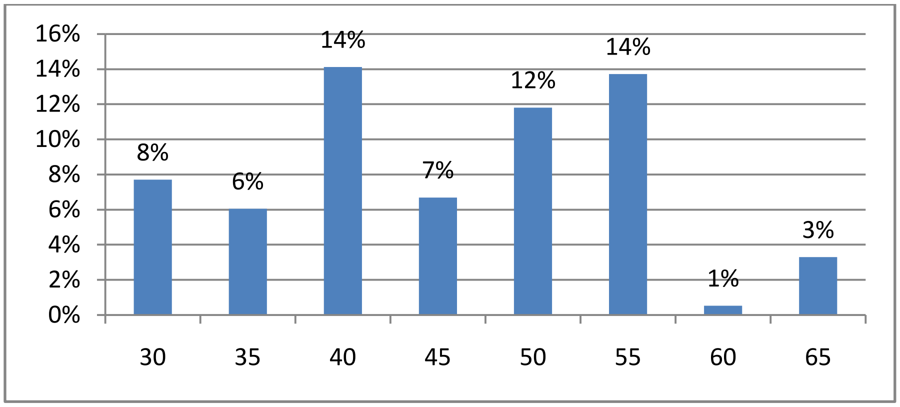


Figure 6: Motorcycle Crashes by Speed Limit

Road Conditions

Road conditions were classified as holes and ruts, defects on the road and its shoulder, foreign material, loose surface material, and not signed or lighted obstruction. In 79 percent of crashes—11,385 out of 14,434— there were no defects on the road. Shoulder defect was reported as the known reason in 7 percent of cases (Figure 7).

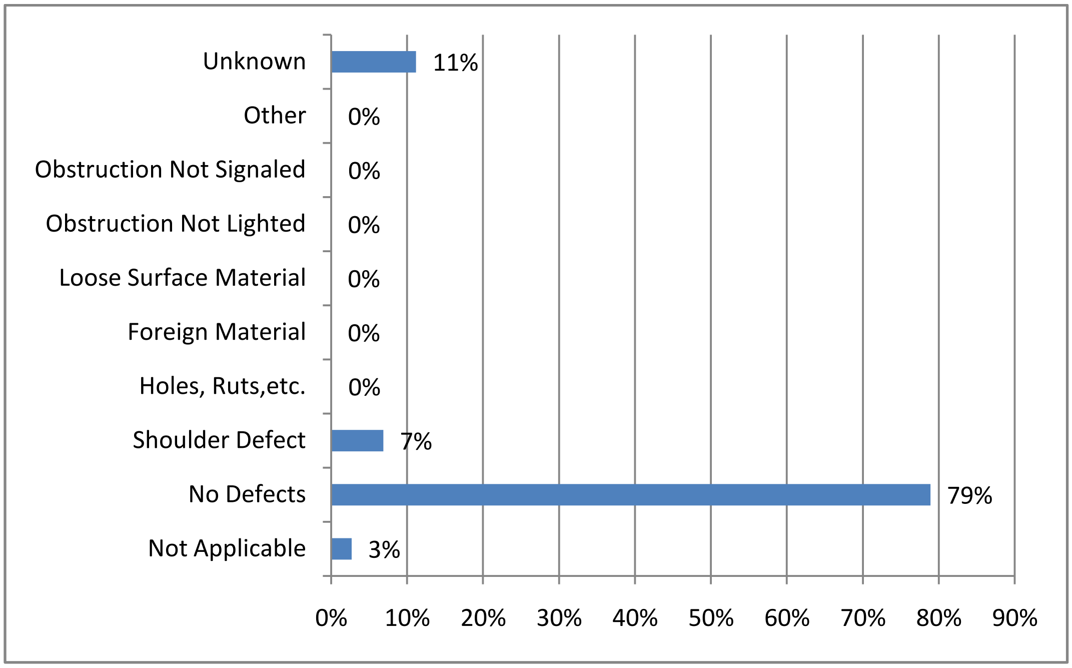


Figure 7: Motorcycle Crashes by Road Conditions

Weather Conditions

More than 96 percent of the crashes occurred when conditions were clear or cloudy, illustrating that inclement weather may not be an important factor in motorcycle crashes (Figure 8). This may be due to the fact that people are less likely to use their motorcycles in bad weather. Three percent of crashes occurred when it was raining.

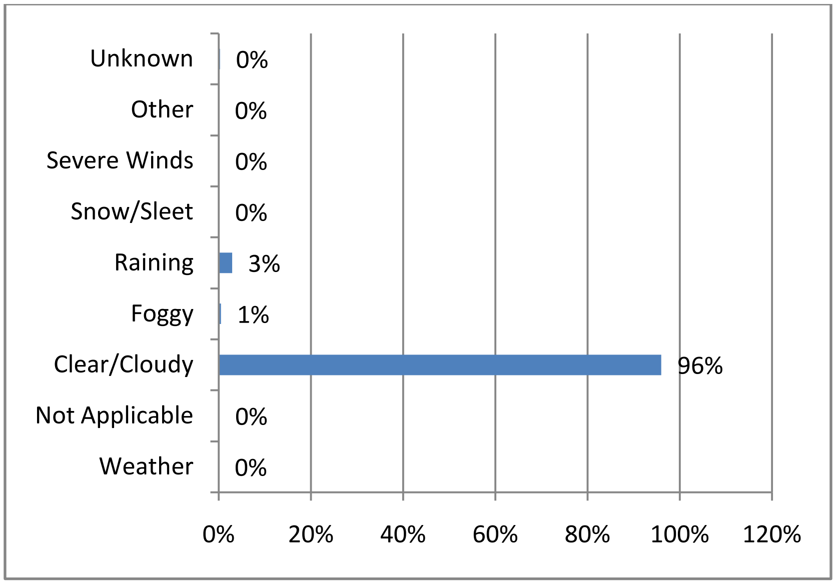


Figure 8: Motorcycle Crashes by Weather Conditions

Surface Conditions

Surface conditions of the road were categorized as dry or wet. Wet conditions include rain, snow, ice, and mud. As presented in Figure 9, 93 percent of the motorcycle crashes happened on a dry road surface. This is probably because cyclists would not ride their motorcycles during inclement weather.

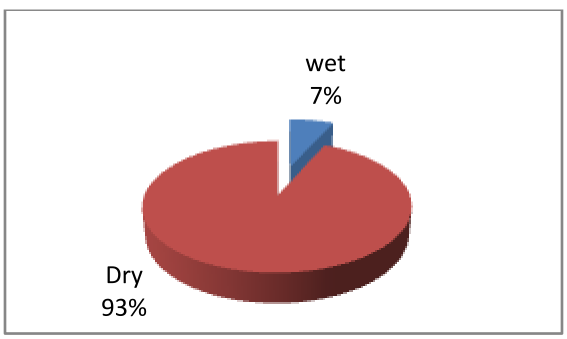


Figure 9: Road Surface Condition When Motorcycle Crash Happened

Light

Motorcycles are less visible in the dark than cars. Additionally, most riders' accessories (such as helmets and gloves) are usually black, and, therefore, difficult to see at night. However, only 18 percent of crashes occurred when it was dark and lights-on and 9 percent occurred when it was dark and there was no light (Figure 10). Almost 70 percent of crashes occurred during the day. This is probably because most people ride their motorcycles during the day.

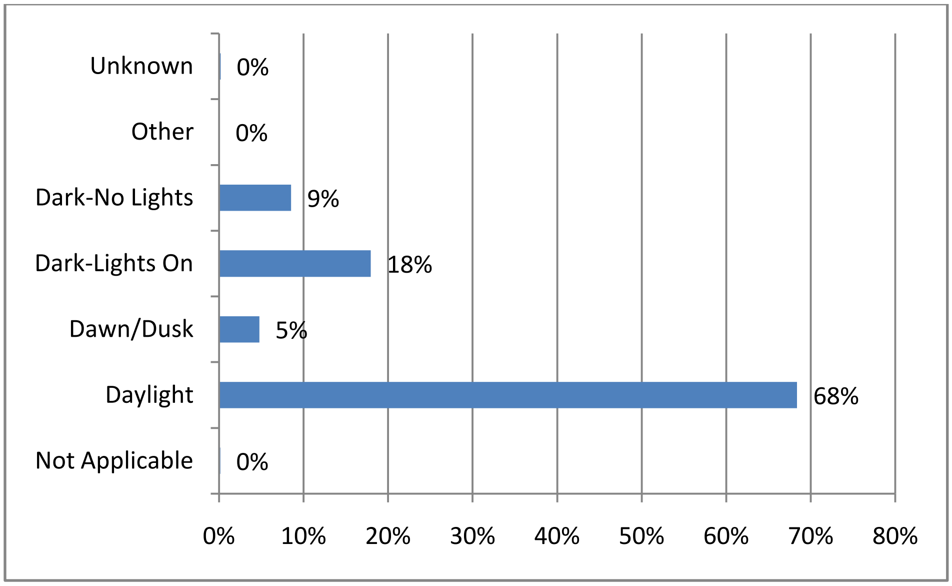


Figure 10: Light Condition When Motorcycle Crash Happened

Collision Type

As presented in Figure 11, more than 40 percent of the crashes were single-vehicle collisions. This may mean that road characteristics are an important factor in motorcycle crashes. The second most frequent collision type was same-direction-rear-end, which accounted for 13 percent of all crashes.

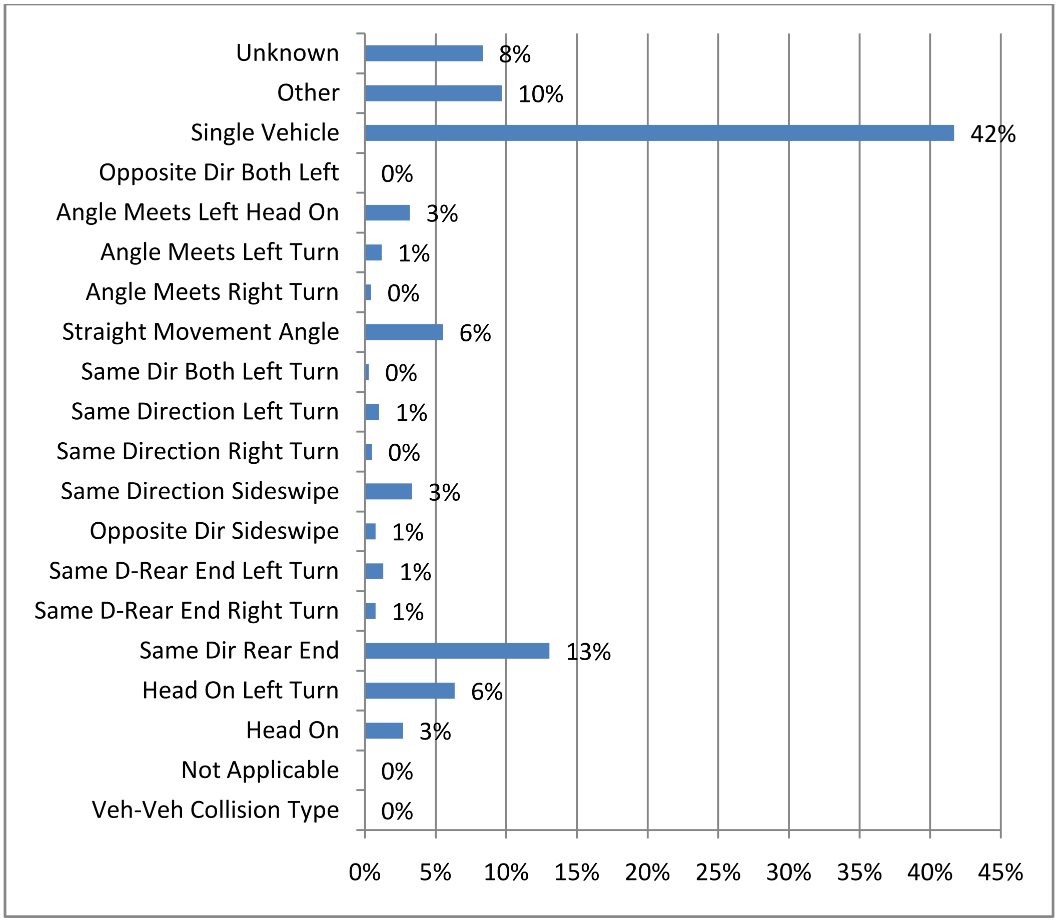


Figure 11: Motorcycle Crashes by Collision Type

Vehicle Movement

Figure 12 indicates that 40 percent of the crashes happened when the motorcycle was moving at a constant speed. Interestingly, only 14 percent occurred during a left turn, and 11 percent occurred when slowing down or stopping.

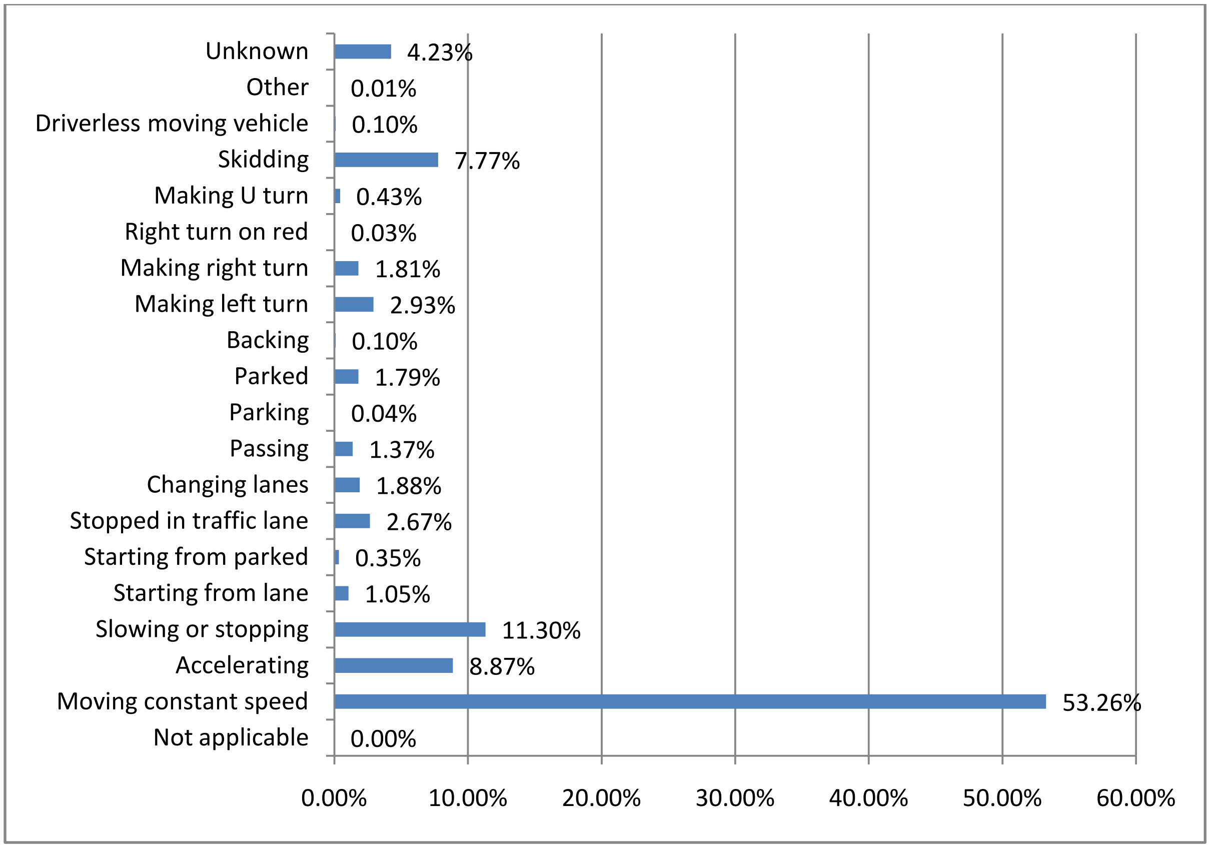


Figure 12: Motorcycle Movement When the Crash Happened

Intersections

As presented in Figure 13, only 28 percent of crashes happened in intersections, and half of those crashes happened in signalized intersections. The results suggest that traffic signals do not reduce motorcycle crashes.

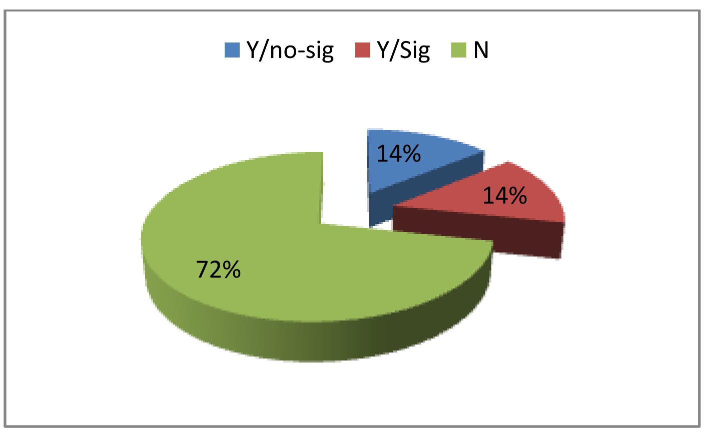


Figure 13: Motorcycle Crashes and Intersections

Road Divisions

It seems that road divisions can help reduce motorcycle crashes. As presented in Figure 14, undivided roads were the site of 57 percent of crashes, and divided roads without any barriers were the site of 21 percent of crashes. Roads divided with barriers were the site of 15 percent of crashes.

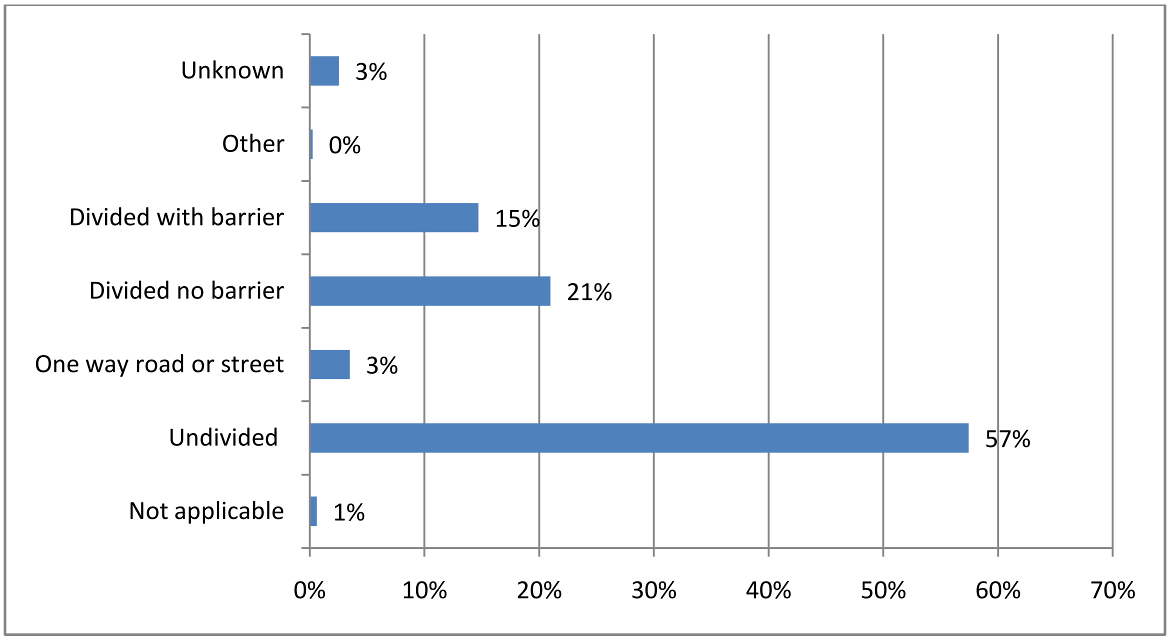


Figure 14: Motorcycle Crashes by Road Divisions

Access Control

The level of access control on the road segment was categorized as full access control, partial access control, and no access control. Full access control roads give preference to through-traffic movements by providing interchange type with selected public roads and by prohibiting crossing at a grade and direct driveway connection. Partial access control roads also give preference to through-traffic movement. In addition to interchanges, there may be some crossings at grade with public road, but they use frontage roads and other local access restrictions to minimize direct private driveway connections. As shown in Figure 15, most crashes happened on roads without any access control.

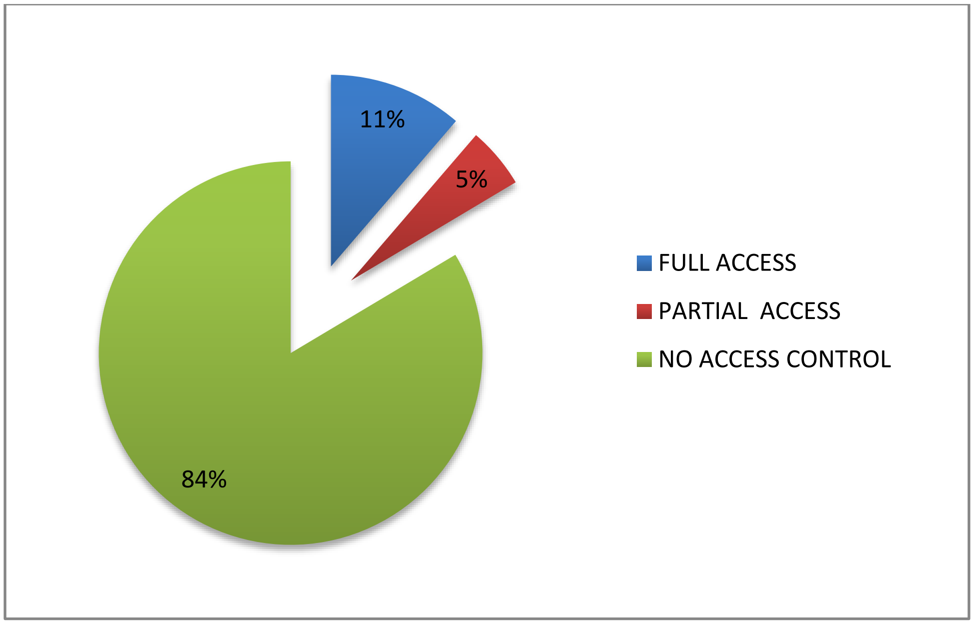


Figure 15: Motorcycle Crashes by Road Access Control

State Highway Routes

State highway routes were classified as state primary or state secondary. The state primary highway consists of approximately 1,200 miles of state maintained routes, which is 25 percent of the total state-maintained road mileage. The state primary system was adopted in 1972 and revised in 1978 in accordance with the provision of the state law. The primary system serves the state in the same manner that the interstate system serves the nation. However, it has been the SHA's policy to develop a primary system that has a maximum practical degree of access control for the motorist.

The secondary highway is a network of routes that serves inter-regional and localized traffic. This network consists of approximately 3,900 miles (75 percent) of the total state-maintained roadways. It provides feeder and support functions to the primary system and complements the county highway system. Figure 16 shows that 41 percent of motorcycle crashes occurred on state secondary highways, 21 percent occurred on state primary highways, and 37 percent occurred on roads that are not state highways.

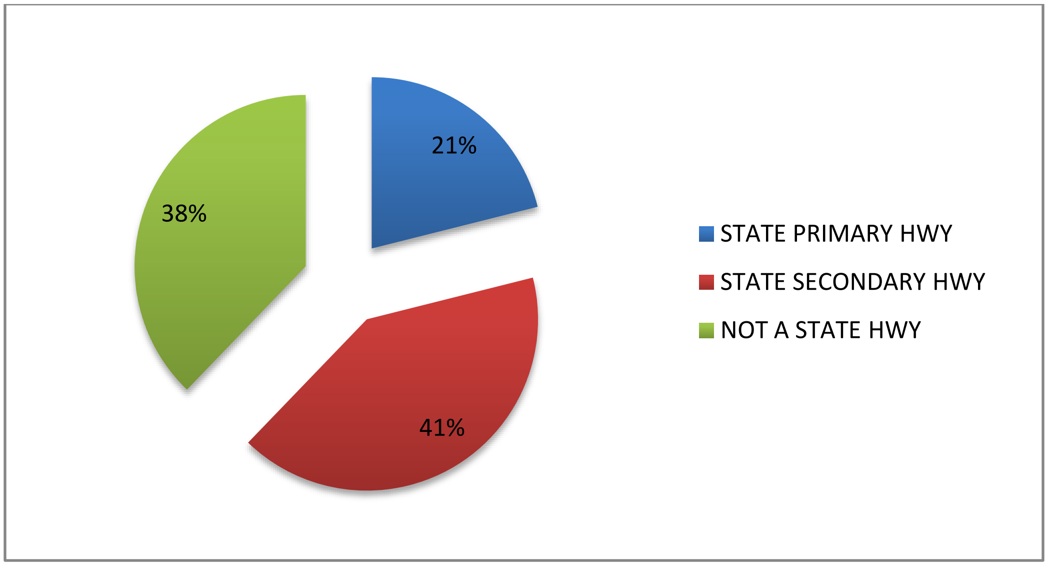


Figure 16: Motorcycle Crashes on State Highway Routes

Area Type

A road section can be federal or state. It can also be rural or urban. Federal urban areas are defined by population density from census data, while state urban areas are defined by incorporated municipality boundaries. Therefore, a road might be classified as a rural road in federal classifications but as an urban road in state classifications, and vice versa.

As presented in Figure 17, most motorcycle crashes happened on federal urban/state rural roads (61 percent). Also, 87 percent (61 percent + 26 percent) of crashes have happened on state rural road sections.

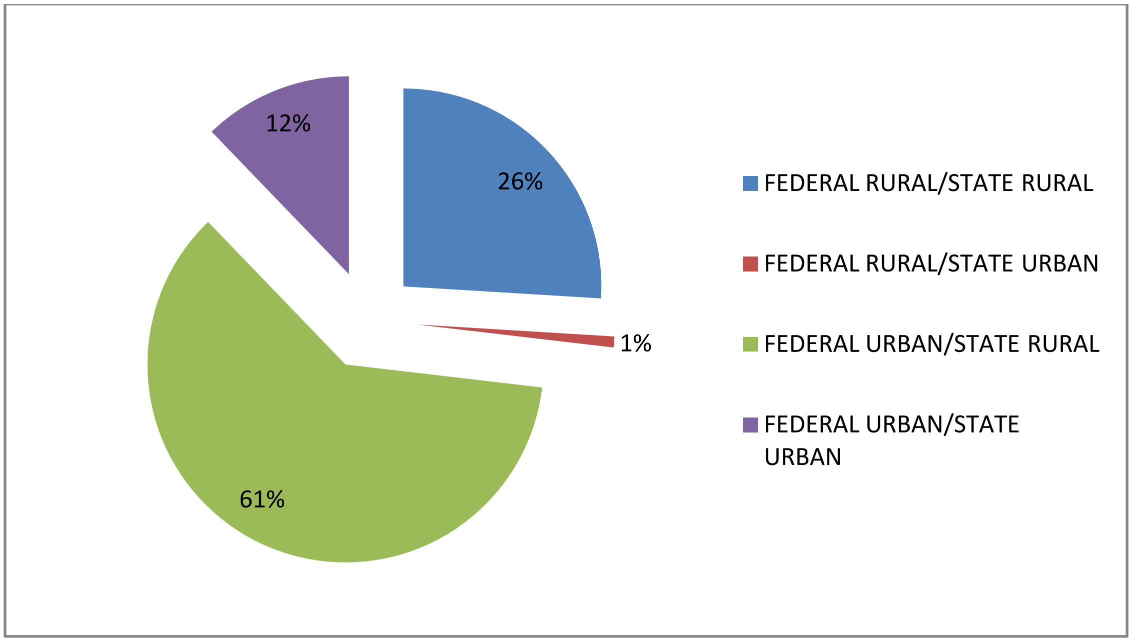


Figure 17: Motorcycle Crashes and Federal/State Area Type

Areas with populations under 50,000 are classified as rural, small urban areas. Medium urban areas have populations of 50,000-199,999, and large urban areas have populations of 200,000 or more. Figure 18 shows that most motorcycle crashes happened in large urban areas (53 percent).

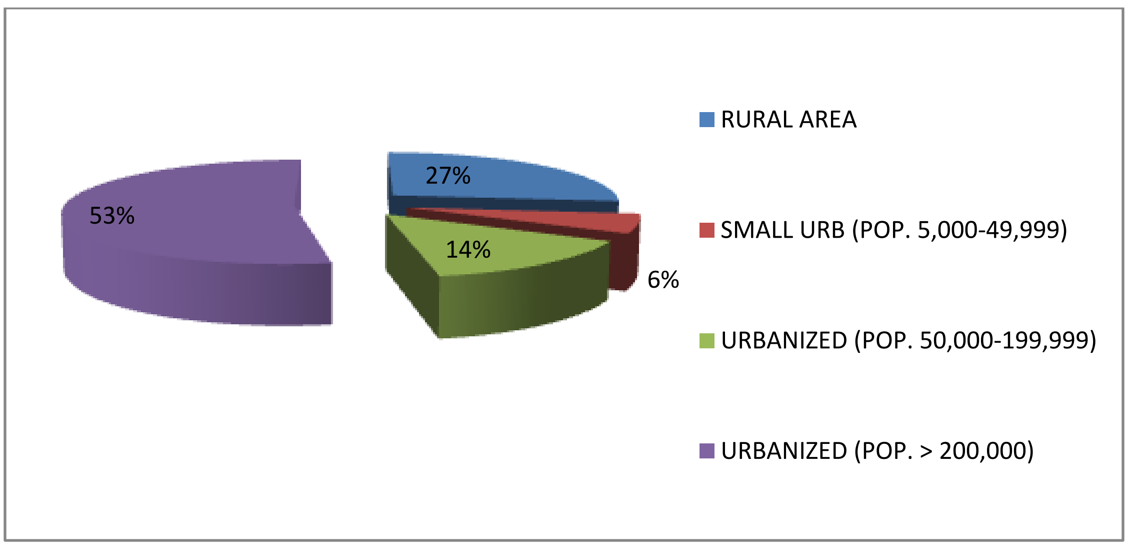


Figure 18: Motorcycle Crashes and Area Type

Classification of Roads

Roads were classified according to their intended service. The categories are rural or urban interstate, other principal arterial, minor arterial, major collector, minor collector, and local. As presented in Figure 19, the highest percentage of motorcycle crashes happened on urban other principal roads (22 percent).

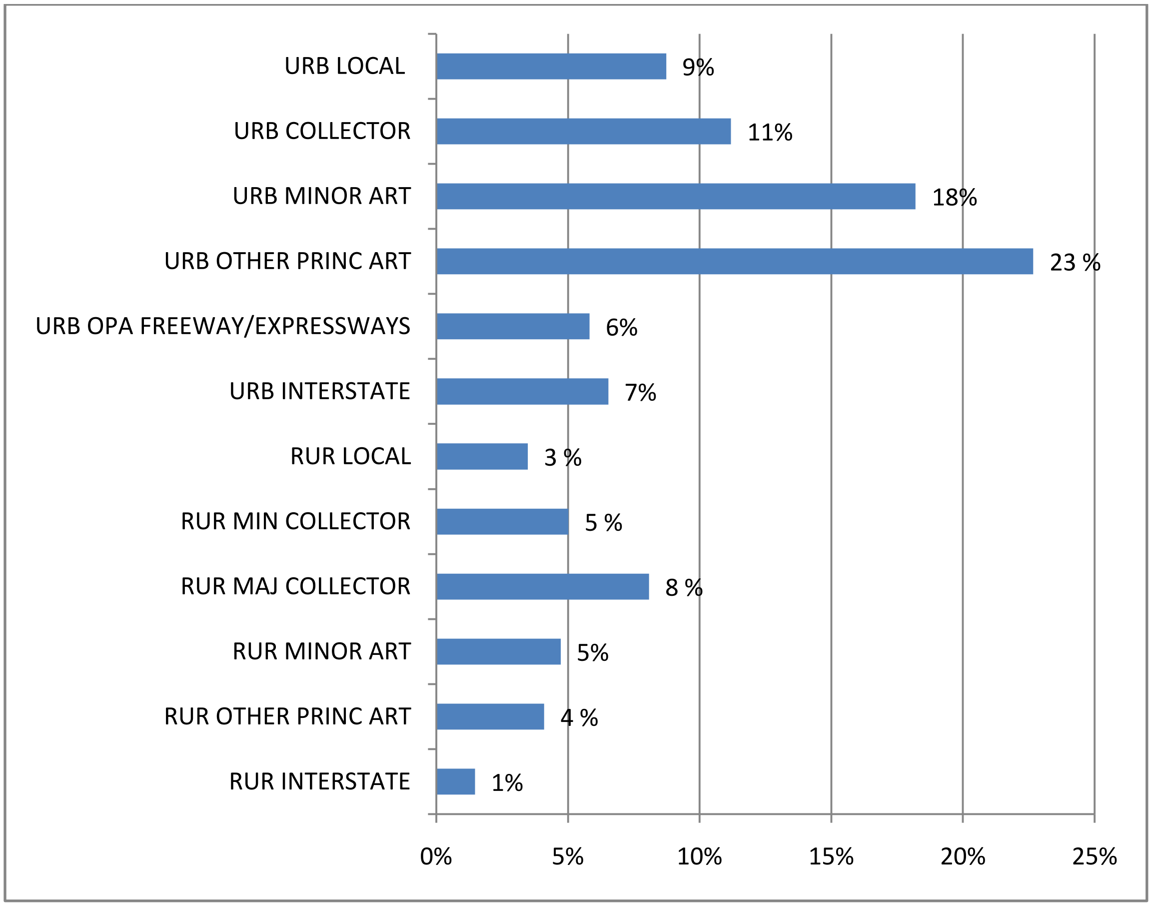


Figure 19: Motorcycle Crashes and Functional Classification of Roads

Government Control

Government control refers to the government agency that maintains the roads. As presented in Figure 20, the majority of motorcycle crashes happened on state roads (61 percent).

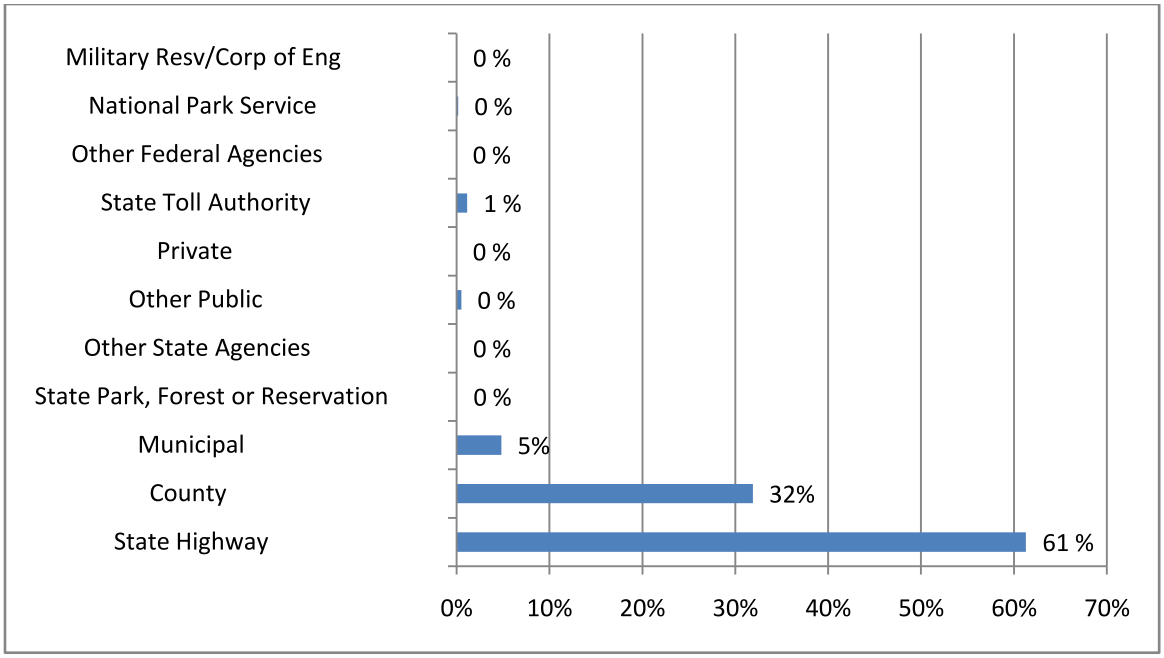


Figure 20: Motorcycle Crashes and Government Control on Roads

Intelligent Transportation System (ITS)

The data indicates that more than 99 percent of crashes happened on road sections without any electronic surveillance, toll (with its stops and pattern changes), incident detection technology, or variable message signs. More than 96 percent of crashes occurred on road sections without surveillance camera coverage and more than 91 percent of crashes happened on road sections without advisory radio.

Road Surface Type of the Left Roadway

The road surface type for the left roadway of divided highways was classified as unimproved road; graded and drained; soil, gravel or stone; bituminous surface treated; mixed bituminous; bituminous penetration; high flexible; composite; high grid; or brick, block, other, or a combination of brick, block, and another material. The data indicates that 61 percent of motorcycle crashes happened on undivided roads, and 38 percent of crashes happened on the left roadway of divided highways with a high flexible surface (Figure 21).

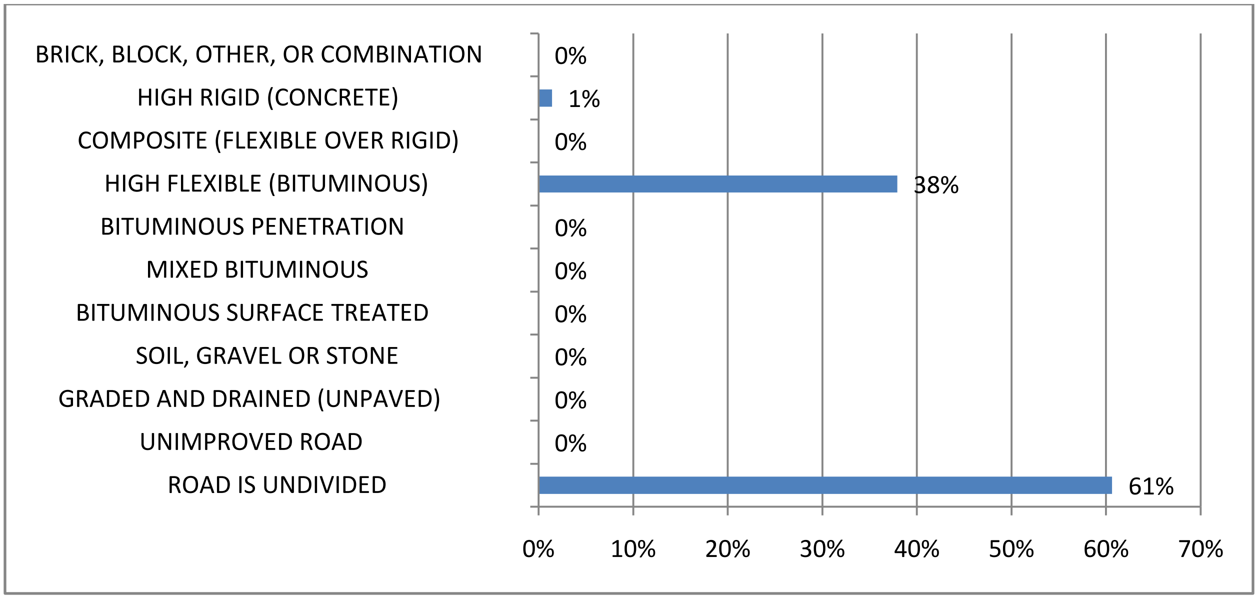


Figure 21: Motorcycle Crashes and Road Surface Type of the Left Roadway

Road Surface Type of the Right Roadway

On divided highways, the right roadway refers to the road section that is to the right of the median. On undivided highways, it represents the surface type of the entire traveled way. As presented in Figure 22, 94 percent of the motorcycle crashes happened on a high flexible road surface.

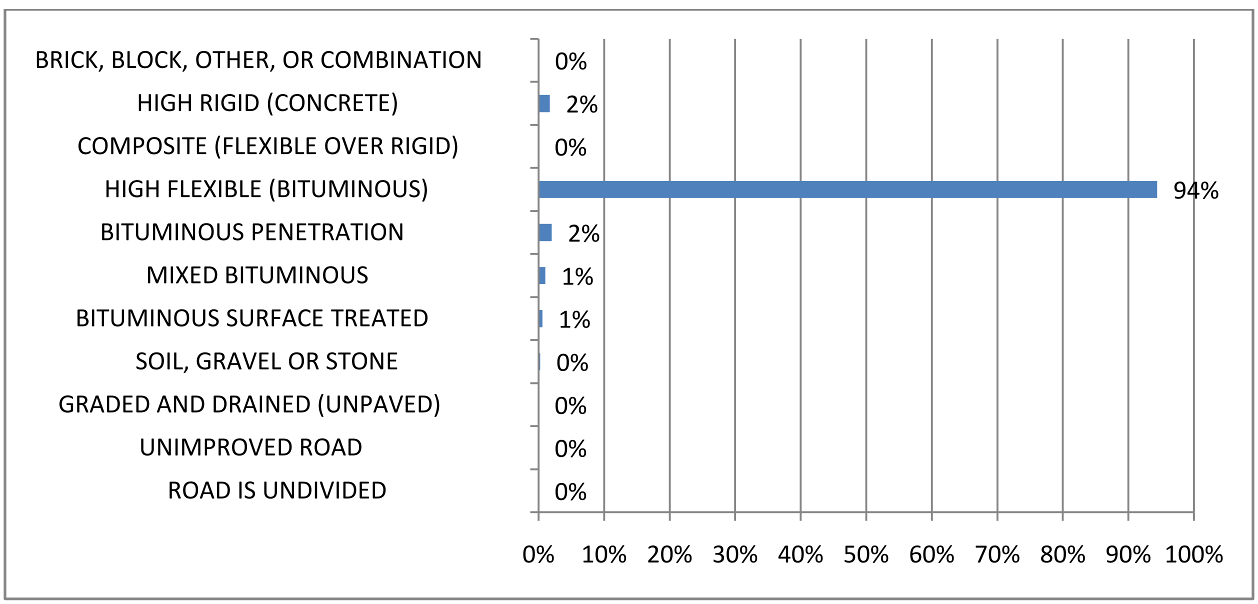


Figure 22: Motorcycle Crashes and Road Surface Type of the Right Roadway

Auxiliary Lanes

Auxiliary lanes include acceleration, deceleration, and turning lanes. The data indicates that 90 percent of motorcycle crashes happened on roads with no auxiliary lane. Nine percent of crashes happened on roads with one auxiliary lane and 1 percent occurred on roads with two auxiliary lanes.

Marked Lanes

As shown in Figure 23, 71 percent of motorcycle crashes happened on highways with marked lanes.

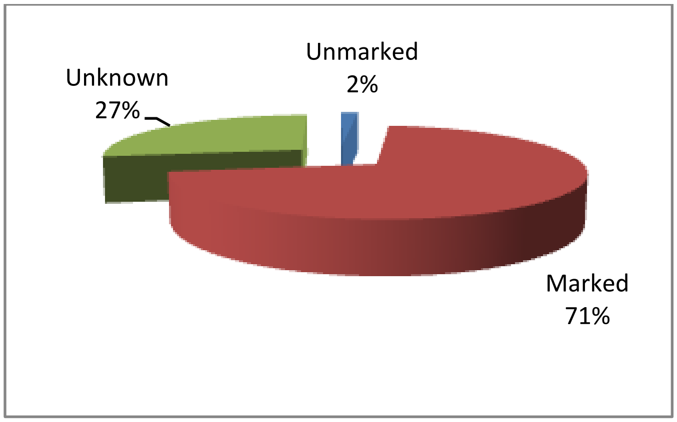


Figure 23: Motorcycle Crashes and Highways with Marked Lanes

Construction and Maintenance Zones

Motorcycles are more sensitive to a working area's facilities. However, as reported in the database, only 7 percent of all crashes happened in construction or maintenance zones (Figure 24).

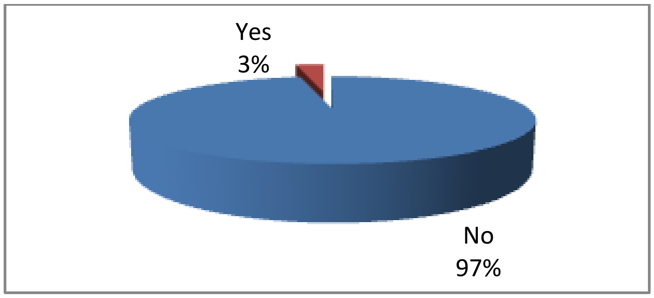


Figure 24: Motorcycle Crashes and Construction and Maintenance Zones

International Roughness Index (IRI)

The average IRI of the road section is provided in the data. IRI measures pavement roughness in terms of the number of inches per mile that a laser, mounted in a specialized van, jumps as it is driven across the interstate and expressway system. The lower the IRI number is, the smoother the ride. An IRI of less than 95 indicates a good road, between 95 and 170 indicates a fair road, and above 170 indicates a poor road. Figure 25 shows that only 15 percent of crashes happened on poor roads. However, the road's IRI was unknown for 34 percent of crashes.

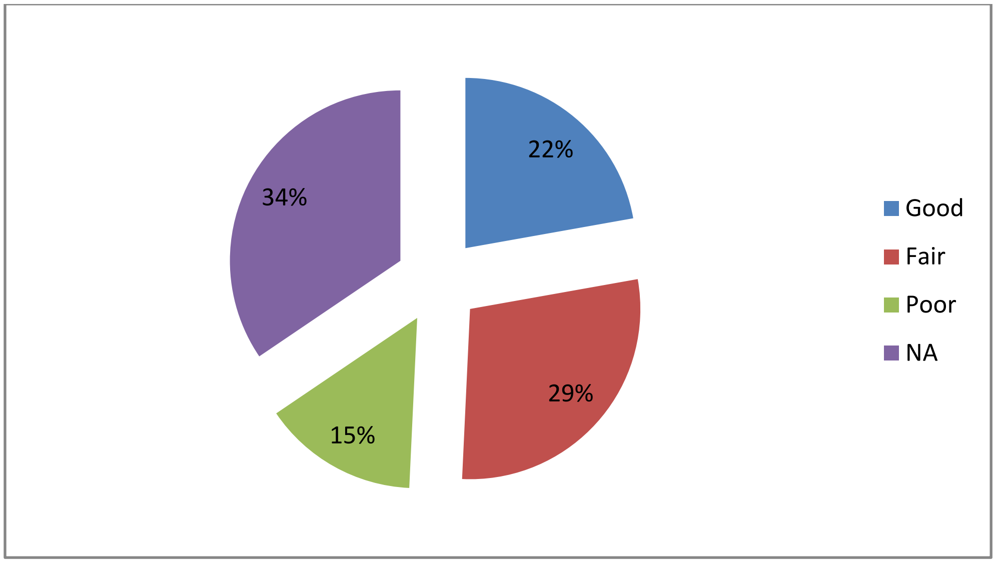


Figure 25: Motorcycle Crashes and the IRI

Median Type

Figure 26 shows that a median is an effective tool for reducing motorcycle crashes. Medians were classified as curbed (concrete border or row of joined stones forming part of a gutter), positive barrier (existence of guardrail, guard cable, concrete barrier, or thick vegetation), unprotected (without a barrier and 4 or more feet wide), none, center TLA undivided (turning lane at the center of the road), roundabout, or painted (no median and separated by paint). Fifty-seven percent of motorcycle crashes happened on roads without a median. In comparison, 15 percent of crashes happened on roads with a curbed median, and 13 percent happened on roads with a positive barrier median. Ten percent of crashes occurred on roads with an unprotected median.

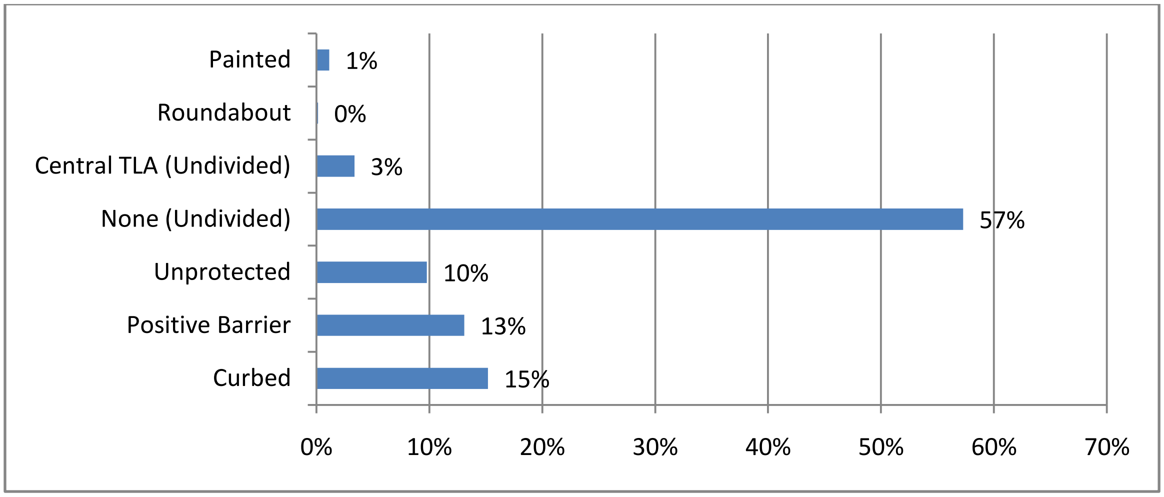
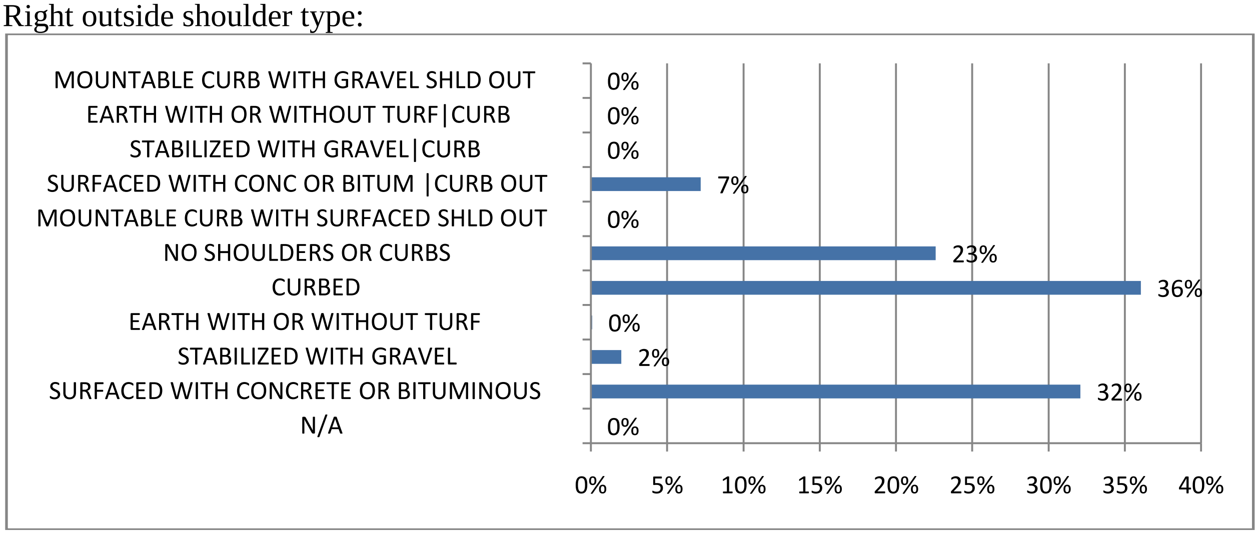


Figure 26: Motorcycle Crashes and Median Type

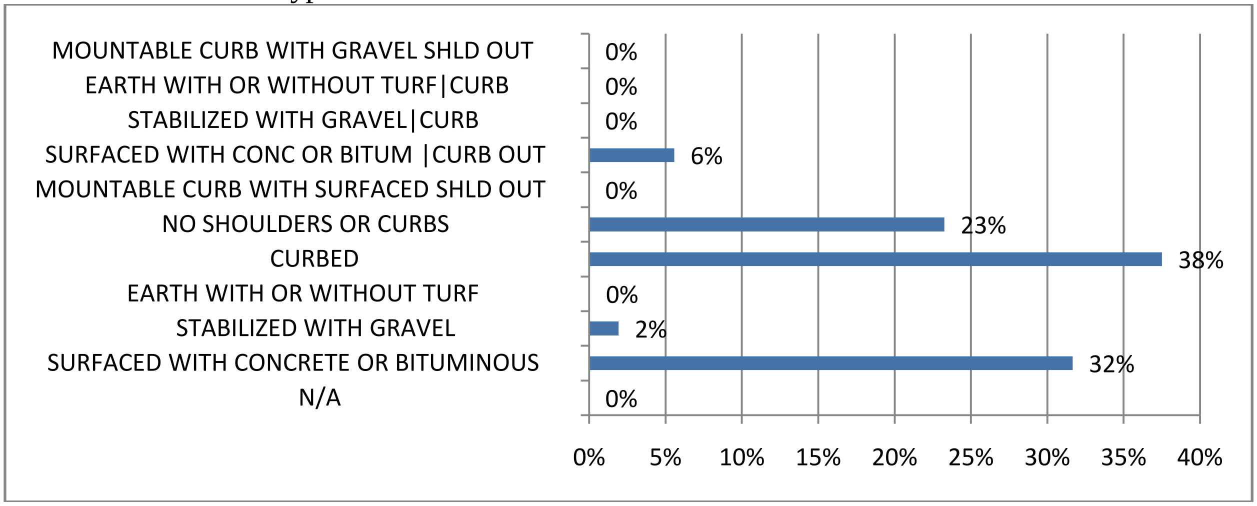
Shoulder Type

Road shoulders were classified as surfaced with concrete or bituminous, stabilized with gravel, earth with or without turf, curbed, no shoulders or curbs, mountable curb with surface shoulder out, mountable curb with gravel shoulder out, surfaced with concrete or bituminous, stabilized with gravel, or earth (with or without turf). The shoulder type was reported for left, right, inside, and outside shoulders. As presented in Figure 27, the most crashes occurred on roads with outside curbed shoulders and no inside shoulders.

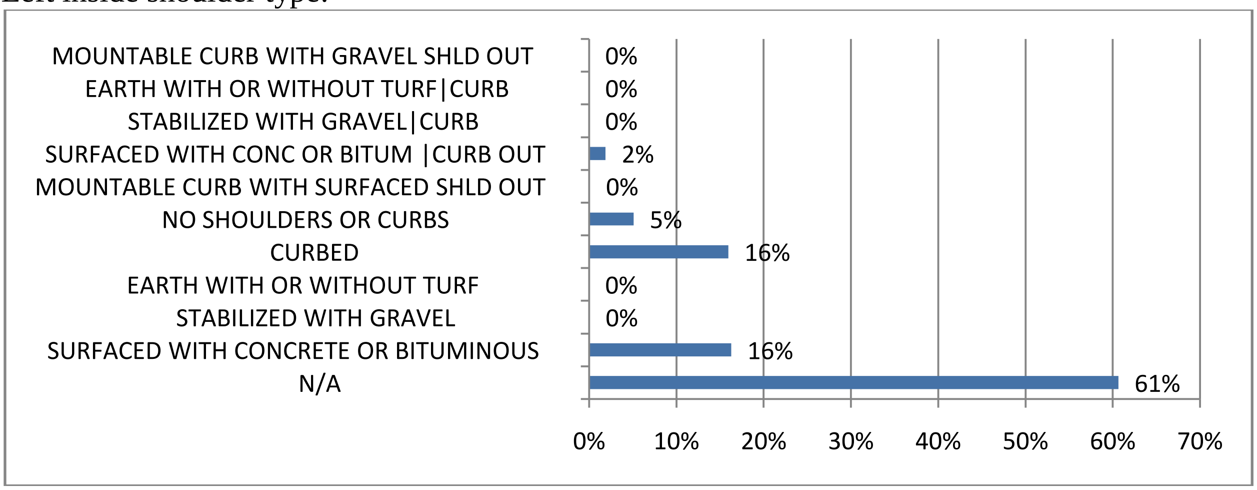
Right outside shoulder type:



Left outside shoulder type:



Left inside shoulder type:



Right inside shoulder type:

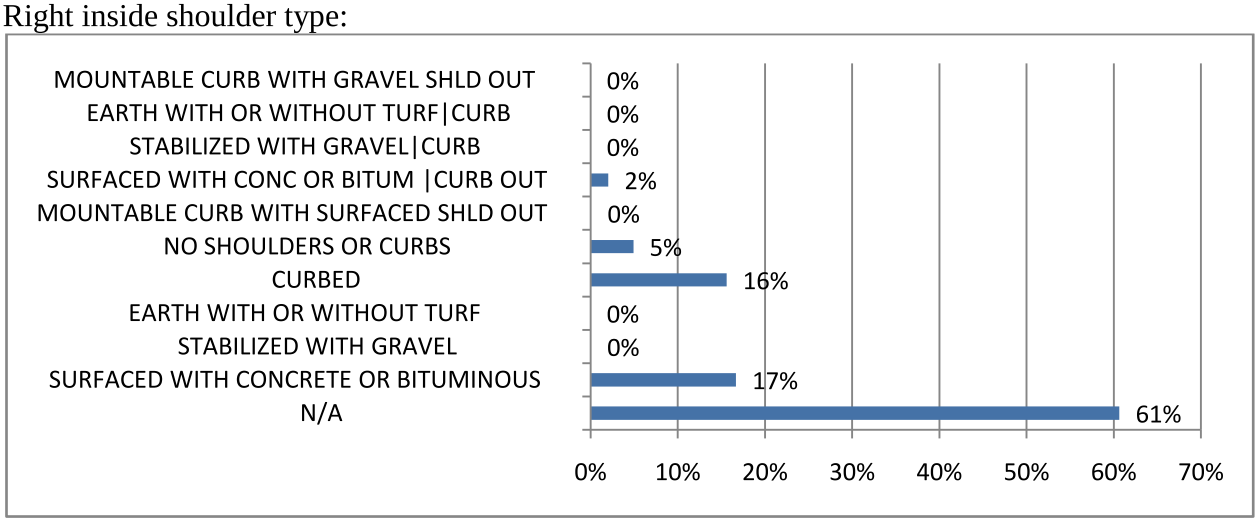


Figure 27: Motorcycle Crashes and Shoulder Type

Truck Route

Most crashes happened on the road sections that are not designated truck routes. Only 13 percent of the crashes happened on designated truck routes (Figure 28).

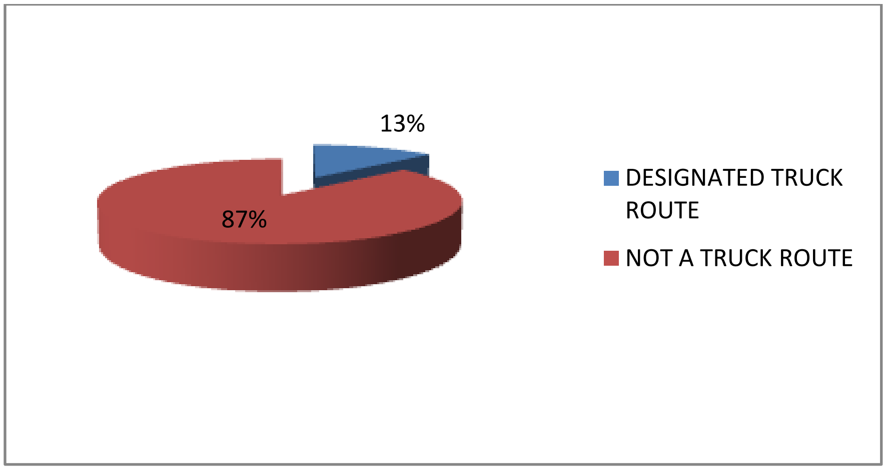


Figure 28: Motorcycle Crashes and Truck Routes

Annual Average Daily Traffic (AADT)

There is no specific AADT group in which motorcycle crashes are very high. As presented in Figure 29, the highest percentage of motorcycle crashes happened on roads with AADT of 10,000-50,000 (47 percent).

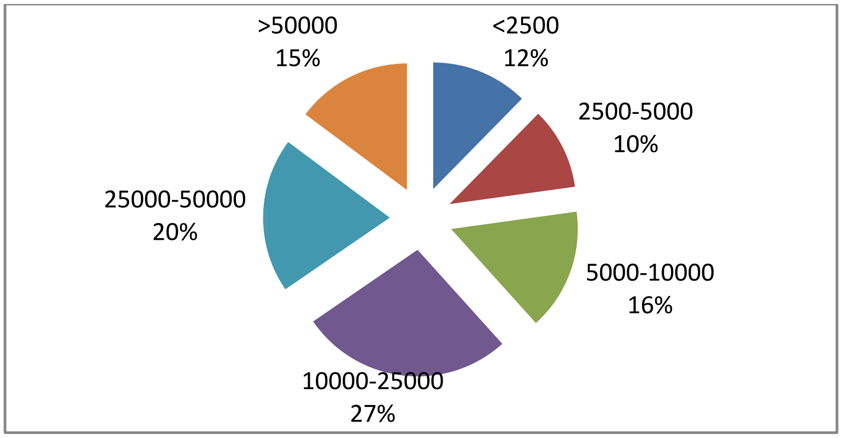


Figure 29: Motorcycle Crashes and AADT

Injury Severity

Figure 30 categorizes the severity of injuries from the examined crashes as fatal, injured, possible injury, or disabled. Most crashes involved multiple injuries, but only 5 percent of crashes resulted in fatalities.

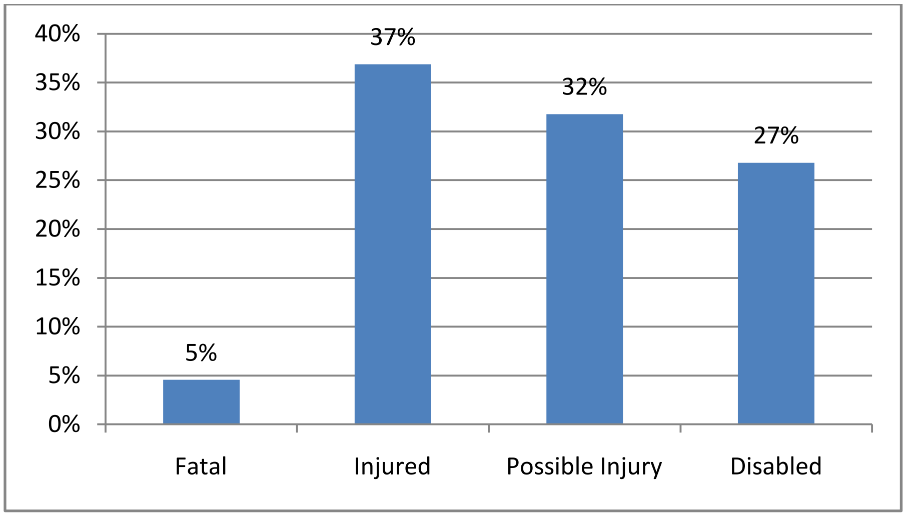


Figure 30: Injury Severity in Motorcycle Crashes

As presented in Figure 31, the percentage of injured motorcyclists more than doubled from 1998 to 2007. The fatality percentage increased over these years as well. However, the percentage of drivers disabled in crashes fluctuated.

The research team also compared the fatality trend in Maryland to the national fatality trend from 1994 to 2007. The national trend data was obtained from the Fatality Analysis Reporting System. Since the number of fatalities in Maryland was much lower than the national number, the research team divided the national fatality numbers by 100 so that both trends could be seen clearly. As presented in Figure 32, Maryland's fatality rate was typical of the national trend.

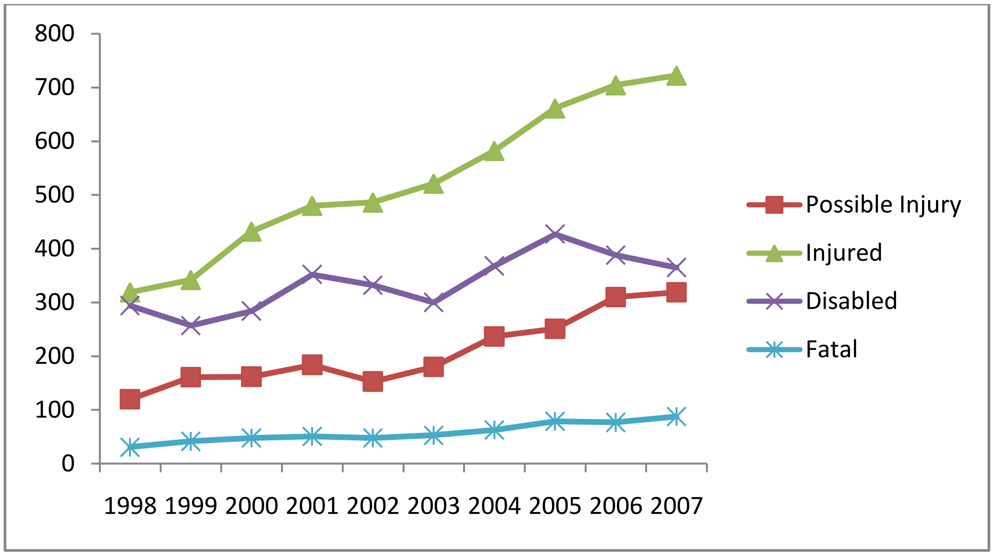


Figure 31: Injury Severity in Motorcycle Crashes per Year

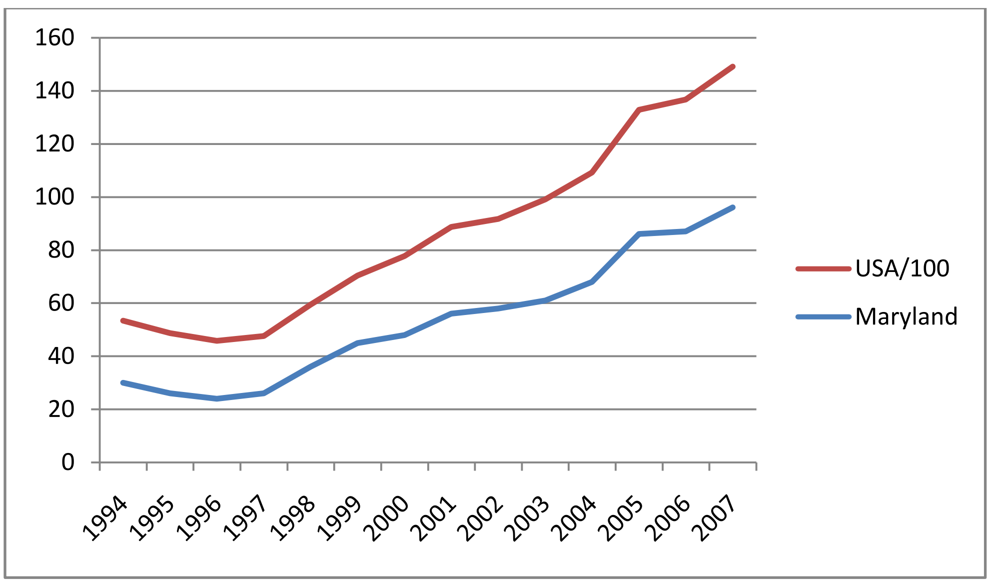


Figure 32: Motorcycle Fatality Trend in Maryland vs. National Trend

Crash Time and Day

Most crashes occurred on the weekend between 9 a.m. and 4 p.m., probably because cyclists use their motorcycles more as a hobby rather than as a regular mode of transportation (Figures 33 and 34).

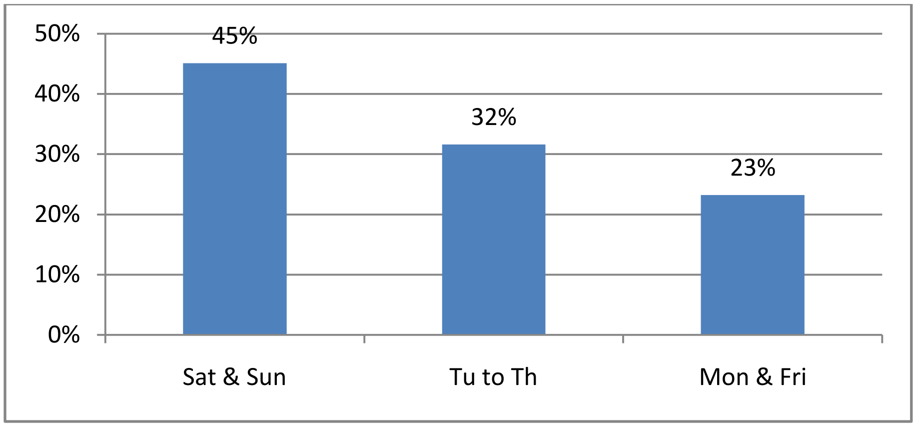


Figure 33: Weekday Variables

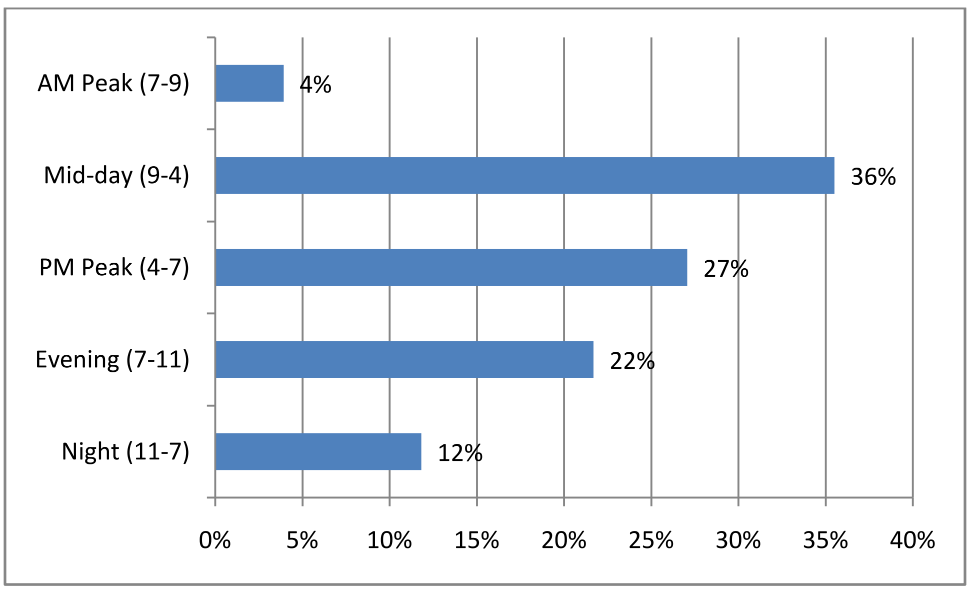


Figure 34: Crash Time Variables

Drivers' Gender

As presented in Figure 35, men were the motorcycle drivers in 93 percent of crashes. The number of crashes involving male drivers more than doubled from 1998 to 2006, while the number of crashes involving female drivers increased less rapidly during this period. This is probably because most motorcycle riders are men.

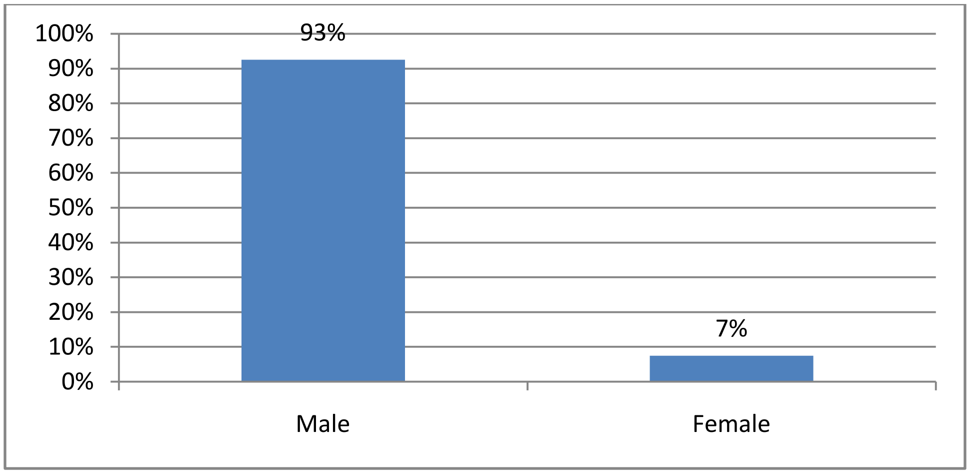


Figure 35: Motorcycle Drivers' Gender

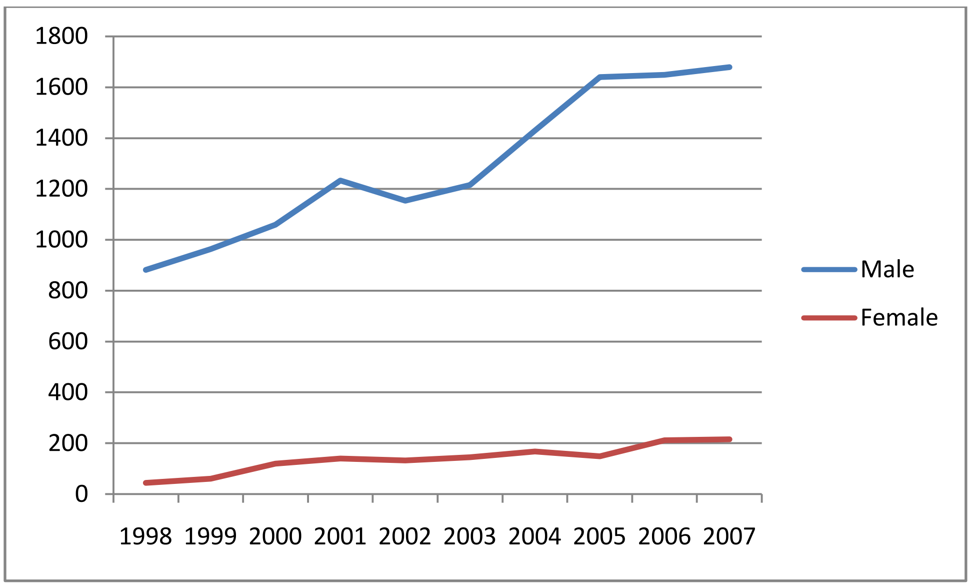


Figure 36: Motorcycle Drivers' Gender (1998-2007)

Drivers' Age

Figure 37 shows that the 20- to 45-year-old age group is responsible for most crashes, and the peak number of crashes occurred at age 22. Figure 38 presents the percentages of motorcycle crashes by age for each year.

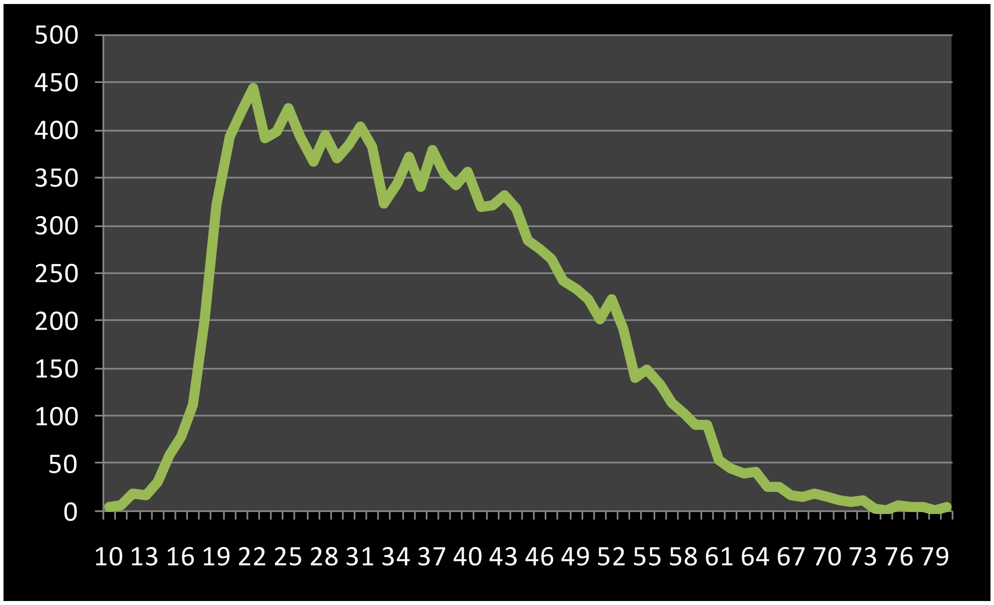


Figure 37: Motorcycle Drivers' Age

Drivers' Condition

As presented in Figure 39, 79 percent of motorcycle drivers were in normal condition. Only 7 percent were drunk, and the percentage of drivers who were fatigued or were under the influence of drugs was almost zero.

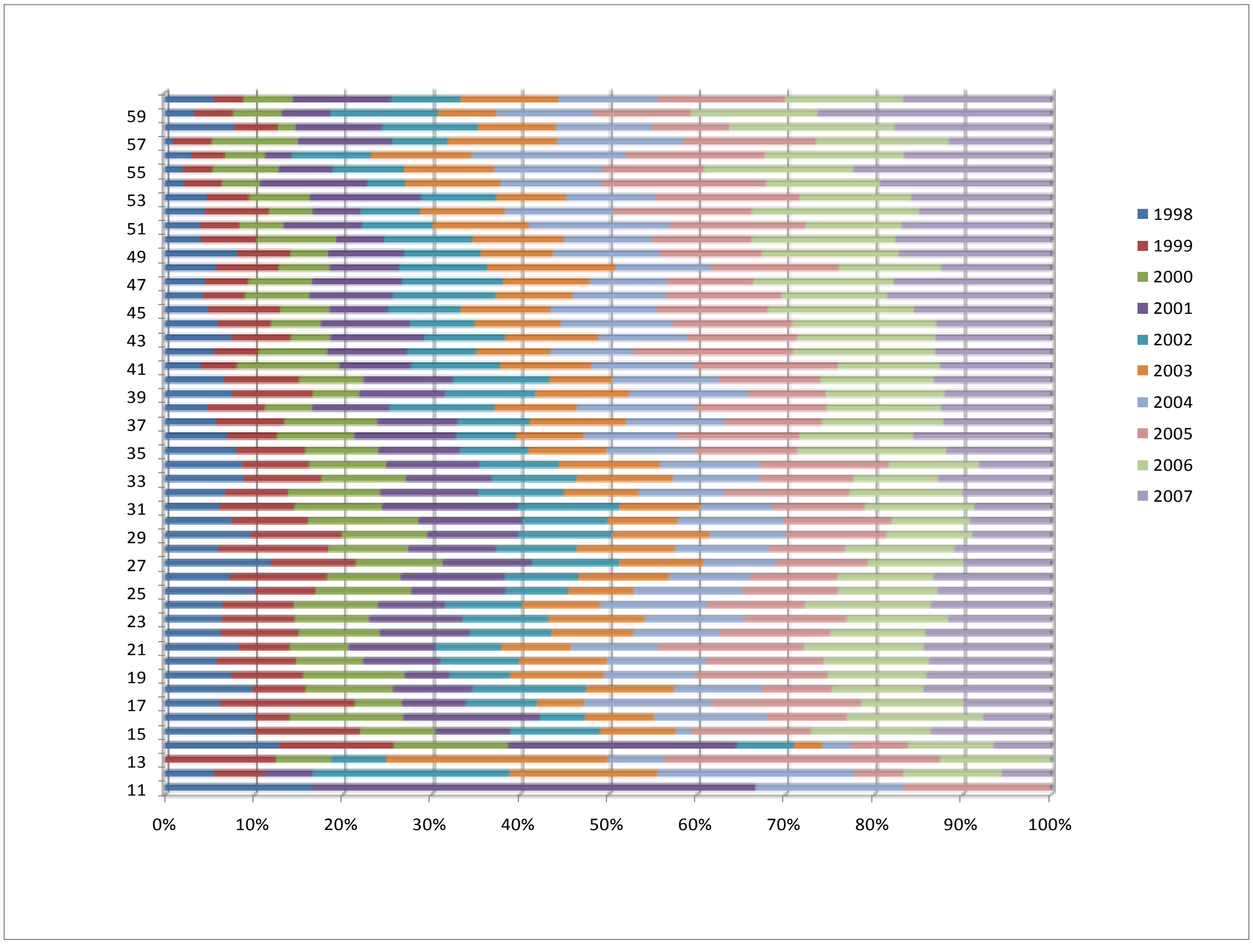


Figure 38: Motorcycle Drivers' Age in Each Year

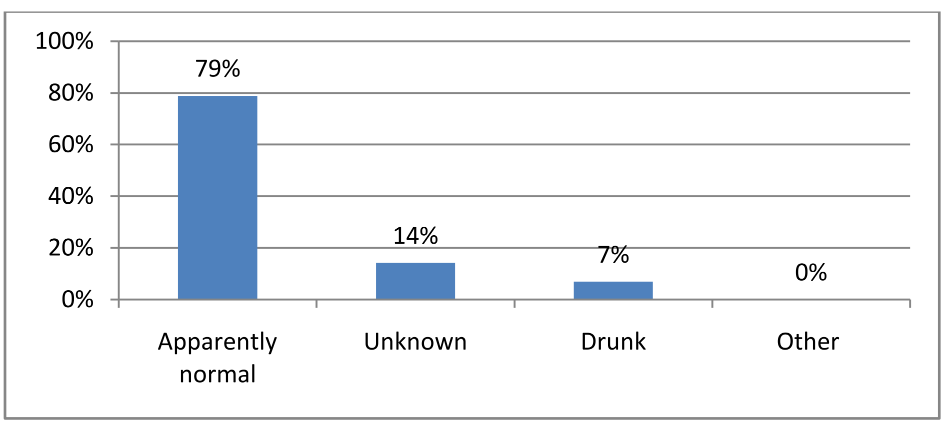


Figure 39: Drivers' Condition

Safety Equipment Usage

As presented in Figure 40, more than 70 percent of the drivers involved in the crashes were using a helmet or both a helmet and shield.

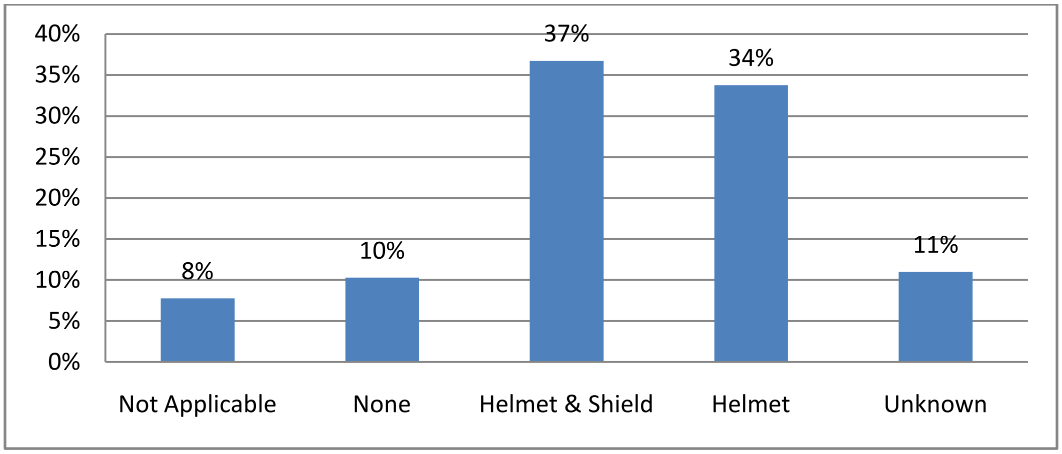


Figure 40: Safety Equipment Usage

The preliminary data analysis indicates that most motorcycle crashes happened on state roads with no access control and a speed limit of 40-55 mph. These roads are urban-other-principal arterials, urban minor arterials, or urban collectors. The roads are mostly undivided, two-way roads with two through marked lanes and no auxiliary lanes.

The crashes typically occurred during the day when weather conditions were sunny or cloudy and the road surface was dry. The majority of crashes were single-vehicle collisions in which the motorcycle was moving straight in a constant speed far from an intersection. The drivers, who were mostly 20-to-45-year-old men, were in normal condition and using helmets.

Prince George's County, Baltimore County, Baltimore City, Anne Arundel County, and Montgomery County, had the highest percentage of the motorcycle crashes.

Based on this analysis, it seems that SHA needs to concentrate on undivided, two-way urban arterial roads in the aforementioned areas. The following section will present the research team's statistical analysis.

METHODOLOGY

A conventional statistical analysis would not produce acceptable results because of the crash data's not normal distribution, large amount of categorical information, and missing values. Therefore, the following methods and software were studied and tested in order to make a reasonable analysis of the motorcycle crash data: Bayesian networks (BNs), fault tree analysis (FTA), factor analysis, categorical principal component analysis (CATPCA), variable reduction, generalized linear model (GLM), categorical regression (CATREG), and ordinal logistic model. FTA, variable reduction, and CATPCA were used to explain the current situation and to find the most important factors that caused motorcycle crashes in Maryland. CATREG was also used to predict the number of crashes on each road type.

Data Classification

In order to perform the analyses, the data was organized in the following categories:

- Rural/Urban: The crash happened on a rural or urban road.
- Road Class: The road on which the crash happened was a freeway & interstate, arterial, collector, or local.
- Age: Driver's age. This was broken into four subcategories: less than 25, 25 to 40, 40 to 55, and 55+. If the driver's age was unknown or missing, it was tagged as not available (NA).
- Sex: Driver's gender. For the few unknown entries, the amount was distributed evenly to avoid the creation of unnecessary categories.
- Weekday: The data was divided into three major categories: Monday and Friday (special weekday), Tuesday to Thursday (regular weekday), and Saturday and Sunday (weekend). Monday and Friday were separated from the other weekdays, since they are the first and last day of the weekdays and drivers may have different behavior.
- Acc_Time: The most important issue regarding crash time was whether the crash happened during peak hours. Based on the data distribution, 7 a.m. to 9 a.m. was defined as AM peak, 9 a.m to 4 p.m. was defined as mid-day off peak, 4 p.m. to 7 p.m. was defined as evening peak, 7 p.m. to 11 p.m. was defined as evening off peak, and 11 p.m to 7 a.m. was defined as night.
- Surf_Cond: Surface conditions were originally classified as dry, wet, snow, ice, or mud; however, less than 0.1 percent of crashes involved snow, ice, or mud. As a result, those crashes were grouped as wet and the data was simply distributed as dry or not dry.
- Weather: Weather conditions were originally classified as clear/cloudy, fog, rain, snow/sleet, or severe wind. However, they were re-grouped only as "clear/cloudy" or "not clear."
- Light: This variable was regrouped as daylight and dark.
- Speed_Limit: The speed limit of the road.
- GOV_Ctrl: This variable is based on the government entity that controls and maintains each specific road segment. This was classified as state highway, county, and others (e.g., municipality, private, military, etc.).
- Intersect: Y (yes) and N (no) indicate whether the crash took place at or near an intersection.
- IRI: The international roughness index of the road.

- Road_Div: Road division was reclassified as “undivided,” “divided with barrier,” “divided with no barrier,” and “other.”
- AADT: Average annual daily traffic of the road.
- Meadian_TY: The type of median was “curbed,” “positive barrier,” “unprotected,” “undivided,” “center TLA (undivided),” “roundabout,” and “painted.”
- Left_out_shoulder: Left outside shoulder type was reclassified as “curbed,” “surface with concrete or bituminous,” and “no shoulder or curbs.”
- Right_out_shoulder: Right outside shoulder type was reclassified as “curbed,” “surface with concrete or bituminous,” and “no shoulder or curbs.”
- Left_out_shoulder_Width: Width of the left outside shoulders.
- Right_out_shoulder_Width: Width of the right outside shoulders.
- Left_in_shoulder: Left inside shoulder type was reclassified as “curbed,” “surface with concrete or bituminous,” and “no shoulder or curbs.”
- Right_in_shoulder: Right inside shoulder type was reclassified as “curbed,” “surface with concrete or bituminous,” and “no shoulder or curbs.”
- Left_in_shoulder_Width: Width of the left inside shoulders.
- Right_in_shoulder_Width: Width of the right inside shoulders.

Other variables that were the same more than 90 percent of the time, such as ITS, were not considered.

Fault Tree Analysis

Fault tree analysis (FTA) was implemented to find the combination of the variables that best cause motorcycle crashes. FTA is a hierarchical model that is typically used to analyze risk, but some researchers are starting to use it for crash analysis. FTA graphically represents the causal relations obtained when a system failure is traced backward. In this case, a crash would be considered a system failure. FTA determines the minimum cut set (i.e., the smallest chain of events) that cause a failure.

In order to perform the FTA, the factors were grouped as crash or road characteristics. Crash characteristics are the variables that are related to the crash, crash environment, and the driver (e.g., the driver’s age and gender, the weather, day, and time of crash). Road characteristics are the variables related to the road (e.g., speed limit, IRI, number of lanes). Tables 1 and 2 present part of the FTA results.

COLLTYPEINJ SEVAGESexweekdayACC_TIMELIGHTWeather	NUMBER
Single VehicleInjured25 - 40MaleSat & SunPM Peak (4-7)DaylightClear/Cloudy	67
Single VehicleInjured25 - 40MaleSat & SunMid-day off peak (9-4)DaylightClear/Cloudy	66
Single VehicleInjured40 -55MaleSat & SunMid-day off peak (9-4)DaylightClear/Cloudy	60
Single VehicleDisabled40 -55MaleSat & SunMid-day off peak (9-4)DaylightClear/Cloudy	38
Single VehicleDisabled25 - 40MaleSat & SunMid-day off peak (9-4)DaylightClear/Cloudy	38
Single VehicleDisabled25 - 40MaleSat & SunPM Peak (4-7)DaylightClear/Cloudy	35
Single VehiclePossible Injury25 - 40MaleSat & SunPM Peak (4-7)DaylightClear/Cloudy	35
Single VehiclePossible Injury25 - 40MaleSat & SunMid-day off peak (9-4)DaylightClear/Cloudy	33
Single VehicleDisabled40 -55MaleSat & SunPM Peak (4-7)DaylightClear/Cloudy	32
Same Dir Rear EndPossible Injury40 -55MaleSat & SunMid-day off peak (9-4)DaylightClear/Cloudy	32
Single VehicleInjured55 +MaleSat & SunMid-day off peak (9-4)DaylightClear/Cloudy	30
Single VehiclePossible Injury40 -55MaleSat & SunMid-day off peak (9-4)DaylightClear/Cloudy	30
Single VehicleInjuredless than 25MaleSat & SunPM Peak (4-7)DaylightClear/Cloudy	30
Single VehicleInjured40 -55MaleSat & SunPM Peak (4-7)DaylightClear/Cloudy	30

Table 1: Fault Tree Analysis for the Crash Characteristics

AREA_TYPEFUNC_CLGOVT_CONTRROUGHNESSSPEED_LIMIAADTMEDIAN_WDSURFCONDINTRSECTRoad DivisionLT_OUT_TYRT_OUT_TYMEDIAN_TYLT_OUT_WRT_OUT_WLT_IN_WRT_IN_W	
RURALCOLLECTORCounty NANALess than 2500NADryNNot Divided no shoulder or curbsno shoulder or curbsCENTER TLA (UNDIV)NANANANA	146
RURALLOCAL County NANALess than 2500NADryNNot Divided no shoulder or curbsno shoulder or curbsCENTER TLA (UNDIV)NANANANA	85
URBANFREEWAYState Highway Good40 to 55More than 500000 to 9DryNDivided with barriersurfaced with concrete or bituminoussurfaced with concrete or bituminousUNPROTECTED	61
RURALCOLLECTORCounty NANA2500 to 5000NADryNNot Divided no shoulder or curbsno shoulder or curbsCENTER TLA (UNDIV)NANANANA	60
RURALCOLLECTORState Highway Fair5 to 402500 to 5000NADryNNot Divided no shoulder or curbsno shoulder or curbsCENTER TLA (UNDIV)NANANANA	43
URBANARTERIALCounty NANA10000 to 25000NADryNNot Divided curbedcurbedCENTER TLA (UNDIV)NANANANA	42
URBANLOCAL County NANALess than 2500NADryNNot Divided no shoulder or curbsno shoulder or curbsCENTER TLA (UNDIV)NANANANA	41
URBANLOCAL County NANALess than 2500NADryYNot Divided curbedcurbedCENTER TLA (UNDIV)NANANANA	39
URBANFREEWAYState Highway Good40 to 55More than 5000010+DryNDivided with barriersurfaced with concrete or bituminoussurfaced with concrete or bituminousUNPROTECTED	37
URBANCOLLECTORCounty NANA2500 to 5000NADryNNot Divided no shoulder or curbsno shoulder or curbsCENTER TLA (UNDIV)NANANANA	36
URBANLOCAL County NANALess than 2500NADryNNot Divided curbedcurbedCENTER TLA (UNDIV)NANANANA	36
URBANLOCAL County NANALess than 2500NADryYDivided no barriercurbedcurbedCENTER TLA (UNDIV)NANANANA	34
RURALLOCAL County NANALess than 2500NADryYNot Divided no shoulder or curbsno shoulder or curbsCENTER TLA (UNDIV)NANANANA	34
URBANLOCAL County NANALess than 2500NADryYNot Divided no shoulder or curbsno shoulder or curbsCENTER TLA (UNDIV)NANANANA	31

Table 2: Fault Tree Analysis for the Road Characteristics

The crash characteristic results indicate that the highest crash frequency (67) was a single vehicle crash on a weekend during the day in clear/cloudy weather. The driver, a 25- to 40-year-old male, was injured.

The road characteristic results indicate that the highest crash frequency (146) was on a county-maintained rural collector road. The road, which had a dry surface, is undivided, has no shoulder or curb, and has an AADT less than 2500.

Variable Selection

Variable selection is a statistical method used to identify the most important factors (X_is) that affect the variable under study (Y). Y in this section refers to the total number of crashes in each combination of variables. The variable selection was done by using two different stepwise regressions (adding or deleting variables one at a time). The forward selection method sequentially adds variables to the model, while the backward elimination method sequentially deletes variables from the model. In each stage, the variable is added to the model if it has the highest partial correlation, increases the R^2, and produces the largest absolute t or F statistics. The backward elimination deletes the variable with the smallest absolute t or F statistic.

Since most of the variables were categorical or ordinal, each variable was converted into several dummy binary variables. The variable with *n* classes was transformed into n-1 binary variables. Similar to the previous section, the variables were categorized into two groups, crash characteristics (ergonomic) and road characteristics. The two variable groups and their transformations are presented in Tables 3 and 4. The crash characteristics that had the highest effect on the number of crashes were gender, age, crash time, light, and weather condition.

Ergonomic Variables							
AGE		Sex		weekday		Accident Time	
25 - 40	AGE1	Female	Sex1	Mon & Fri	wee1	AM Peak (7-9)	TIM1
40 -55	AGE2	Male	Sex2	Sat & Sun	wee2	Evening off-peak (7-11)	TIM2
55 +	AGE3			Tu to Th	wee3	Mid-day off peak (9-4)	TIM3
less than 25	AGE4					Nigh (11-7)	TIM4
						PM Peak (4-7)	TIM5
LIGHT		Weather		Speed Limit			
Dark-Lights On	LIT1	Clear/Cloudy	Wter1	5 to 40			
Dark-No Lights	LIT2	Not Clear	Wter2	40 to 55			
Dawn/Duck	LIT3			55+			
Daylight	LIT4						

Table 3: The Crash Variables and Their Transformations

Among the road variables, road class, surface condition, government control, intersection, IRI, AADT, left outside and inside shoulder type, and median type were the most important factors in motorcycle crashes.

Road Characteristic Variables											
Rural or Urban		Road Class		SURFCOND		GOVT_CONTR		INTRSECT		ROUGHNESS	
Rur	Rural	Arterial	R_C1	Dry	SUR1	County	G_C1	No	INTR1	Fair	ROUF1
Urb	Urban	Collector	R_C2	Not Dry	SUR2	State Highway	G_C2	Yes	INTR2	Good	ROUF2
		Freeway & Interstate	R_C3							Poor	ROUF3
		Local	R_C4								
Road Division		Right Out Shoulder Wide		Right Out Shoulder Type		Left Out Shoulder Wide		Left Out Shoulder Type		Inside Shoulder	
Divided no barrier	RDi1	0 to 9	ROW1	*CURBED*	ROT1	0 to 9	LOW1	*CURBED*	LOT1	*CURBED*	INR1
Divided with barrier	RDi2	*10+*	ROW2	*NO SHOULDERS OR CURBS*	ROT2	*10+*	LOW2	*NO SHOULDERS OR CURBS*	LOT2	*SURFACED WITH CONCRETE OR BITUMINOUS*	INR2
Not Divided	RDi3	No SHL	ROW3	*SURFACED WITH CONCRETE OR BITUMINOUS*	ROT3	No Shoulder	LOW3	*SURFACED WITH CONCRETE OR BITUMINOUS*	LOT3	*NO SHOULDERS OR CURBS*	INR3

AADT	Median Type	
less than2500	CENTER TLA (UNDIV)	M_T1
2500_5000	CURBED	M_T2
5000_15000	NONE (UNDIV)	M_T3
15000_25000	PAINTED	M_T4
25000_35000	POSITIVE BARRIER	M_T5
35000_45000	ROUNDABOUT	M_T6
45000_55000	UNPROTECTED	M_T7
55000_65000		
more than 65000		

Table 4: The Road Variables and Their Transformations

Factor Analysis and Categorical Principal Component Analysis

Factor analysis, a statistical method, identifies the underlying variables that explain the pattern of correlations within a set of observed variables. Factor analysis is generally utilized in variable reduction (i.e., to specify the minimum number of variables that explain most of the observed variance). It can also be used to generate hypotheses regarding causal mechanisms or to screen variables for subsequent analysis.

Categorical principal component analysis (CATPCA), which is factor analysis for categorical data, quantifies categorical variables while reducing the dimensionality of the data. This method reduces variables to a smaller set of uncorrelated variables (components) that represent most of the information in the original variables. CATPCA is most useful when a large number of variables prohibit a reasonable relationship between the dependent and independent variables. Since there were a number of categorical variables, CATPCA was used to group the variables and reduce the number of variables in the regression model. A summary of the analysis is presented in Tables 5-7.

The component loading table (Table 5) shows the extent of the relationship between each variable and each user-defined dimension. After trying different dimensions, it was concluded that the best model had 10 dimensions. The table is colorized so that the relationships are clear. Blue cells have the highest relation to their dimension.

Table 6 presents the final variable grouping produced by the factor analysis (optimal scaling). Age, median width, road class, road division, intersection, and rural/urban were placed in a separate category and used as individual inputs for the regression because they did not correlate with any dimensions. Also, no variable could be associated with category 10, so it was removed in the final table (Table 6). Based on the results, two pairs of categories—Surface Condition and Weather, and Light and Crash Time—essentially described the same thing. As a result, only one variable was used (e.g., Surface Condition, Light, etc.) from each pair in the regression analysis.

	Dimension									
	1	2	3	4	5	6	7	8	9	10
Column1	Colun	Colur	Colur	Colu	Colu	Colu	olu	olu	olu	olun
Road_Div	-.502	.313	.117	.021	.321	.025	.051	-.074	-.081	.075
Lt_In_Sh	-.180	.802	.311	-.007	.053	-.003	.207	.274	-.013	-.022
Rt_In_Sh	-.179	.798	.322	-.005	.054	-.002	.207	.271	-.004	-.018
Intersect	-.164	-.247	-.017	-.057	-.003	.036	.057	.199	.472	-.526
IRI	-.144	-.306	-.363	-.045	.547	.124	.393	.151	-.136	.137
Light	-.055	.052	-.001	-.147	-.061	.760	-.188	.084	.067	-.044
Age	-.050	.153	-.101	.043	-.066	.272	.325	-.426	.361	-.399
Acc_Time	-.036	.015	-.017	-.102	-.063	.722	-.242	.195	-.024	.233
Sex	.000	.022	-.007	-.042	.035	-.111	.054	-.069	.755	.631
Weekday	.001	-.092	.043	-.059	.094	-.168	-.147	.641	.226	-.137
Surf_Cond	.004	-.027	-.032	.882	.053	.094	-.045	.059	.027	-.008
Weather	.038	-.033	-.028	.879	.047	.084	-.063	.072	.050	.022
Rural/Urban	.259	-.469	.084	-.066	.276	-.118	-.212	.241	.043	-.073
Lt_Out_Sh_W	.289	-.336	.664	.034	-.141	.084	.352	.019	-.041	.057
Rt_Out_Sh_W	.305	-.286	.661	.041	-.130	.088	.333	.026	-.019	.059
Road Class	.331	.447	.359	.034	-.065	-.038	-.261	-.129	.004	.029
Rt_Out_Sh	.375	.593	-.464	-.009	-.063	-.063	-.054	.009	.018	-.009
Lt_Out_Sh	.414	.610	-.431	.005	-.058	-.059	-.068	.024	.031	-.022
GOV_Ctrl	.429	.038	-.531	.002	.160	.145	.535	.123	-.052	.056
Median_W	.567	.039	-.096	.012	-.551	-.055	.090	.226	-.034	.043
Lt_In_Sh_W	.676	.263	.271	-.029	.465	.040	-.133	-.135	.050	-.080
Rt_In_Sh_W	.677	.256	.277	-.033	.459	.039	-.137	-.137	.061	-.080
Speed_Limit	.772	.395	-.012	.021	-.219	.034	.143	.048	.002	-.002
Lane	.830	-.376	-.050	-.023	.055	.029	-.019	.005	-.009	.009
Median_TY	.832	-.360	-.159	-.009	-.111	-.013	-.056	-.028	-.005	-.010
AADT	.896	-.030	.028	-.026	.180	.032	.007	.044	-.006	-.001

Table 5: Component Loadings

The Left and Right Shoulder Types and Shoulder Widths were combined since left and right shoulders were always in the same group. Similarly, only Out-Shoulder-Type and Out-Shoulder-Width were used since they were similar to In-Shoulder-Type and In-Shoulder-Width. In-Shoulder-Type and In-Shoulder-Width were also missing many data points. Although AADT, median type, speed limit, and number of lanes are in the same group, they were used separately in the regression analysis because they are important factors in motorcycle crashes. Therefore, regression analysis was used to find which of the aforementioned factors had more of an effect on the number of crashes.

	1	2	3	4	5	6	7	8	9
Age	Lane	Lt_In_Sh	Lt_Out_Sh_W	Weather	IRI	Light	GOV_Ctrl	Weekday	Sex
Road Class	Lt_In_Sh_W	Rt_In_Sh	Rt_Out_Sh_W	Surf_Cond		ACC_Time			
Road_Div	Rt_In_Sh_W	Lt_Out_Sh							
Intersect	AADT	Rt_Out_Sh							
Rural/Urban	Median_TY								
Median_W	Speed_Limit								

Table 6: Variable Grouping

The research team rearranged the data prior to the regression analysis in order to find the number of crashes for each road segment. The road segments were defined by SHA in the road inventory data. The new data set contained 5,308 data points. The number of crashes, which is discrete, was used as the dependent variable in the regression model.

Generalized Linear Model (GLM)

As stated earlier, most of the data was ordinal and categorical. Also, the probability distribution of the dependent variable within each road class fit the logarithmic function. Therefore, a special case of GLM, called ordinal logistic model, was used. The model assumes that there is a continuous outcome variable, and the observed ordinal outcome results from discretizing the scale into j-ordered groups. The model is as follows.

Equation 1: The Ordinal Logistic Model

$$\ln\left(\frac{\gamma_i}{1-\gamma_i}\right) = \frac{\theta_j - [\beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k]}{\exp(\tau_1 z_1 + \tau_2 z_2 + \ldots + \tau_m z_m)}$$

where, γj is the cumulative probability of the *j*th category, θj is the threshold for the *j*th category, β_is (i= 1-k) are the regression coefficients, x_is are the predictor variables, k is the number of predictors, and τ_ls and z_ls (l=1-m) are coefficients and predictor variables for the scale component. $\ln\left(\frac{\gamma_i}{1-\gamma_i}\right)$ is the Logit function. The numerator presents the location of the model and the denominator presents the scale. z_ls are chosen from the same set of variables as the x_is. The scale variables improve the model when there are variables with large variances.

The regression was conducted on all roads as well as the four road classes (freeway, arterial, collector, and local) to predict the number of crashes. Tables 7-16 present the regression results.

All Roads Combined

Based on the regression results for the 5,308 records, the most important factors in motorcycles crashes on all roads are area type, median type, speed limit, AADT, IRI, and number of through lanes for 90 percent confidence interval. The coefficients of many other variables are not significantly different from zero (Table 8); however, removing them from the model would worsen it. There is a higher probability of motorcycle crashes in rural areas than in urban areas. Roads with a speed limit of 25-60 mph are more likely to have more motorcycle crashes than roads with other speed limits.

The probability of event *j* (number of crashes =*j*) can be calculated as

Equation 2: The Probability of Output Events

$$\text{Prob}\,(\text{event } j) = \frac{1}{1 + e^{\frac{-(\alpha_j - \beta x)}{\exp(\tau z)}}}$$

As presented in Table 7, the difference between the two log-likelihoods has a significant level of 0.000. Therefore, the null hypothesis (both the location and scale parameters are zero) is rejected. The three pseudo R^2—Cox and Snell (0.749), Nagellkerke (0.992), and McFadden (0.983)—are high enough to demonstrate that the dependent variable is significantly related to the independent variables (Cameron and Trivedi, 1998). Over 80 percent of the observed number of crashes fit the model based on the predicted values. Crash numbers not included in this data set can be found through interpolation or extrapolation.

Model Fitting Information

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	1517.752			
Final	.000	1517.752	43	.000

Link function: Logit.

Table 7: Regression Results for All Roads Combined (Model Fitting)

		Estimate	Std. Error	Wald	df	Sig.	Interval	
							Lower	Upper
Threshold	[NUMBER_OF_ACCIDENTS = 1]	1.597	.607	6.919	1	.009	.407	2.786
	[NUMBER_OF_ACCIDENTS = 2]	3.163	1.044	9.178	1	.002	1.117	5.209
	[NUMBER_OF_ACCIDENTS = 3]	4.504	1.540	8.557	1	.003	1.486	7.522
	[NUMBER_OF_ACCIDENTS = 4]	6.636	2.425	7.492	1	.006	1.884	11.388
	[NUMBER_OF_ACCIDENTS = 5]	7.446	2.795	7.098	1	.008	1.968	12.923
	[NUMBER_OF_ACCIDENTS = 6]	8.129	3.130	6.747	1	.009	1.995	14.263
	[NUMBER_OF_ACCIDENTS = 7]	9.376	3.818	6.032	1	.014	1.894	16.858
Location	[AREA_TYPE=RURAL]	.522	.260	4.034	1	.045	.013	1.031
	[AREA_TYPE=URBAN]	0[a]	.	.	0	.	.	.
	[GOVT_CONTR=County]	-3.935	8.969	.192	1	.661	-21.513	13.644
	[GOVT_CONTR=Other]	-.421	.570	.546	1	.460	-1.539	.697
	[GOVT_CONTR=State Highway]	0[a]	.	.	0	.	.	.
	[MEDIAN_TY=NA]	1.035	.518	3.998	1	.046	.020	2.049
	[MEDIAN_TY=NONE (UNDIV)]	-.029	.236	.015	1	.902	-.492	.434
	[MEDIAN_TY=POSITIVE BARRIER]	.599	.426	1.972	1	.160	-.237	1.435
	[MEDIAN_TY=ROUNDABOUT]	.258	1.275	.041	1	.839	-2.240	2.756
	[MEDIAN_TY=UNPROTECTED]	0[a]	.	.	0	.	.	.
	[SH_OUT_TY=surfaced with concrete or bitu]	0[a]	.	.	0	.	.	.
	[SPEED_LIMI_AC=25]	2.862	1.303	4.826	1	.028	.308	5.415
	[SPEED_LIMI_AC=30]	-2.170	2.267	.917	1	.338	-6.613	2.272
	[SPEED_LIMI_AC=35]	-1.869	1.903	.965	1	.326	-5.599	1.861
	[SPEED_LIMI_AC=40]	-1.838	1.413	1.691	1	.194	-4.608	.932
	[SPEED_LIMI_AC=45]	-.351	.609	.332	1	.565	-1.544	.843
	[SPEED_LIMI_AC=50]	-.293	.424	.480	1	.488	-1.124	.537
	[SPEED_LIMI_AC=55]	.158	.302	.275	1	.600	-.434	.750
	[SPEED_LIMI_AC=60]	1.035	.453	5.215	1	.022	.147	1.923
	[SPEED_LIMI_AC=65]	0[a]	.	.	0	.	.	.
	SH_OUT_W_AC	.016	.028	.312	1	.576	-.040	.071
	THROUGH_LA_AC	-.125	.130	.932	1	.334	-.380	.129
	AADT_AC	.000	.000	3.376	1	.066	.000	.000
	MEDIAN_WACD	-.002	.002	.740	1	.390	-.007	.003
	ROUGHNESS_AC	.004	.002	2.991	1	.084	.000	.008
	[RoadDivision=Divided no barrier]	-.124	.276	.203	1	.653	-.665	.417
	[RoadDivision=Divided with barrier]	-.338	.307	1.213	1	.271	-.940	.264
	[RoadDivision=Not Divided]	-.079	.341	.054	1	.817	-.747	.589
	[RoadDivision=Other]	0[a]	.	.	0	.	.	.
Scale	[AREA_TYPE=RURAL]	-.660	.190	12.056	1	.001	-1.033	-.288
	[AREA_TYPE=URBAN]	0[a]	.	.	0	.	.	.
	[GOVT_CONTR=County]	.888	1.032	.742	1	.389	-1.134	2.911
	[GOVT_CONTR=Other]	-.003	.289	.000	1	.991	-.570	.563
	[GOVT_CONTR=State Highway]	0[a]	.	.	0	.	.	.
	[MEDIAN_TY=NA]	-2.027	.773	6.875	1	.009	-3.542	-.512
	[MEDIAN_TY=NONE (UNDIV)]	-.313	.163	3.660	1	.056	-.633	.008
	[MEDIAN_TY=POSITIVE BARRIER]	-.381	.237	2.588	1	.108	-.845	.083
	[MEDIAN_TY=ROUNDABOUT]	-.054	.474	.013	1	.909	-.983	.875
	[MEDIAN_TY=UNPROTECTED]	0[a]	.	.	0	.	.	.
	[SH_OUT_TY=surfaced with concrete or bitu]	0[a]	.	.	0	.	.	.
	[SPEED_LIMI_AC=25]	-4.155	5.215	.635	1	.426	-14.375	6.066
	[SPEED_LIMI_AC=30]	.586	.582	1.013	1	.314	-.555	1.727
	[SPEED_LIMI_AC=35]	.340	.545	.390	1	.532	-.727	1.408
	[SPEED_LIMI_AC=40]	.261	.392	.444	1	.505	-.507	1.029
	[SPEED_LIMI_AC=45]	-.045	.309	.021	1	.884	-.650	.560
	[SPEED_LIMI_AC=50]	-.144	.242	.354	1	.552	-.620	.331
	[SPEED_LIMI_AC=55]	-.220	.188	1.374	1	.241	-.588	.148
	[SPEED_LIMI_AC=60]	-1.593	.573	7.718	1	.005	-2.716	-.469
	[SPEED_LIMI_AC=65]	0[a]	.	.	0	.	.	.
	SH_OUT_W_AC	-.017	.021	.649	1	.420	-.058	.024
	AADT_AC	.000	.000	6.330	1	.012	.000	.000
	MEDIAN_WACD	.001	.001	1.824	1	.177	-.001	.004
	THROUGH_LA_AC	.162	.069	5.591	1	.018	.028	.296
	ROUGHNESS_AC	.000	.001	.127	1	.721	-.002	.003

Table 8: Regression Results for All Roads Combined (Coefficients)

Arterial Roads

There are 2,646 arterial road segments. The regression results indicate that the important factors in the number of motorcycle crashes on Maryland's arterial road segments are road division, area type, AADT, shoulder width, median type, and the interaction of IRI, AADT, and shoulder width.

As presented in Table 9, the difference between the two log-likelihoods has a significant level of 0.000. Therefore, the null hypothesis is rejected. The three pseudo R^2—Cox and Snell (0.670), Nagellkerke (0.984), and McFadden (0.971)—are sufficiently high enough to demonstrate that the dependent variable is significantly related to the independent variables.

Model Fitting Information

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	508.550			
Final	.000	508.550	35	.000

Link function: Logit.

Table 9: Regression Results for Arterial Roads (Model Fitting)

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[NUMBER_OF_ACCIDENTS = 1]	11.564	19.894	.338	1	.561	-27.427	50.556
	[NUMBER_OF_ACCIDENTS = 2]	15.284	28.268	.292	1	.589	-40.119	70.688
	[NUMBER_OF_ACCIDENTS = 3]	21.943	44.991	.238	1	.626	-66.237	110.124
	[NUMBER_OF_ACCIDENTS = 4]	27.818	60.364	.212	1	.645	-90.493	146.129
	[NUMBER_OF_ACCIDENTS = 6]	31.753	70.813	.201	1	.654	-107.037	170.543
Location	[AREA_TYPE=RURAL]	4.903	13.228	.137	1	.711	-21.024	30.830
	[AREA_TYPE=URBAN]	0[a]	.	.	0	.	.	.
	[GOVT_CONTR=County]	-15.398	50.691	.092	1	.761	-114.751	83.955
	[GOVT_CONTR=Other]	-5.505	15.221	.131	1	.718	-35.338	24.327
	[GOVT_CONTR=State Hi]	0[a]	.	.	0	.	.	.
	[MEDIAN_TY=NONE (UN]	-.188	.759	.061	1	.805	-1.674	1.299
	[MEDIAN_TY=POSITIVE]	-1.282	3.539	.131	1	.717	-8.218	5.653
	[MEDIAN_TY=ROUNDABO]	-2.434	6.763	.130	1	.719	-15.688	10.821
	[MEDIAN_TY=UNPROTEC]	0[a]	.	.	0	.	.	.
	[THROUGH_LA_AC=2]	10.292	17.624	.341	1	.559	-24.251	44.834
	[THROUGH_LA_AC=3]	6.217	13.421	.215	1	.643	-20.087	32.521
	[THROUGH_LA_AC=4]	6.709	13.255	.256	1	.613	-19.270	32.688
	[THROUGH_LA_AC=5]	3.120	15.370	.041	1	.839	-27.005	33.246
	[THROUGH_LA_AC=6]	6.971	13.535	.265	1	.607	-19.556	33.499
	[THROUGH_LA_AC=7]	0[a]	.	.	0	.	.	.
	AADT_AC	.000	.000	.128	1	.720	-.001	.000
	SH_OUT_W_AC	.295	.822	.129	1	.720	-1.316	1.905
	MEDIAN_WACD	-.003	.010	.111	1	.739	-.024	.017
	ROUGHNESS_AC * SH_OUT_W_AC	-.004	.011	.134	1	.714	-.025	.017
	AADT_AC * ROUGHNESS_AC	.000	.000	.137	1	.711	.000	.000
	[RoadDivision=Divided]	-2.722	7.440	.134	1	.715	-17.305	11.861
	[RoadDivision=Not Divi]	-2.495	6.846	.133	1	.716	-15.913	10.923
	[RoadDivision=Other]	0[a]	.	.	0	.	.	.
Scale	[RoadDivision=Divided]	1.678	.761	4.861	1	.027	.186	3.170
	[RoadDivision=Not Divi]	1.645	.786	4.383	1	.036	.105	3.185
	[RoadDivision=Other]	0[a]	.	.	0	.	.	.
	[AREA_TYPE=RURAL]	-1.721	.379	20.594	1	.000	-2.464	-.978
	[AREA_TYPE=URBAN]	0[a]	.	.	0	.	.	.
	AADT_AC	.000	.000	4.861	1	.027	.000	.000
	SH_OUT_W_AC	-.148	.066	5.020	1	.025	-.278	-.019
	ROUGHNESS_AC * SH_OUT_W_AC	.001	.000	6.980	1	.008	.000	.002
	AADT_AC * ROUGHNESS_AC	.000	.000	10.638	1	.001	.000	.000
	[THROUGH_LA_AC=2]	-1.606	2.620	.376	1	.540	-6.741	3.529
	[THROUGH_LA_AC=3]	.106	2.646	.002	1	.968	-5.080	5.292
	[THROUGH_LA_AC=4]	.359	2.549	.020	1	.888	-4.637	5.354
	[THROUGH_LA_AC=5]	.611	2.585	.056	1	.813	-4.456	5.678
	[THROUGH_LA_AC=6]	-.223	2.556	.008	1	.930	-5.233	4.787
	[THROUGH_LA_AC=7]	0[a]	.	.	0	.	.	.
	[MEDIAN_TY=NONE (UN]	-.224	.215	1.084	1	.298	-.646	.198
	[MEDIAN_TY=POSITIVE]	.075	.222	.115	1	.734	-.360	.510
	[MEDIAN_TY=ROUNDABO]	1.189	.543	4.799	1	.028	.125	2.252
	[MEDIAN_TY=UNPROTEC]	0[a]	.	.	0	.	.	.
	[GOVT_CONTR=County]	1.144	1.031	1.231	1	.267	-.877	3.165
	[GOVT_CONTR=Other]	-.186	1.592	.014	1	.907	-3.305	2.934
	[GOVT_CONTR=State Hi]	0[a]	.	.	0	.	.	.

Table 10: Regression Results for Arterial Roads (Coefficients)

Freeway/Expressway Roads

Table 11 presents the regression results for 678 freeway road segments. The model fitting information rejects the null hypothesis. The three pseudo R^2—Cox and Snell (0.740), Nagellkerke (0.927), and McFadden (0.841)—are sufficiently high and demonstrate that the dependent variable is significantly related to the independent variables.

No variable directly affected the number of motorcycle crashes on freeways because this type of road has a limited range of variables. For example, over 60 percent of freeways are divided, contain barriers, and have a speed limit of 55 mph (Table 12).

Collectors

There are 1,038 collector road segments. The regression results indicate that the important factors in motorcycle crashes on these segments are road division, area type, number of through lanes, IRI, and the interaction of IRI, the number of through lanes, and shoulder width.

As presented in Table 13, the null hypothesis is rejected. The three pseudo R^2—Cox and Snell (0.690), Nagellkerke (0.945), and McFadden (0.895)—are sufficiently high and demonstrate that the dependent variable is significantly related to the independent variables.

Model Fitting Information

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	947.343			
Final	1.164	946.179	14	.000

Table 11: Regression Results for Freeway/Expressway Roads (Model Fitting)

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Threshold	[NUMBER_OF_ACCIDENTS = 1]	1.090	.000	.	1	.	1.090	1.090
	[NUMBER_OF_ACCIDENTS = 2]	.655	.000	.	1	.	.655	.655
	[NUMBER_OF_ACCIDENTS = 3]	.383	.000	.	1	.	.383	.383
	[NUMBER_OF_ACCIDENTS = 4]	-.107	.000	.	1	.	-.107	-.107
	[NUMBER_OF_ACCIDENTS = 5]	-.415	7.170	.003	1	.954	-14.468	13.638
Location	IRI	.015	.213	.005	1	.943	-.402	.433
	THROUGH_LA * IRI	-.003	.035	.006	1	.939	-.071	.065
	AADT_AC * LT_OUT_W_AC	.000	.000	.005	1	.942	.000	.000
	[MEDIAN_TY=NONE (UNDIV)]	-.115	2.139	.003	1	.957	-4.307	4.077
	[MEDIAN_TY=POSITIVE BAR]	1.114	176.123	.000	1	.995	-344.080	346.308
	[MEDIAN_TY=UNPROTECTED]	0[a]	.	.	0	.	.	.
	AADT_AC	.000	.000	.013	1	.911	.000	.000
	THROUGH_LA_AC	.063	2.281	.001	1	.978	-4.408	4.535
Scale	AADT_AC	.000	.000	.019	1	.890	.000	.000
	THROUGH_LA_AC	-.173	1.348	.016	1	.898	-2.815	2.470
	ROUGHNESS_AC	-.019	.077	.061	1	.805	-.170	.132
	[MEDIAN_TY=NONE (UNDIV)]	-.125	1.841	.005	1	.946	-3.734	3.484
	[MEDIAN_TY=POSITIVE BAR]	-.373	74.538	.000	1	.996	-146.465	145.719
	[MEDIAN_TY=UNPROTECTED]	0[a]	.	.	0	.	.	.
	THROUGH_LA * IRI	.004	.012	.101	1	.750	-.019	.026
	AADT_AC * LT_OUT_W	.000	.000	.000	1	.984	.000	.000

Link function: Logit.

a. This parameter is set to zero because it is redundant.

Table 12: Regression Results for Freeway/Expressway Roads (Coefficients)

Model Fitting Information

Model	Likelihood	Chi-Square	df	Sig.
Intercept Only	1496.735			
Final	0	1496.735	54	0

Link function: Logit.

Table 13: Regression Results for Collector Roads (Model Fitting)

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Threshold	[NUMBER_OF_ACCIDENTS_1 = 1]	702.436	1926.040	.133	1	.715	-3072.534	4477.406
	[NUMBER_OF_ACCIDENTS_1 = 2]	782.921	1955.488	.160	1	.689	-3049.766	4615.608
	[NUMBER_OF_ACCIDENTS_1 = 3]	852.924	2071.152	.170	1	.680	-3206.460	4912.308
	[NUMBER_OF_ACCIDENTS_1 = 4]	930.880	2282.516	.166	1	.683	-3542.769	5404.528
	[NUMBER_OF_ACCIDENTS_1 = 5]	1009.488	2562.496	.155	1	.694	-4012.911	6031.887
	[NUMBER_OF_ACCIDENTS_1 = 6]	1089.078	2894.593	.142	1	.707	-4584.220	6762.375
Location	[RoadDivision=Divided no barrier]	-39.682	235.629	.028	1	.866	-501.506	422.143
	[RoadDivision=Divided with barrier]	-47.900	283.259	.029	1	.866	-603.078	507.277
	[RoadDivision=Not Divided]	-46.575	276.028	.028	1	.866	-587.581	494.431
	[RoadDivision=Other]	0[a]	.	.	0	.	.	.
	[AREA_TYPE=RURAL]	7.826	47.895	.027	1	.870	-86.046	101.697
	[AREA_TYPE=URBAN]	0[a]	.	.	0	.	.	.
	[GOVT_CONTR=County]	-1.152	33.588	.001	1	.973	-66.982	64.679
	[GOVT_CONTR=Other]	-3.638	39.880	.008	1	.927	-81.802	74.525
	[GOVT_CONTR=State Highway]	0[a]	.	.	0	.	.	.
	[MEDIAN_TY=CENTER TLA (UNDIV)]	744.351	1966.665	.143	1	.705	-3110.242	4598.944
	[MEDIAN_TY=NA]	-236.261	8081.046	.001	1	.977	-16074.821	15602.298
	[MEDIAN_TY=NONE (UNDIV)]	794.141	2010.844	.156	1	.693	-3147.042	4735.323
	[MEDIAN_TY=PAINTED]	-233.587	9276.963	.001	1	.980	-18416.101	17948.927
	[MEDIAN_TY=POSITIVE BARRIER]	746.696	1966.042	.144	1	.704	-3106.675	4600.067
	[MEDIAN_TY=ROUNDABOUT]	0[a]	.	.	0	.	.	.
	[SH_OUT_TY=curbed]	21.148	125.192	.029	1	.866	-224.225	266.520
	[SH_OUT_TY=no shoulder or curbs]	-2.608	22.946	.013	1	.910	-47.582	42.365
	[SH_OUT_TY=surfaced with concrete or	0[a]	.	.	0	.	.	.
	MEDIAN_WACD_1	-.441	2.795	.025	1	.875	-5.919	5.036
	[SPEED_LIMI_AC_1=25.0]	-25.510	197.926	.017	1	.897	-413.438	362.418
	[SPEED_LIMI_AC_1=30.0]	-20.006	172.400	.013	1	.908	-357.904	317.892
	[SPEED_LIMI_AC_1=35.0]	33.632	223.035	.023	1	.880	-403.508	470.772
	[SPEED_LIMI_AC_1=39.8]	50.922	315.828	.026	1	.872	-568.089	669.934
	[SPEED_LIMI_AC_1=40.0]	4.441	117.536	.001	1	.970	-225.926	234.807
	[SPEED_LIMI_AC_1=45.0]	-67.640	439.457	.024	1	.878	-928.960	793.680
	[SPEED_LIMI_AC_1=50.0]	-.482	118.506	.000	1	.997	-232.750	231.785
	[SPEED_LIMI_AC_1=55.0]	0[a]	.	.	0	.	.	.
	AADT_AC_1	.000	.002	.027	1	.870	-.004	.005
	THROUGH_LA_AC_1	-76.242	453.436	.028	1	.866	-964.960	812.476
	ROUGHNESS_AC_1	-.402	2.393	.028	1	.867	-5.091	4.288
	SH_OUT_W_AC_1	-8.172	50.944	.026	1	.873	-108.021	91.677
	THROUGH_LA_AC_1 * SH_OUT_W_AC_1	5.246	31.799	.027	1	.869	-57.079	67.571
	THROUGH_LA_AC_1 * ROUGHNESS_AC_1	.284	1.674	.029	1	.865	-2.996	3.564
Scale	[RoadDivision=Divided no barrier]	1.265	.542	5.446	1	.020	.202	2.327
	[RoadDivision=Divided with barrier]	1.116	.597	3.486	1	.062	-.055	2.287
	[RoadDivision=Not Divided]	1.218	.531	5.261	1	.022	.177	2.259
	[RoadDivision=Other]	0[a]	.	.	0	.	.	.
	[AREA_TYPE=RURAL]	.253	.139	3.283	1	.070	-.021	.526
	[AREA_TYPE=URBAN]	0[a]	.	.	0	.	.	.
	[GOVT_CONTR=County]	.200	.273	.537	1	.463	-.335	.735
	[GOVT_CONTR=Other]	.095	.322	.086	1	.769	-.536	.725
	[GOVT_CONTR=State Highway]	0[a]	.	.	0	.	.	.
	[MEDIAN_TY=CENTER TLA (UNDIV)]	-.707	5.481	.017	1	.897	-11.449	10.036
	[MEDIAN_TY=NA]	.051	7.308	.000	1	.994	-14.274	14.375
	[MEDIAN_TY=NONE (UNDIV)]	-2.301	5.518	.174	1	.677	-13.116	8.514
	[MEDIAN_TY=PAINTED]	2.539	8.686	.085	1	.770	-14.486	19.564
	[MEDIAN_TY=POSITIVE BARRIER]	-1.174	5.489	.046	1	.831	-11.933	9.584
	[MEDIAN_TY=ROUNDABOUT]	0[a]	.	.	0	.	.	.
	[SH_OUT_TY=curbed]	-.115	.188	.375	1	.541	-.484	.254
	[SH_OUT_TY=no shoulder or curbs]	.213	.151	1.993	1	.158	-.083	.508
	[SH_OUT_TY=surfaced with concrete or	0[a]	.	.	0	.	.	.
	[SPEED_LIMI_AC_1=25.0]	-.610	.779	.612	1	.434	-2.136	.917
	[SPEED_LIMI_AC_1=30.0]	-.463	.734	.398	1	.528	-1.902	.976
	[SPEED_LIMI_AC_1=35.0]	-.437	.740	.349	1	.555	-1.887	1.013
	[SPEED_LIMI_AC_1=39.8]	-1.024	.747	1.876	1	.171	-2.489	.441
	[SPEED_LIMI_AC_1=40.0]	-.451	.713	.400	1	.527	-1.848	.947
	[SPEED_LIMI_AC_1=45.0]	-.469	.866	.293	1	.588	-2.166	1.229
	[SPEED_LIMI_AC_1=50.0]	-.506	.713	.503	1	.478	-1.903	.892
	[SPEED_LIMI_AC_1=55.0]	0[a]	.	.	0	.	.	.
	AADT_AC_1	.000	.000	.029	1	.864	.000	.000
	THROUGH_LA_AC_1	2.489	.918	7.358	1	.007	.691	4.288
	ROUGHNESS_AC_1	.016	.008	4.346	1	.037	.001	.032
	SH_OUT_W_AC_1	.368	.228	2.603	1	.107	-.079	.815
	MEDIAN_WACD_1	-.033	.033	.993	1	.319	-.096	.031
	THROUGH_LA_AC_1 * SH_OUT_W_AC_1	-.207	.110	3.551	1	.060	-.422	.008
	THROUGH_LA_AC_1 * ROUGHNESS_AC_1	-.009	.004	5.082	1	.024	-.016	-.001

Table 14: Regression Results for Collector Roads (Coefficients)

Locals

There are 705 local road segments, and the regression results indicate that speed limit is the only significant factor in the number of motorcycle crashes on local road segments in Maryland.

As presented in Table 15, the null hypothesis that both the location parameters and the scale parameters are zero is rejected. The three pseudo R^2—Cox and Snell (0.681), Nagellkerke (0.991), and McFadden (0.984)—are sufficiently high and demonstrate that the dependent variable is significantly related to the independent variables.

Model Fitting Information

Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	85.648			
Final	.000	85.648	28	.000

Link function: Logit.

Table 15: Regression Results for Local Roads (Model Fitting)

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Threshold	[NUMBER_OF_ACCIDENTS = 1]	-6.688	37.250	.032	1	.858	-79.697	66.321
	[NUMBER_OF_ACCIDENTS = 2]	29.319	82.335	.127	1	.722	-132.055	190.694
	[NUMBER_OF_ACCIDENTS = 3]	69.537	209.628	.110	1	.740	-341.326	480.400
Location	[GOVT_CONTR=County]	-219.334	1075.092	.042	1	.838	-2326.476	1887.808
	[GOVT_CONTR=Other]	88.059	298.170	.087	1	.768	-496.343	672.460
	[GOVT_CONTR=State Highway]	0[a]	.	.	0	.	.	.
	[MEDIAN_TY=CENTER TLA (UNDIV)]	-14.000	50.450	.077	1	.781	-112.881	84.881
	[MEDIAN_TY=NA]	-385.509	2130.332	.033	1	.856	-4560.882	3789.864
	[MEDIAN_TY=PAINTED]	-204.529	1657.683	.015	1	.902	-3453.529	3044.470
	[MEDIAN_TY=POSITIVE BARRIER]	0[a]	.	.	0	.	.	.
	ROUGHNESS_AC_1* SH_OUT_W_AC_1	.001	.027	.001	1	.976	-.052	.054
	[SPEED_LIMI_AC=25]	-98.379	331.084	.088	1	.766	-747.291	550.533
	[SPEED_LIMI_AC=30]	-95.397	319.610	.089	1	.765	-721.822	531.028
	[SPEED_LIMI_AC=35]	12.549	876.134	.000	1	.989	-1704.643	1729.741
	[SPEED_LIMI_AC=40]	-249.400	832.646	.090	1	.765	-1881.356	1382.555
	[SPEED_LIMI_AC=45]	-44.105	161.232	.075	1	.784	-360.113	271.903
	[SPEED_LIMI_AC=50]	0[a]	.	.	0	.	.	.
	[SH_OUT_TY=curbed]	-20.223	64.631	.098	1	.754	-146.897	106.452
	[SH_OUT_TY=no shoulder or curbs]	8.905	34.759	.066	1	.798	-59.222	77.031
	[SH_OUT_TY=surfaced with co or bit]	0[a]	.	.	0	.	.	.
	[RoadDivision=Divided no barrier]	17.740	60.345	.086	1	.769	-100.534	136.014
	[RoadDivision=Divided with barrier]	108.810	324.095	.113	1	.737	-526.404	744.024
	[RoadDivision=Not Divided]	4.205	39.182	.012	1	.915	-72.591	81.000
	[RoadDivision=Other]	0[a]	.	.	0	.	.	.
	[AREA_TYPE=RURAL]	-9.982	36.864	.073	1	.787	-82.235	62.271
	[AREA_TYPE=URBAN]	0[a]	.	.	0	.	.	.
Scale	IRI* SH_OUT_W	.000	.001	.163	1	.687	-.001	.001
	[SPEED_LIMI_AC=25]	1.987	1.096	3.289	1	.070	-.160	4.135
	[SPEED_LIMI_AC=30]	1.398	.824	2.879	1	.090	-.217	3.013
	[SPEED_LIMI_AC=35]	-2.278	2715.105	.000	1	.999	-5323.786	5319.230
	[SPEED_LIMI_AC=40]	2.896	1.186	5.966	1	.015	.572	5.220
	[SPEED_LIMI_AC=45]	1.496	1.197	1.562	1	.211	-.850	3.842
	[SPEED_LIMI_AC=50]	0[a]	.	.	0	.	.	.
	[MEDIAN_TY=CENTER TLA (UNDIV)]	2.625	3.055	.738	1	.390	-3.362	8.612
	[MEDIAN_TY=NA]	4.726	4.659	1.029	1	.310	-4.405	13.857
	[MEDIAN_TY=PAINTED]	4.175	5.294	.622	1	.430	-6.202	14.551
	[MEDIAN_TY=POSITIVE BARRIER]	0[a]	.	.	0	.	.	.
	[GOVT_CONTR=County]	1.722	2.350	.537	1	.464	-2.884	6.327
	[GOVT_CONTR=Other]	-1.672	1.110	2.271	1	.132	-3.847	.502
	[GOVT_CONTR=State Highway]	0[a]	.	.	0	.	.	.

Table 16: Regression Results for Collector Roads (Coefficients)

Probability Distribution for the Number of Crashes

The probability distribution for the dependent variable (number of crashes) and each road class were fitted into logarithmic functions that can be seen in Figures 41-45.

	Logarithmic	θ=0.85706

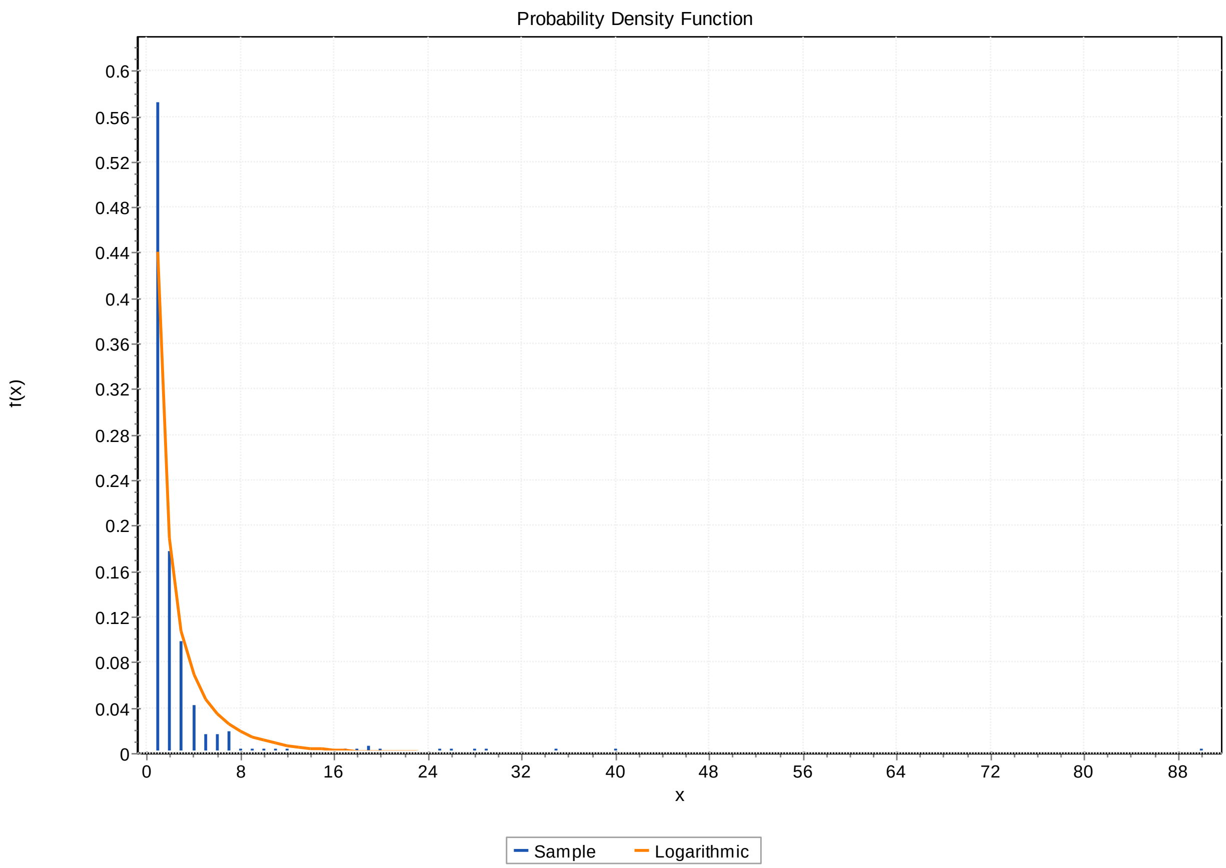


Figure 41: Probability Distribution Function for Number of Crashes on Arterial Roads

	Logarithmic	θ=0.86643

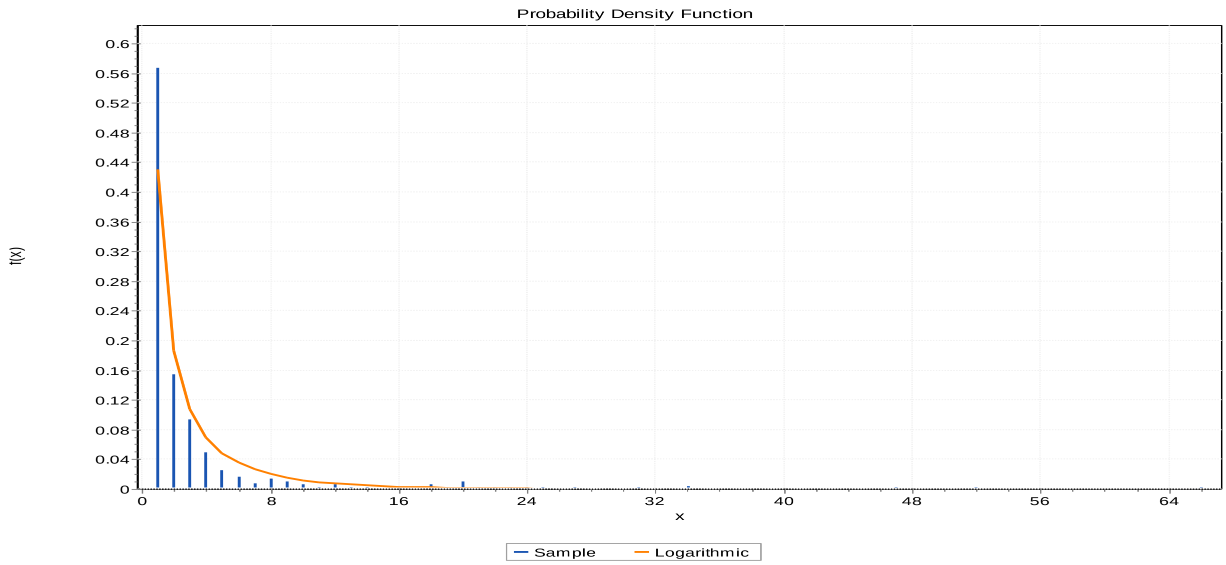


Figure 42: Probability Distribution Function for Number of Crashes on Collector Roads

	Logarithmic	θ=0.89031

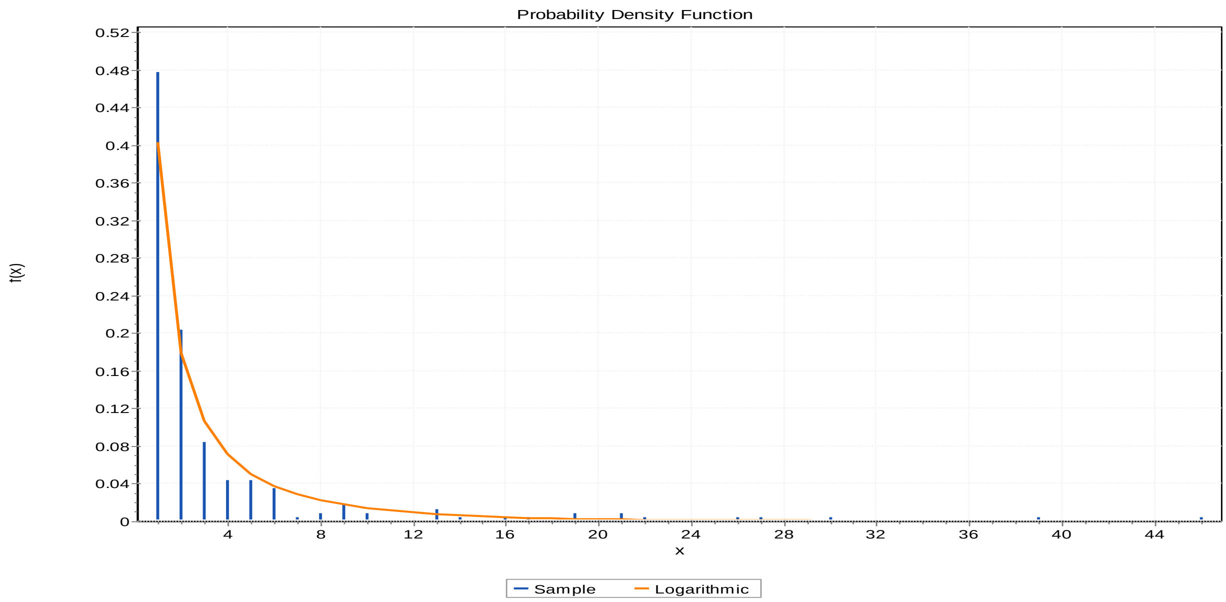


Figure 43: Probability Distribution Function for Number of Crashes on Freeway Roads

	Logarithmic	θ=0.85706

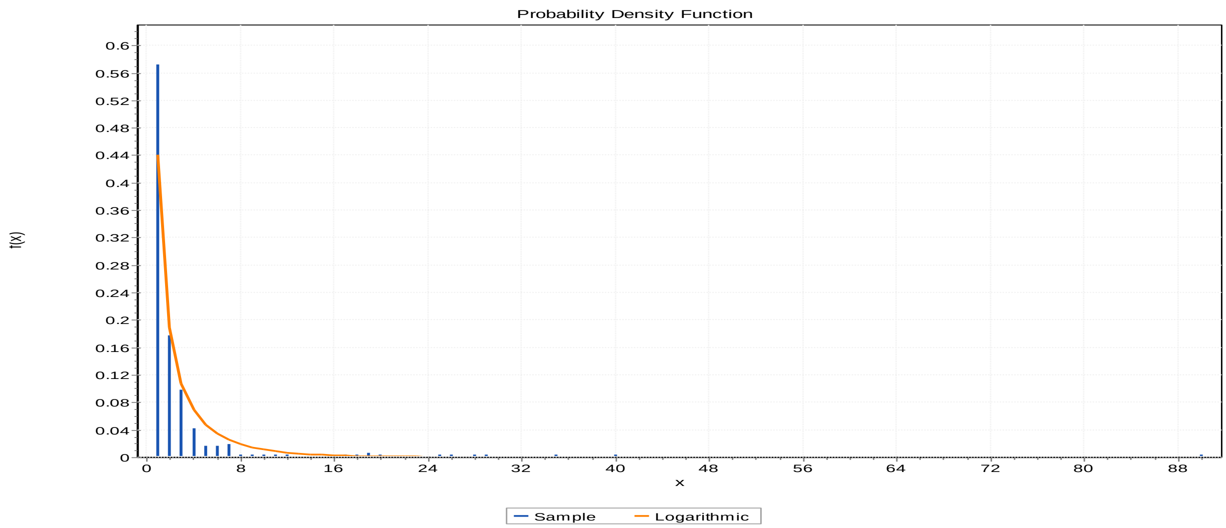


Figure 44: Probability Distribution Function for Number of Crashes on Local Roads

	Logarithmic	θ=0.84023

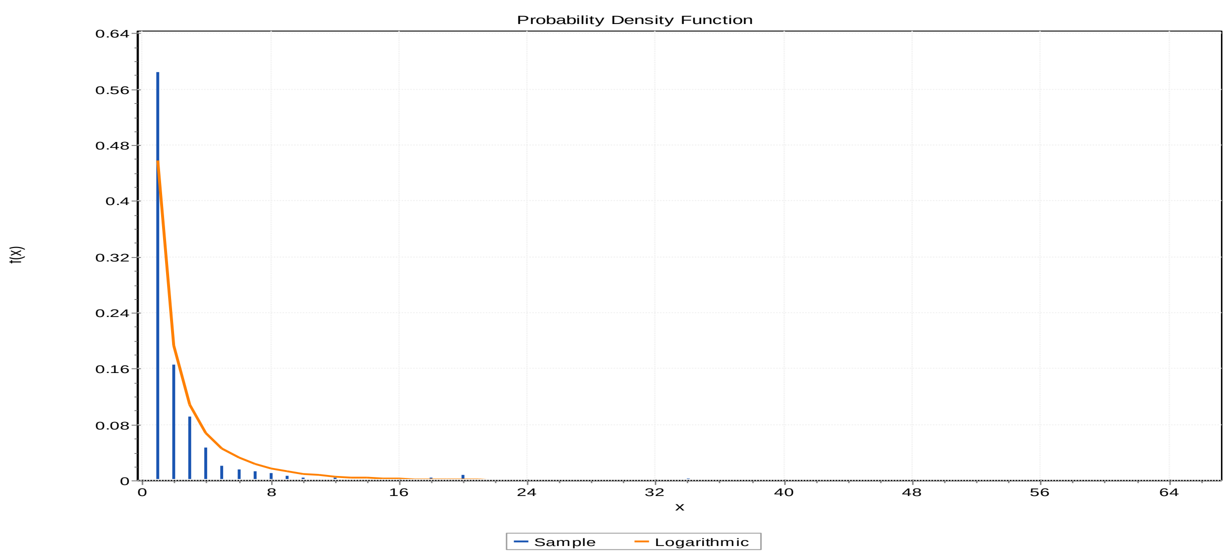


Figure 45: Probability Distribution Function for Number of Crashes on Collector and Local Roads

CONCLUSIONS

The preliminary data analysis shows that most motorcycle crashes happened on state roads with no access control and speed limits of 40-55 mph. These roads—which can be classified as urban-other-principal arterials, urban minor arterials, or urban collectors—had good or fair surfaces. They were mostly undivided, two-way roads with two through marked lanes and no auxiliary lanes. The crashes usually happened during the day when weather conditions were sunny or cloudy and the road surface was dry.

The crashes, which were most often single-vehicle collisions, occurred when the motorcycle was moving straight at a constant speed far from an intersection. The majority of motorcycle drivers were male.

Prince George's County, Baltimore County, Baltimore City, Anne Arundel County, and Montgomery County had the highest percentage of the motorcycle crashes.

The roads with the highest crashes are presented in Figure 46, and the road segments with the highest crash rates are marked in Figure 47.

Based on the logistic ordinal regression analysis results, area type, median type, speed limit, AADT, IRI, and number of through lanes affect the number of motorcycle crashes on all road segments in Maryland. Interestingly, government control and shoulder type had no significant impact on the number of crashes. For future road impact determinations, the ordinal logistic model that was developed can be used to predict the number of motorcycle crashes for each road characteristic.

The number of crashes on arterial roadways is affected by road division, area type, AADT, shoulder width, median type, the interaction of IRI and AADT, and shoulder width. Based on acceptance of location and scale variable coefficients, the data suggests that the number of crashes could be reduced by widening shoulders, implementing road divisions, and improving IRI.

The model illustrated that speed limit was the only significant factor in motorcycle crashes on local roads. A likely reason is that local roads have a wider range of posted speed limits than other road classes, causing speed to stand out among other variables. Furthermore, the incomplete status of data obtained for local roads makes it difficult to assess the impact of other variables in this analysis. No trend was evident when suggestions for speed improvement were considered. When motorcycle crash percentages were examined independently, over 74 percent were found to occur on undivided roads. This indicates that road divisions might decrease motorcycle crashes on local roads.

Conversely, road division, area type, number of through lanes, IRI, the interaction between IRI and number of through lanes, and IRI and shoulder width were found to be important factors in motorcycle crashes on collector roads. This road class is not usually controlled or maintained by SHA and has a wide range of IRI, shoulder width, and number of through lanes. Most of the crashes on collector roads (80 percent) happened on undivided roads. Therefore, road divisions would probably lead to the greatest reduction of motorcycle crashes on collector roads. The data also supports the improvement of IRI and the widening of road shoulders in pursuit of this goal.

In conclusion, the study found that the implementation of road divisions, widening of shoulders, and improvement of the IRI would have the greatest impact on motorcycle crash reduction for most roads.

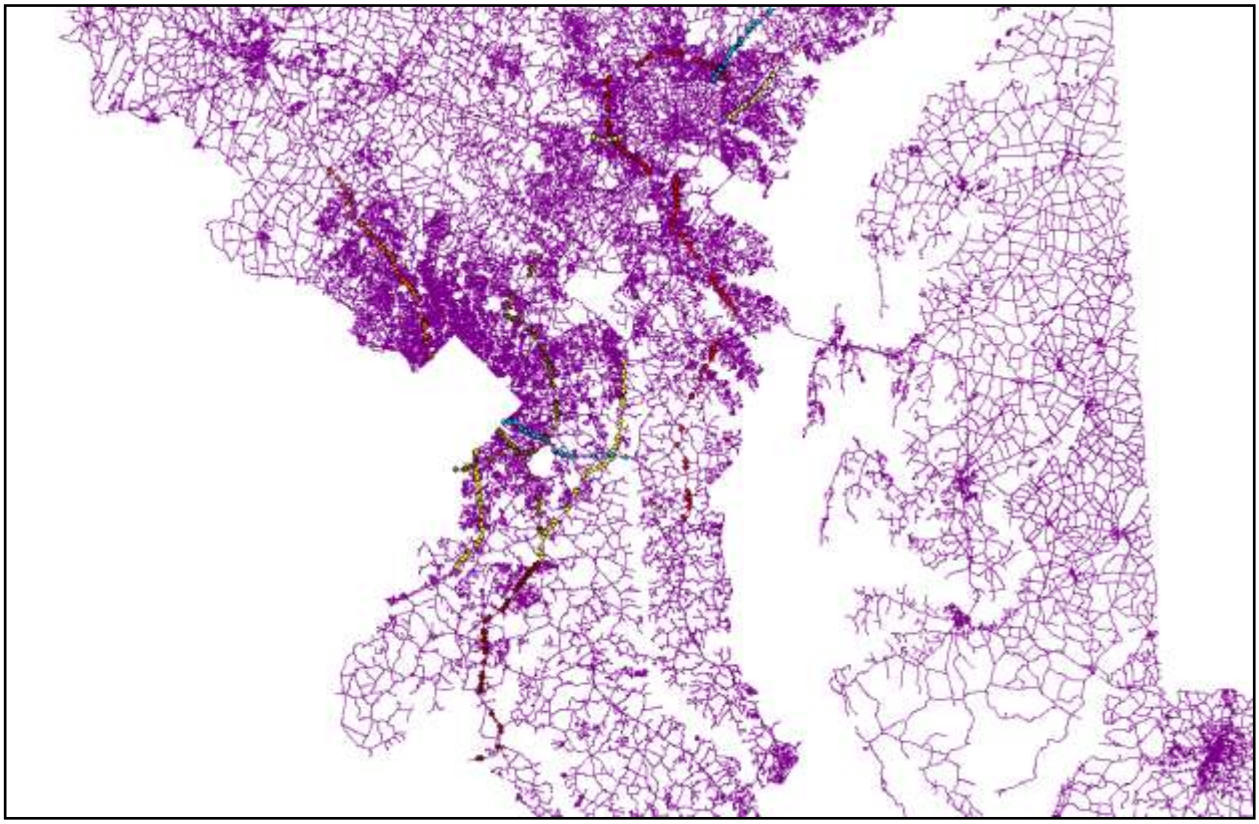


Figure 46: The Roads with the Highest Number of Crashes

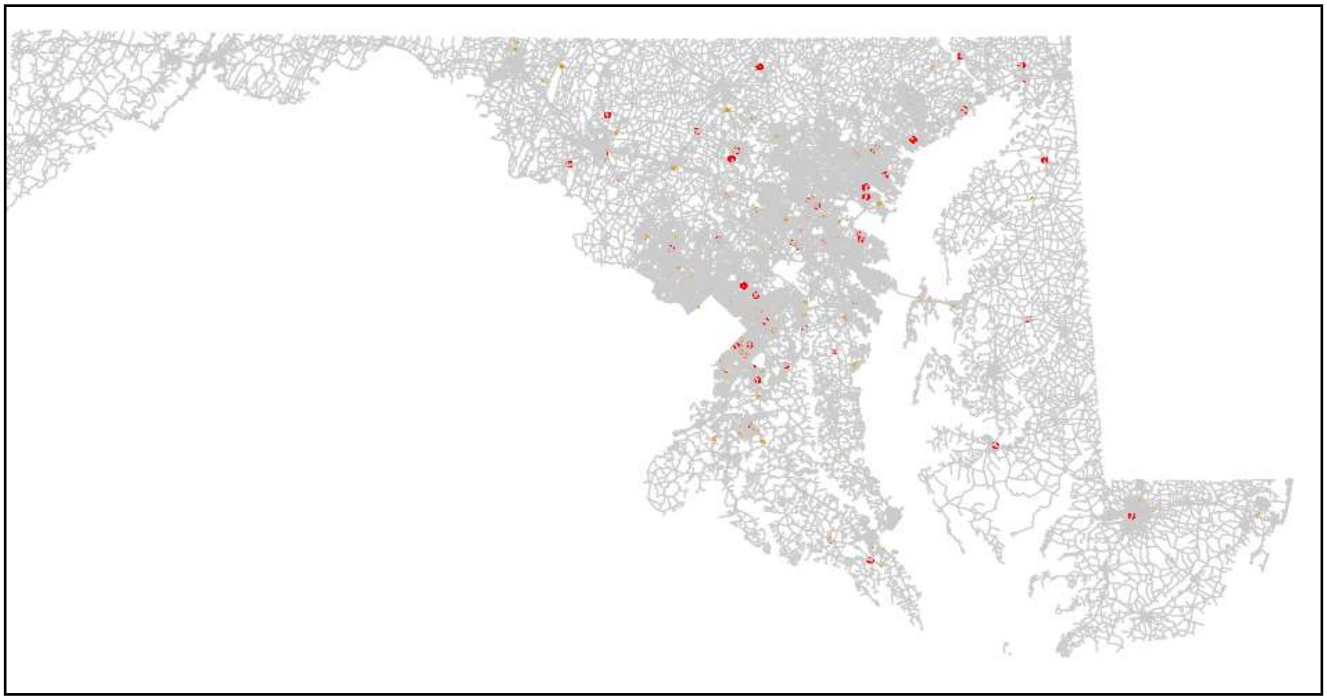


Figure 47: The Road Segments with the Highest Crash Rates

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