Enhancing Motorcycle Conspicuity Awareness in Iowa

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16. Abstract

Previous studies in the United States and internationally suggest that low motorcycle conspicuity, or the inability of the motorcyclist to be seen by other road users, is thought to be an important factor associated with risk of motorcycle crashes. However, there has been limited research on motorcycle conspicuity in the United States in the past two decades, while at the same time; there has been a renewed interest from states in increasing motorcycle conspicuity and motorist awareness. As such, this research revisits the motorcycle conspicuity problem by analysis of helmet-use and motorcycle crash data.

First, this study reviews previous studies on motorcycle conspicuity with a focus on the effectiveness of proposed measures for enhancing motorcycle conspicuity. The major trends in motorcycle helmet use by time of day and road type for motorcyclists, as indicated from three roadside observational roadside surveys in Iowa, are also discussed. Then, using motorcycle crash data for Iowa from 2001 to 2008, this research compares single-and two-vehicle motorcycle crashes and examines the distribution of conspicuity-related factors in light and dark conditions in two-vehicle crashes that could potentially relate to a collision between a motorcycle and another vehicle. The limitations of examining motorcycle conspicuity by analysis of crash data are also discussed. Finally, this report outlines recommendations based on the key findings of the study.

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ENHANCING MOTORCYCLE CONSPICUITY AWARENESS IN IOWA

Final Report
September 2010

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1. INTRODUCTION

1.1 Problem Statement and Background Summary

Motorcycle registrations in Iowa, which numbered more than 200,000 in the early 1980s, started declining until 1999, when they began to increase again. In 2006, nearly 146,000 motorcycles were registered in Iowa. During the period 1995–2005, motorcycle fatalities in Iowa rose on average 46%, while average traffic fatalities, overall, declined nearly 15% (Iowa Comprehensive Highway Safety Plan 2006). The Iowa Department of Public Health (2007) also estimated that motorcycle crashes in Iowa from 2001 to 2005 comprised 12% of the total motor vehicle crash (MVC) hospitalizations and 10% of all MVC fatalities, though they accounted for only 4% of all MVC injuries. During the same period, only 27% of motorcyclists involved in crashes in Iowa were wearing helmets. Motorcycle helmets are one measure that can potentially enhance conspicuity (the ability of the motorcyclist to be seen by other motorists) in Iowa. Additional measures include wearing reflective or fluorescent clothing, daytime headlight operation, and use of headlamp modulators.

Previous studies in the United States and internationally suggest that low motorcycle conspicuity, or the inability of the motorcyclist to be seen by other motorists, is thought to be an important factor associated with risk of motorcycle crashes (Williams and Hoffmann 1979; Hurt et al. 1981; Wulf et al. 1989; Cercarelli et al. 1992). This may result from several factors, including the small size of motorcycle, irregular outline of the vehicle, low luminance or contrast with the background environment, maneuverability, and the ability to travel in unexpected places in the traffic stream. Additional measures to enhancing conspicuity include wearing reflective or fluorescent clothing, wearing white or light-colored helmets, using headlights during daytime, and using headlamp modulators (Rumar 1980, Thomson 1980, Olson et al. 1981, Muller 1984, Jenkins and Wigan 1985, Wells et al. 2004, Torrez 2008). Safety campaigns also advocate the importance of conspicuity to all motorcyclists. Most states have implemented conspicuity and/or motorist awareness campaigns (Baer et al. 2010). In addition, recommendations encourage states to:

- Initiate public awareness efforts focused on the use of high-visibility riding gear and daytime running lights;
- Take steps to alert motorists about motorcyclists, using strategies such as incorporating “Share the Road” messages as part of driver education classes;
- Amplify public information and outreach efforts (Baer and Skemer 2009).

However, it is not an easy task to motivate all motorcyclists to wear the proper type of reflective gear, especially when not enforced by law. To date, 20 states and the District of Columbia have universal motorcycle helmet laws that require all riders to wear a helmet. Twenty-seven states require only some riders to wear a helmet, and three states (Illinois, Iowa, and New Hampshire) do not have a motorcycle helmet law. While the majority of states promote helmet use (77% of 43 states), only a little more than half emphasize the use of eye and face protection (54% of 43 states) (Baer et al. 2010).

Given that low motorcycle conspicuity is thought to be an important factor associated with risk of motorcycle crashes, a need to communicate conspicuity-related issues to the motorcyclist community and increase driver awareness exists in Iowa.

First, this study reviews previous studies on motorcycle conspicuity and focuses on the effectiveness of proposed measures for enhancing conspicuity. Then, using motorcycle crash data for Iowa from 2001 to 2008, this study compares single-and two-vehicle motorcycle crashes and identifies motorcycle-conspicuity factors that could potentially relate to a collision between a motorcycle and another vehicle. This study also explores trends in motorcycle helmet use through observational roadside surveys that were conducted in 2006, 2008, and 2009. Finally, this study discusses the limitations of examining motorcycle conspicuity by analysis of crash data.

1.2 Research Objectives and Benefits

The proposed research would study motorcycle conspicuity in Iowa with a focus on how to increase awareness of the issues to both motorcyclists and drivers of other vehicles in the traffic stream. The study would make recommendations to the Iowa Department of Transportation (Iowa DOT) regarding motorcycle conspicuity-related campaigns and interventions. The research project included the following tasks.

Task 1: Establish a Technical Advisory Committee (TAC) for the project.

Potential Technical Advisory Committee (TAC) members were identified in consultation with representatives from the Office of Traffic and Safety and the Motorcycle Task Force. The TAC included representatives from the Iowa DOT, the Iowa Governor's Traffic Safety Bureau (Iowa GTSB), A Brotherhood Aimed Towards Education (ABATE) of Iowa, the National Off-Highway Vehicle Conservation Council (NOHVCC), the Iowa Off-Highway Vehicle Association (IOHVA), and Women on Wheels. A meeting of the TAC convened quarterly.

Task 2: Summarize previous research findings on the effectiveness of motorcycle conspicuity measures.

The research team synthesized the effectiveness of motorcycle measures, which have been used in the United States and abroad, in enhancing motorcycle conspicuity and reducing conspicuity-related motorcycle crashes.

Task 3: Compile and analyze available statewide motorcycle crash data.

The research team compiled and analyzed reportable motorcycle crashes on Iowa's public roads during a recent period (2001–2008) in a bid to determine the major factors for motorcycle crashes (by severity, type of crash and other). Moreover, a statistical analysis was conducted to examine potential conspicuity-related factors (such as light conditions, helmet use, and time of day). In addition, this analysis identified specific areas (rural versus urban and intersection versus non-intersection) at a higher risk for motorcycle crashes, in search of other conspicuity-related campaign and intervention ideas.

Task 4: Present conclusions and recommendations

A summary of the results from the analysis of Iowa's motorcycle helmet-use data and crash data were presented. Additional limitations were identified, as well. Based on the results, guidelines were provided on how to improve motorcycle conspicuity and driver awareness in Iowa, and recommendations were made to the Iowa DOT and the Iowa Governor's Traffic Safety Bureau (GTSB) related to conspicuity campaigns and interventions.

1.3 Report Organization

Table 1.1 lists the tasks for this project and the corresponding sections of this report.

Table 1.1. Tasks and corresponding report sections

Project task	Corresponding report section
1. Selection of TAC	1. Introduction
2. Literature review	2. State of the Practice and Literature Review
3. Data compilation and analysis	3. Data Description 4. Data Analysis
4. Conclusions and recommendations	5. Summary, Limitations, and Recommendations

2. STATE OF THE PRACTICE AND LITERATURE REVIEW

2.1 Motorcycle conspicuity in the United States

2.1.1 Overview

About half of the motorcycle crashes in the United States involve another vehicle and, in most cases, the driver of the other vehicle was reported to have not seen the motorcycle until it was too late. Therefore, a need exists, not only to increase driver awareness of motorcyclists on the roads, but for motorcyclists to be as conspicuous as possible.

Most states include conspicuity in their motorcycle manual, listing eight important ways to increase conspicuity: clothing, headlight, signals, break lights, mirrors, head checks, horns, and riding at night. Table 2.1 shows which states include conspicuity in their motorcycle manuals. 78% (39 states) include eight ways of increasing conspicuity and five states include three or four ways to increase conspicuity. Maine, Massachusetts, Oregon, and Wyoming do not include conspicuity in their motorcycle manuals. The manuals for motorcyclists in New Hampshire and Rhode Island were not available.

Table 2.1. Conspicuity coverage in the motorcycle manuals of the 50 states

Conspicuity included in the motorcycle manual (39 states)
Alabama, Arizona, California, Connecticut, Delaware, Florida, Georgia, Hawaii, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Jersey, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin
Conspicuity partially included in the motorcycle manual (5 states)
Arkansas, Colorado, Alaska, New Mexico, South Carolina
Conspicuity not in the motorcycle manual (4 states)
Maine, Massachusetts, Oregon, Wyoming
Motorcycle manual was not available (2 states)
New Hampshire, Rhode Island

The Iowa DOT worked with the Motorcycle Safety Foundation (MSF), which provides information on rider training, licensing, and government relations, to develop the Iowa Motorcycle Operator manual (Iowa DOT 2009). Nancy Richardson, Director of the Iowa DOT, reminds motorcyclists: “It is your responsibility to help the motoring public be aware of you while you are on the road.”

In 2009, the National Highway Traffic Safety Administration (NHTSA) examined the policies that states have implemented to promote motorcycle safety. Then, they offered recommendations for additional steps that states could take to encourage safe riding and reduce crashes, injuries, and fatalities (Baer and Skemer 2009). Nine states were surveyed: Florida, Hawaii, Illinois, Michigan, Minnesota, Missouri, Washington, West Virginia, and Wisconsin.

Conspicuity was one of seven main topic areas. After reviewing the states' efforts to increase the conspicuity of motorcyclists, 24 recommendations in the area of conspicuity were offered, which were categorized into four subtopics: allocate funds for conspicuity efforts (2 recommendations); promote motorcyclist conspicuity (5 recommendations); promote motorist awareness (13 recommendations); and public information and education (4 recommendations). 13 of 24 recommendations under conspicuity were implemented (54%).

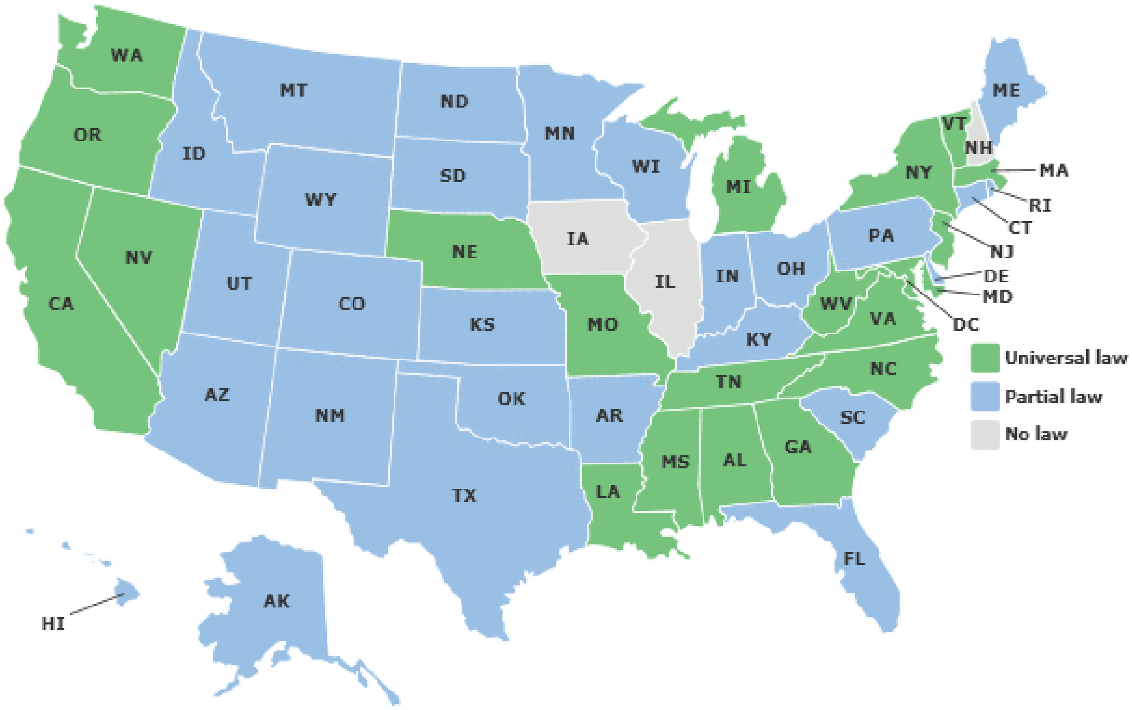
Besides recommendations, barriers to implementation of conspicuity recommendations were also suggested by reviewers. Time constraints/competing commitments was the greatest barrier to the implementation of conspicuity recommendations (45% of all barriers), while the second greatest obstacle was insufficient funding/resources (28%). Turning to the percentage of barriers to implementing conspicuity recommendations, nearly half (45%) were related to promoting motorist awareness.

NHTSA recently released a report on the "evaluation of state motorcycle safety programs," and presented conspicuity-related programs by state (Baer et al. 2010). The majority (82% of 44 states) of motorist awareness programs included ways other motorists can increase their awareness of motorcyclists, and three-fourths (75% of 44 states) recommended that motorcyclists wear brightly-colored clothing and reflective material (including helmets with high conspicuity). Slightly more than half of states reported that their conspicuity programs include daytime use of motorcycle headlights (57%). Overall, states have adopted different ways to increase motorcyclist conspicuity, such as encouraging motorcyclists to wear brightly-colored clothing, and also educating other motorists to be more aware of the motorcyclists on the road.

2.1.2 Helmet Color and Use

Motorcycle helmets provide the best protection from head injury for motorcyclists involved in traffic crashes, and NHTSA encourages states to enact the law that requires all motorcyclists to wear a helmet. Moreover, brightly-colored helmets, such as yellow, or lime yellow, can also help others to see motorcyclists. In a NHTSA report, the majority of states promoted helmet use (77% of 43 states), but just more than half emphasized the use of eye and face protection (54% of 43 states) (Baer et al. 2010).

Figure 2.1 is a map of motorcycle helmet laws in the United States. To date, 20 states, most of which are located on the east or west coasts, and the District of Columbia have universal motorcycle helmet laws, requiring all motorcyclists to wear helmets. Twenty seven states require only some riders to wear a helmet and three states (Illinois, Iowa, and New Hampshire) do *not* have a motorcycle helmet law.



Source: Insurance Institute for Highway Safety. http://www.iihs.org/laws/HelmetUseOverview.aspx

Figure 2.1. Map of motorcycle helmet laws

National statistics in 2009 indicated that the use of helmets meeting federal safety regulations was 86% in states with mandatory helmet use, while the use of helmets in states without mandatory use was 55% (NHTSA 2009a). The percentages show the notable difference in usage as a result of a helmet law.

In addition, NHTSA (2009b) and the National Cooperative Highway Research Program (NCHRP) Report 622 reviewed countermeasures that work (Preusser et al. 2008). Counter-measures were rated as proven, likely, unknown, or proven not to work. In this report, helmet laws were proven effective.

In the NHTSA report, different aspects were given 1 to 5 stars, with 5 stars being most effective. State helmet laws were given 5 stars; helmet-use promotion programs and helmet law enforcement for noncompliant helmets were given 1 star.

2.1.3 Daytime Running Lights and Modulating Headlamps

In Canada and many European countries, daytime running lights (DRLs) are required for all vehicles. Finland mandated DRLs during winter on rural roads in 1972 and eventually made them mandatory throughout the year. Sweden's law on DRLs was effective in 1977, Iceland's in 1988, and Denmark's in 1990. Canada requires DRLs for vehicles made after December 1, 1989. Although federal law in the United States does not mandate the use of daytime running lights, 24 states require daytime headlight use (Motorcycle Safety Foundation 2007). As such, most manufacturers have equipped motorcycles with automatic-on headlamps since 1979 (Insurance Institute for Highway Safety).

The Iowa Code Section 321.275 states that “a person shall not operate a 1977 or later model year motorcycle or any model year motorized bicycle upon the highways without displaying at least one lighted headlamp that meets the mandatory lighting equipment specifications (outlined in section 321.409)”.

Federal law (under Federal Motor Vehicle Safety Standards) allows motorcycle headlight modulation systems, which cause the headlight to move from high- to low-beam rapidly, in all 50 states, provided they comply with the standards set forth in section 49 CFR Part 571.108 S7.9.4. Modulating headlamps that conform to the standards are permitted on a motorcycle in Iowa (Iowa Code Section 321.423). However, adoption of these technologies has been low so far (Governor’s Highway Safety Association 2010).

2.1.4 Safety Campaigns

Most states have implemented conspicuity and/or motorist awareness campaigns (96% of 44 states), and half (50% of 44 states) indicated they have programs at schools to educate students about motorcycle safety (Baer et al. 2010). Typical themes are “Share the Road” or “Watch for Motorcyclists.”

A good campaign, including market research, message development and testing, and implementation, would require at least six months to plan and implement (Governor’s Highway Safety Association 2010). This subsection provides additional information about specific campaigns in three states: Florida, Minnesota, and Michigan.

In 2008, the Department of Highway Safety and Motor Vehicles (DHSMV) and the Florida Rider Training Program (FRTP) joined Miami motorcyclists at the Enforcers Motorcycle Annual event to promote the new motorcycle safety campaign. The campaign, “Ride Proud, Dress Loud,” focused on promoting motorcycle visibility and safety to reduce fatalities on Florida roadways. According to the most recent Florida traffic crash statistics, Miami-Dade County reported the highest number of motorcycle fatalities in the state. Research suggests that motorcyclists who make themselves more visible or conspicuous are less likely to have their right-of-way violated by other vehicles on the roadways (Crist et al. 2008). Therefore, to enhance the conspicuity, motorcyclists were encouraged to wear brightly-colored or reflective, upper-torso apparel, and also to put reflective strips, high-beams and vibrant-colored decals on the motorcycle itself. More beneficial safe driving campaigns in Florida also included “Share the Road” and “Look Twice, Save a Life.” In a continued effort to promote safe riding, all motorcyclists in Florida were required by law, effective July 1, 2008, to take and pass the Basic Rider Course for licensure and endorsement.

The 2008-2009 “Rider Conspicuity Campaign in Minnesota” was designed by the Minnesota Department of Public Safety (Minnesota DPS) with assistance from the Minnesota Motorcycle

Safety Advisory Committee, conspicuity product retailers, and volunteer motorcyclists. Conspicuity information and strategies were put on the website http://www.highviz.org/. Through the optional computer quiz, website visitors can choose from up to 20 recommendations to increase their conspicuity, each with point values. Visitors are encouraged to choose techniques that best fit into their riding system and add up the points to become a "perfect 10." Top 10 High-Viz Tips included the following ideas**:**

- Fluorescent/reflective safety vest
- White helmet
- Brightly-colored jacket
- Strategic lane positioning
- Headlight modulation
- "Flash your taillight "
- Reflective materials
- Movement
- Auxiliary driving lights
- Hand signals

Michigan organizes a campaign in May, "Motorcycle Safety Awareness Month," to remind motorists of the seasonal return of motorcyclists to the roads. This campaign aims to reduce the number of motorcycle accidents and fatalities on state roadways. The campaign targets both vehicle drivers and motorcycle operators. Drivers should increase their awareness of motorcyclists in traffic, such as getting in the habit of looking for motorcycles as they drive, especially at intersections, and keeping a safe distance from motorcycles. At the same time, motorcyclists should operate their motorcycles safely and wear the proper protective riding apparel, including a DOT-rated helmet. Motorcyclists also need to keep in mind that weather conditions, road surfaces, and fatigue are greater problems to them than to other motorists. Overall, "sharing the road safely" is emphasized to both vehicle drivers and motorcyclists.

2.2 Review of Past Studies

This section summarizes past studies on motorcycle conspicuity, categorized by measures to enhance conspicuity.

2.2.1 Clothing and Gear

The injury reduction benefits of motorcycle rider clothing have been well established in the literature (de Rome 2006). Certain types of rider clothing and gear have also been associated with the reduced risk of being involved in motorcycle collisions.

A New Zealand case study showed the risk involved in motorcycle collisions was somewhat correlated with what the rider was wearing. The risk was 37% lower of a motorcyclist getting into a traffic collision if the driver was wearing any reflective or fluorescent clothing, and the risk was 24% lower if the driver was wearing a white helmet, instead of a black one (Wells et al. 2004). However, the color of the driver's frontal clothing and motorcycle was not as important.

The study was based on a controlled population in the capital city of Auckland. As a city of about 950,000 people, this study was primarily in an urban setting with the data based only on motorcycle drivers on the main arterial roads between the hours of 6 a.m. to midnight. The motorcycle collisions taken into account were only severe cases—ones in which the driver or riding passenger was killed or had to be treated at a hospital. Motorcyclists were identified by random roadside surveys in the case study region to establish a control for the investigation. Questionnaires were given to both drivers in the collisions and the control roadside surveys about conspicuity measures, such as the color of frontal clothing, reflectivity of clothing, color of the motorcycle, and type and brightness of headlights. The analysis was stratified between different amounts of lighting during the day (daylight, twilight, and night) for the effectiveness of reflective clothing.

Seasonal variations in conspicuity of high-visibility garments were investigated through a naturalistic, daytime field study (Buonarosa and Sayer 2007). Subjects drove an instrumented vehicle along a 29-km route, once in the summer and again in the fall, and were asked to detect *pedestrians* wearing high-visibility garments. The researchers recorded the distances at which pedestrians were first detected. The results showed that the detection distance depended on the season and the amount of background material (jacket or vest). In daytime, the researchers did not find any significant differences in conspicuity if pedestrians were wearing either fluorescent yellow green or fluorescent red orange. However, they found that the conspicuity of fluorescent red-orange garments might depend primarily on color contrast, while the conspicuity of fluorescent yellow-green garments might depend primarily on luminance contrast.

A similar experimental study on *motorcyclists* confirmed that the brightness contrast between the motorcyclist and their surroundings may be a more important conspicuity-related factor than bright clothing and headlight use alone (Hole et al. 1996).

Finally, the Highway Code in the United Kingdom has been advising motorcyclists to wear yellow, white, red, and fluorescent clothing since 1978 (Huang and Preston 2004).

2.2.2 Daytime Headlight Use and Running Lights

A panel study of fatal crashes in the United States from 1975 to 1983 found that motorcycle headlight-use laws were associated with a 13% reduction in fatal daytime crashes (Zador 1985). In addition, if the 30 states without daytime headlight laws in effect during that period had such laws, an average of 140 additional fatal motorcycle crashes could have been prevented each year.

However, in a similar study of fatal crashes in the United States from 1975 to 1980, no significant statistical differences were found between states with and without daytime headlight laws (Muller 1985). Muller attributed this discrepancy to the fact that the Zador study did not differentiate between single-vehicle and multiple-vehicle crashes, but also noted that the estimation methods could be vulnerable to bias from regional differences in motorcycle crashes. As such, the estimated effectiveness of motorcycle headlight-use laws from the Zador study may be overestimated. The safety benefits of motorcycle daytime headlight laws were also questioned by the Federation of European Motorcyclists' Associations (Perlot and Prower 2003).

Another study examined whether the motorcycle headlight legislation in California had been effective in reducing the number of daytime fatalities (Muller 1984). The results showed a slight reduction in the number of multi-vehicle collisions (when compared to the numbers of single-vehicle collisions).

A study was conducted in New Zealand to determine whether the use of headlights during the daytime would lead to a reduction in motorcycle collisions (Thomson 1980). After conducting studies similar to those done in the United States and Australia, which already had headlight-use policies in place, the case study in New Zealand determined that a policy should encourage, if not require, all motorcyclists to have their headlights on during both night and daytime hours. The policy would increase conspicuity and reduce the number of motorcycle crashes.

Another study investigated the effectiveness of the “ride-bright” legislation in Singapore, which made it compulsory for all motorcyclists to switch on their headlights during the day (Yuan 2000). An odds ratio test found that the legislation was effective in reducing the number of fatal and serious injury accidents, consistent with the results of Zador (1985). However, the change in the number of slight injury accidents after the implementation of the legislation was insignificant. The author concluded that daytime headlights increase motorcycle conspicuity, but enhanced conspicuity might lead to risk-perception and risk-compensating (or offsetting) behavior, in which drivers adjust their driving behavior in response to situations that they perceive as comparatively dangerous or safe. For example, having the headlights on during daytime with dry road conditions was perceived as comparatively safe by drivers in Norway (Elvik 1993).

Finland and Sweden require all cars and motorcycles to have daytime running lights. An evaluation study of daytime running lights in Sweden showed that even a low-beam running light could reduce the number of collisions (Rumar 1980). The primary results showed a decrease of multiple vehicular crashes in the daylight by 32% and a 4% decrease at night. The study supported the legislation change in Sweden and many other countries.

In the United Kingdom, about one third of the collisions involving motorcycles are estimated to be conspicuity-related (Donne 1990). Donne and Fulton (1985) examined specifications for daytime running lights and demonstrated that two lamps and lamps over 180mm diameter have greater influence than single or smaller lamps. However, there is no compulsory daytime running headlight law (Huang and Preston 2004).

2.2.3 Motorcycle Actions and Driver Awareness

In Victoria, Australia, a study analyzed 1,508 accidents that involved motorcycles. The Victoria Police Department provided descriptions of the accidents with 69 reported fatalities and 1,432 injury-producing collisions. The analysis showed that motorcycle conspicuity was a factor in 64.5% of all the accidents and a sole identifiable factor in 21% of them (Williams et al. 1979). The most common collisions occurred when motorcycles were hit by vehicles intersecting the roadway at right angles, such as making a left turn. Also, 64% of the left-turning vehicles that crashed into motorcycles did so during the daytime, which led to the assumption that motorcycles are less visible during the daylight hours. The major finding was that conspicuity of the motorcyclist and the frontal part of the motorcycle are the most important factors in these collisions.

In 1975, NHTSA did a conspicuity case study in Texas. They based the study on a sample of 10,000 motorcycle collisions that occurred in Texas that year (Olson et al. 1979). The study compared motorcycle crashes to similar car-related collisions. The results showed that the most common configuration for a motorcycle collision involved a car turning left at an intersection and crashing into a motorcycle traveling straight through the intersection. The data showed a conspicuity problem associated with drivers of vehicles making difficult left turns being unable to recognize motorcycles in comparison to other vehicles. The data also showed significantly fewer collisions with motorcycle drivers wearing brightly-colored clothing. As a result, several conspicuity tests were created for both nighttime and daytime situations. The tests all involved motorcycles in variable conspicuity forms following another vehicle through an intersection. Measurements were taken on the gap distance and gap time that a car turning left in the opposite direction would accept. The more conspicuous a motorcycle was, the less likely the car would accept a short gap between the motorcycle and the car in front of it. Results from the tests showed that conspicuity was improved during the daylight hours by wearing fluorescent clothing and riding with headlamps on. However, the same fluorescent materials were not effective when attached to the actual motorcycle. Lane position also made a difference, with the center of the lane having the least amount of acceptances from cars turning left, compared to the motorcycle being on the left or right side of the lane. The results of the study indicated that motorcyclists can use various methods to improve conspicuity.

A case study in Western Australia showed that comparisons of multi-vehicle and single-vehicle motorcycle crashes can help distinguish the difference between motorcyclist control problems and vehicle driver perceptual problems during the night and day (Cercarelli et al. 1992). The study took 538 motorcycle-car crashes and compared them to 3,136 car-car crashes. The collisions were chosen for analysis because they all dealt with a possibility of poor conspicuity. All of the collisions were situations where one vehicle was in the frontal visual view of the other driver immediately before the collision. The results of the study showed no significant difference in the day/night distribution of car-car and car-motorcycle crashes. In contrast, previous studies indicated that drivers have more trouble spotting motorcycles (as opposed to cars) in the daylight, due to the difference in frontal surface area.

Another reason why collisions occur due to left-turning vehicles is because of the complexity of the situation. According to the motorcycle conspicuity research group at the University of Southern California, test results show that drivers making a left turn significantly increase their head movements, eye movements, and mental workload, in comparison to driving straight through an intersection (Wulf et al. 1989). The test observed head movements, eye-blink frequency, and probe-response time and error—to measure the amount of cognitive workload. The results showed that detecting a motorcycle while making a left turn is much more difficult. Therefore, the probability of detection failure is higher. In these situations, motorcyclists are much safer when wearing highly-detectable and reflective clothing and helmets.

A recent NHTSA study indicated that amber rear-turn signals can have a significant statistical effect on reducing the likelihood of being involved in a rear-end crash, when turning left, turning right, merging into traffic, changing lanes, or entering/leaving a parking space (Allen 2009). While the magnitude of the effect is small (5.3%), it is greater than that of red turn signals. While the study did not look at the effectiveness of the rear-turn signal color on motorcycles, improving the conspicuity of the other vehicles on the road can potentially reduce two-vehicle crashes in which a motorcycle hits another vehicle.

Finally, a recent evaluation of the conspicuity of new lighting technologies, and their effect on driver response to oncoming motorcycles on a test track, showed that "in general—regardless of the conspicuity treatment—motorcyclists were afforded smaller gaps than passenger vehicles" (Binder et al. 2005). Statistical evidence did not strongly support one treatment over any other.

2.2.4 Public Information and Outreach Efforts

Campaigns or interventions also have been claimed to be successful in reducing conspicuity-related motorcycle crashes. One relevant example is the running-headlight campaign in the Malaysian cities of Seremban and Shah Alam. The main mode of transportation in this Southeast Asian country is motorcycles, which account for more than half of all vehicles. As a result of the multitude of motorcyclists, the largest percentage of traffic-related incidents involves motorcycles. A statistical model, called GLIM software, used generalized linear modeling to develop the relationship between the number of motorcycle accidents due to conspicuity issues and a range of conspicuity variables, including the running headlight. The data was very seasonal due to some cultural variables, such as the Muslim fasting months, which saw a vast increase in the amount of motorcycle traffic. The results from the study showed that the running-headlight intervention reduced the conspicuity-related motorcycle accidents by about 29% (Radin et al. 1996). This successful campaign demonstrated one of the ways motorcycles could improve their safety on the roadways.

Publicity campaigns in Victoria, Australia to increase the voluntary use of colored and fluorescent clothing and daytime running lights were found to be effective, but their effect wears off after about nine months (Road Safety Committee 1998).

In the United States, the effectiveness of voluntary-action countermeasures, such as motorcycle education and training courses, motorcycle helmet-use promotion programs, and education encouraging motorcyclists to increase their conspicuity, has not been proven yet, but some evidence suggests that these countermeasures are not likely to be effective (Preusser et al. 2008).

Many state motorcycle safety programs are advocating to change the state laws that prohibit conspicuity enhancement methods (NCHRP 2008). Also, more public awareness campaigns are reaching out to both clothing manufacturers and motorcyclists to encourage the use of highly-reflective materials that improve the visibility of motorcyclists on the road. The Florida Highway Patrol took the initiative in 1998 to look at collision avoidance by examining which colors are best seen in the daylight and at night and found that red is more easily seen in the sunlight (Wells Jr. 2004).

Other programs, such as post-licensing driver-improvement programs, are thought to help in the reduction of collisions. Such programs could be focused, not only for motorcyclists, but for all drivers. Several studies done at the University of South Dakota focused on 59 driver improvement activities (Struckman-Johnson et al. 1988). The major finding was that driver improvement activities result in fewer traffic violations, but not fewer collisions.

The Association of European Motorcycle Manufacturers (ACEM), with the support of the European Commission and other partners, conducted an extensive in-depth study of motorcycle and moped crashes during the period of 1999-2000. The Motorcycle Accidents In-Depth Study (MAIDS) selected five sampling areas in France, Germany, Italy, Netherlands, and Spain. Based on a sample of 921 crashes, the study found that the majority of the crashes involving motorcycles and mopeds were caused by “failure to see the motorcycles and mopeds within the traffic environment, due to lack of driver attention, temporary view obstructions, or the low conspicuity of the motorcycles and mopeds.”

2.2.5 Other Studies

A review of state motorcycle safety program technical assessments offered recommendations for additional steps states might take to increase conspicuity (Baer and Skemer 2009). The recommendations encouraged states to “initiate public awareness efforts focused on the use of high-visibility riding gear and daytime running lights; take steps to alert motorists about motorcyclists, using strategies such as incorporating “Share the Road” messages as part of driver’s education classes; amplify public information and outreach efforts.”

A study was conducted in the United Kingdom to “gain an understanding of motorcyclists’ attitudes to safety and the reasons behind the decisions that impact on their safety” (Christmas et al. 2009). Among the study objectives was to explore how riders choose their protective clothing and helmets. The study classified motorcyclists into seven segments by motivation, based on quantitative and qualitative research: performance disciples, performance hobbyists, riding disciples, riding hobbyists, car rejecters, car aspirants, and look-at-me enthusiasts. Two critical segments of riders were identified: car aspirants, who were young people who ride a motorcycle because they cannot afford a car, and look-at-me enthusiasts, who were young riders for whom riding is about self-expression and looking cool. These two segments had the highest crash propensity and were less likely than other segments to think about the risks of riding without a safe helmet and gear. Looking cool ranked highly in the choice of both helmet and gear, compared to safety, especially for the look-at-me enthusiasts.

2.3 Summary

A common cause of motorcycle crashes involving other vehicles is that other drivers do not detect the oncoming motorcycle. These situations could be attributable to either poor speed-spacing judgment of other drivers or insufficient front motorcycle conspicuity.

One of the most important conspicuity factors is the reflectivity of the rider’s clothing and the frontal area of the motorcycle. Conspicuity can be enhanced by wearing fluorescent clothing, such as yellow green, yellow orange, or red orange, and a brightly-colored helmet. Effectiveness of these efforts depends on the contrast between the motorcycle and its background.

National and international studies also show that daytime headlight use and daytime running lights on motorcycles have reduced the number of multi-vehicle motorcycle crashes during daylight hours.

Safety campaigns or interventions have also been claimed to be successful in reducing conspicuity-related motorcycle crashes.

3. DATA DESCRIPTION

3.1 Overview

This section presents an overview of Iowa's roadside observational motorcycle helmet-use survey in three regions across the state. It presents motorcycle helmet use by time of day and road type for motorcycle riders and their passengers. After that, this section summarizes and interprets data provided by the Iowa DOT on motorcycle crashes from 2001 to 2008, using descriptive analysis techniques.

3.2 Iowa's Motorcycle Helmet-Use Survey

3.2.1 Survey Methodology

Motorcycle helmet-use data are based on three roadside observational surveys of randomly-selected roadway sites in three regions of Iowa (See Figure 3.1). All three surveys were conducted during riding season (May to September) and observers noted motorcycle helmet use by riders and passengers between the hours of 7 a.m. and 6 p.m. The map shows the three regions in Iowa where the data was collected and the corresponding year of the survey: motorcycle helmet use was collected for the Southeast region in 2006, the Southwest region in 2008, and the Northeast region in 2009.

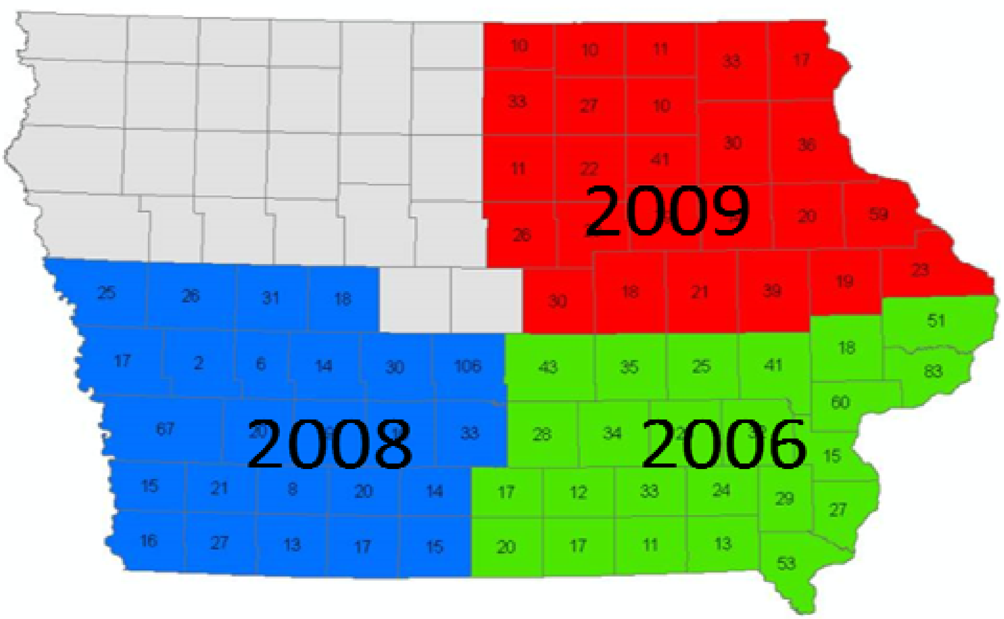


Figure 3.1. Location and year of helmet-use surveys

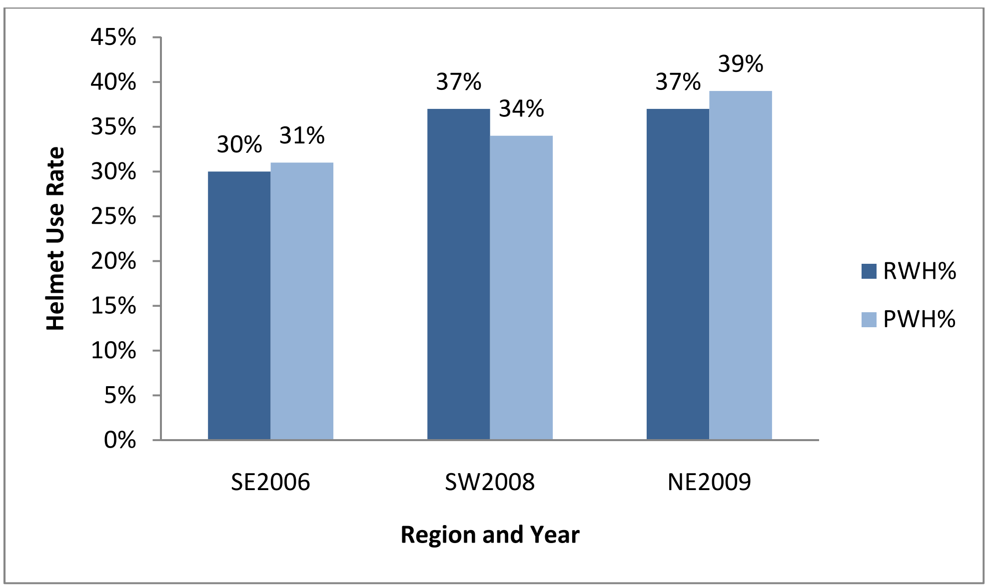
3.2.2 Summary of Helmet-Use Survey Data

Table 3.1 presents the total number of motorcyclists (riders and passengers) observed in each region in the corresponding year. The number of counties surveyed in each region was almost the same. The number of motorcyclists observed in Southeast Iowa in 2006 was higher than that of the other two regions in 2008 and 2009.

Table 3.1. Number of motorcyclists observed by year and region

Year	**2006**	**2008**	**2009**
Region	Southeast	Southwest	Northeast
Number of counties	24	25	25
Riders	24,493	20,072	20,198
Passengers	1,902	2,476	2,514

Figure 3.2 shows the trend of motorcycle helmet use from 2006 to 2009 (without any data for 2007). Since the percentages over years correspond to different regions, they are not directly comparable. The lower helmet-use percentages were observed in the Southeast region in 2006. According to the nationwide helmet-use statistics provided by NHTSA, helmet use increased from 48% in 2005 to 67% in 2009. Compared to those statistics, helmet use in Iowa is very low. This is probably due to that fact that Iowa doesn't have an enforceable helmet law.



DWH=Driver/rider observed wearing helmet; PWH=Passenger observed wearing helmet

Figure 3.2. Helmet use by year and region

3.2.3 Helmet Use by Road Type

Figure 3.3 presents helmet use on five road types. The highest helmet-use rate (45%) was observed on urban roads, followed by interstate roads (39%). Helmet use on city and primary roads were nearly identical percentages, while the lowest percentage of motorcyclists wearing a helmet was on secondary roads.

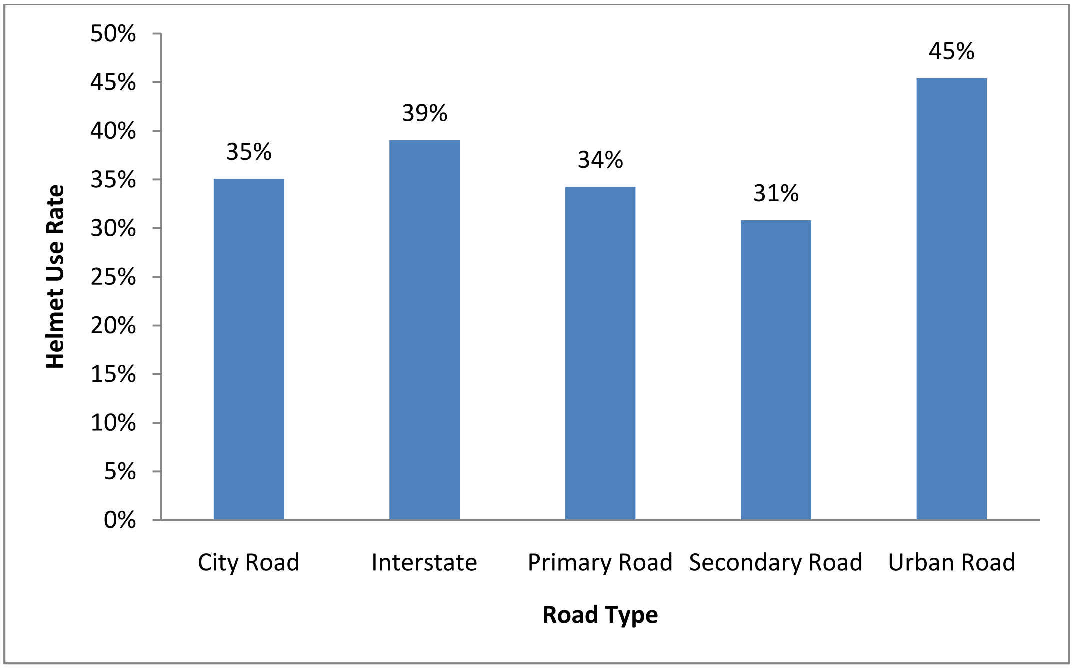


Figure 3.3. Motorcycle helmet use by road type

Figure 3.4 shows the motorcycle helmet use by the five road types and the three regions. Motorcycle helmet-use rates on city, primary, and secondary roads were similar in the Southwest and Northeast regions, while helmet-use rates on those same road types in Southeast Iowa were much lower. The greatest difference in helmet use across road types and regions was found between urban roads in the Southwest and Southeast regions (27%). Note that 71% of the survey data were collected on primary roads, which is the most common road type in Iowa, and that some data were missing for interstate roads in Southeast Iowa.

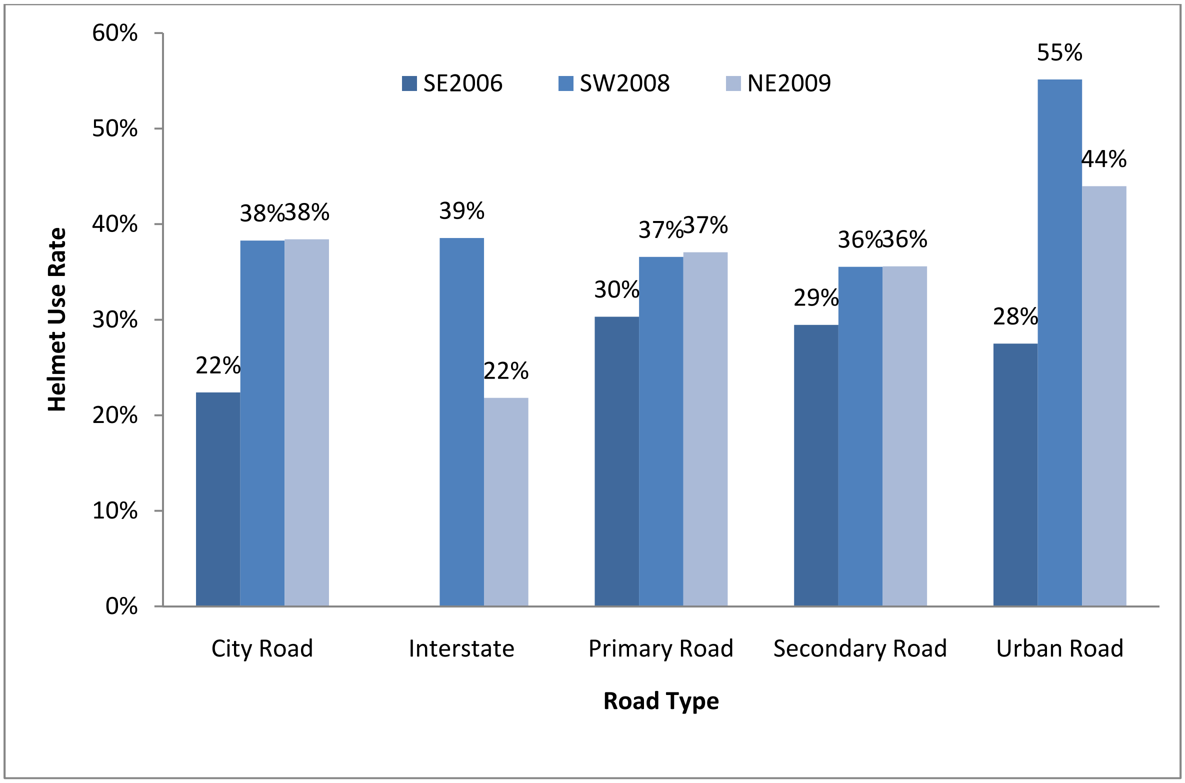


Figure 3.4. Motorcycle helmet use by road type and region

3.2.4 Helmet Use by Time of Day

Helmet-use data were collected during three peak-hour periods: morning, mid-afternoon, and evening (See Figure 3.5). Helmet use was higher in the morning across all regions and years compared to mid-afternoon and evening.

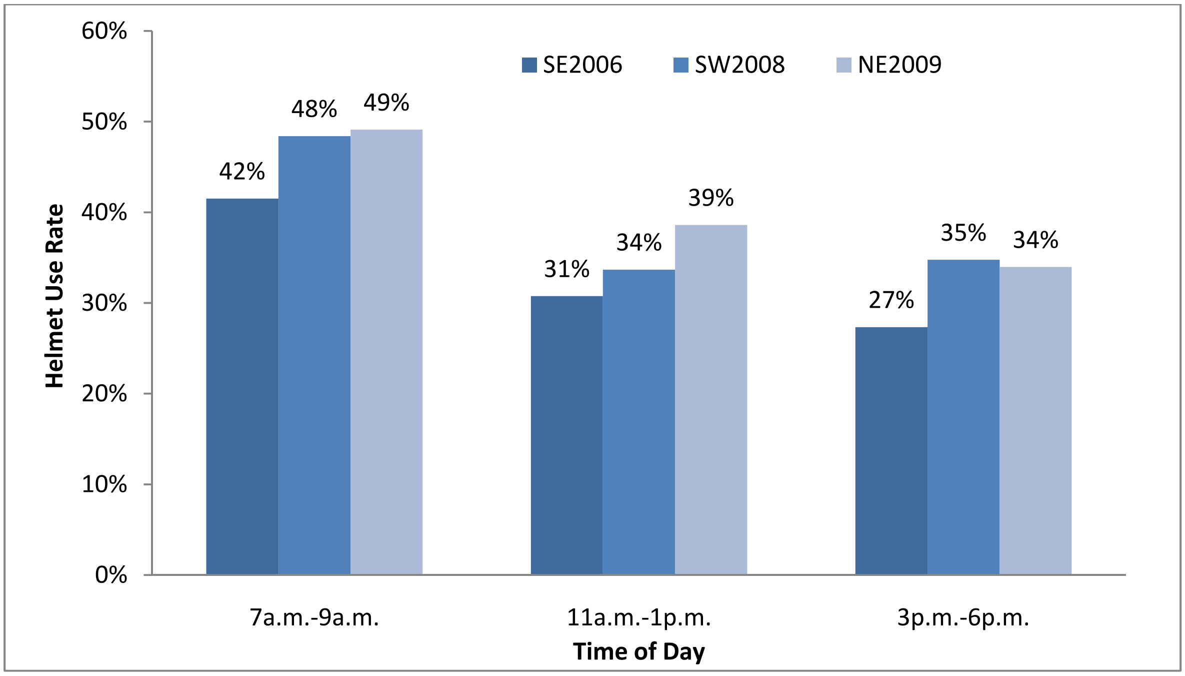


Figure 3.5. Helmet use by time of day

3.2.5 Summary of the Survey

Table 3.2 shows the comparison of helmet use by region and year, road type, and time of day. A much higher percentage of riders with helmets (RWH) were observed than passengers with helmets (PWH) on interstate roads, which is probably due to fewer observations collected for passengers on interstate roads. More specifically, 56 passengers were observed in 2008 and only eight in 2009. Rider and passenger helmet-use rates on primary and secondary roads were similar percentages, which may indicate that rider and passenger decisions to wear a helmet on these types of roads are interrelated. Turning to the time of day, rider and passenger helmet-use rates during the evening peak period were similar.

Table 3.2. Helmet-use rate summary (percentages)

	Southeast 2006			**Southwest 2008**			**Northeast 2009**		
All motorcyclists	30			37			37		
Riders (RWH)	30			37			37		
Passengers (PWH)	31			34			39		
Road type	**All**	**RWH**	**PWH**	**All**	**RWH**	**PWH**	**All**	**RWH**	**PWH**
City Road	22	23	17	38	39	25	38	38	45
Interstate	n/a	n/a	n/a	39	40	18	22	26	0
Primary Road	30	30	32	37	37	35	37	37	39
Secondary Road	29	30	28	36	36	35	36	35	38
Urban Road	28	29	0	55	57	33	44	44	43
Time of day	**All**	**RWH**	**PWH**	**All**	**RWH**	**PWH**	**All**	**RWH**	**PWH**
Morning peak hour (7 a.m.-9a.m.)	42	41	58	48	48	47	49	48	66
Mid-afternoon (11a.m.-1p.m.)	31	30	38	34	34	31	39	38	46
Evening peak hour (3p.m.-6p.m.)	27	27	27	35	35	34	34	34	34

In summary, higher helmet-use rates were observed from year 2006 to 2009, both for riders and passengers. However, note that different regions were surveyed each year, so the trend could be misleading. Lower helmet-use rates were observed on interstate, primary, and secondary roads, compared to rates on city and urban roads. Also significant, about half of the motorcyclists observed during the morning peak hour wore a helmet.

3.3 Analysis of Iowa's Motorcycle Crash Data 2001-2008

3.3.1 Overview of motorcycle crash data in Iowa

The Iowa DOT provided data on crashes involving at least one vehicle that was identified as a motorcycle from 2001 to 2008. The data included information, such as year, month, day, and time of crash; location of crash; road surface and environmental conditions; crash type; crash severity; major cause of the crash; events contributing to the crash; and number of vehicles involved. The data also included other information about the motorcycle rider and the driver of the non-motorcycle vehicle involved in the crash.

The crashes occurring within one mile of the corporate city limits were defined as urban, while the crashes occurring outside the city boundaries were defined as rural. All reportable crashes on Iowa's public roads during the analysis period were included in the analysis. Accurate information on motorcycle-miles-traveled (motorcycle exposure) was not available.

Table 3.3 shows the summary statistics for the variables selected for the analysis in the remainder of this report. In the interest of brevity, the variables are presented horizontally, separated by backslashes (such as 5.2/24.5/41.5/19.3/9.5), rather than vertically (with only one variable per line). Note that (*value* SD) in the table provides the standard deviation.

Table 3.3. Summary statistics for variables selected for analysis

	Single-Vehicle Crash No. (% or SD)	**Two-Vehicle Crash No. (% or SD)**
Number of crashes	3,632 (49.6%)	3,316 (45.0%)
Average number of crashes per year	454 (72.8 SD)	414.5 (46.1 SD)
Variable	**Single-Vehicle Crash Percentage**	**Two-Vehicle Crash Percentage**
Crash severity: Fatal/Major injury/Minor injury/Possible or unknown/ Property damage only	5.2/24.5/41.5/19.3/9.5	4.5/18.0/34.1/22.8/20.7
Year: 2001 to 2008	10.0/10.3/11.9/11.0/13.9/ 13.2/ 15.6/14.0	11.0/10.7/11.5/12.1/13.8/ 13.4/13.0/14.5
Month of year: Jan/Feb/Mar/Apr/May/Jun/ Jul/Aug/Sep/Oct/Nov/Dec	0.3/0.7/2.3/9.0/12.9/17.9/ 17.8/15.9/12.2/7.7/2.7/0.6	0.6/0.6/2.7/8.8/12.1/17.0/ 16.6/15.8/13.6/8.0/3.5/0.5
Day of week: Mon/Tue/Wed/Thu/ Fri/Sat/Sun	20.2/10.9/9.5/9.7/ 11.5/15.0/23.0	13.8/11.5/11.9/12.4/ 12.8/18.5/19.1
Time of day: 0-7/7-9/9-11/11-13/13-16/16-18/ 18-24	13.8/2.4/4.3/7.8/18.7/15.3/ 37.7	4.3/4.2/5.6/10.5/25.2/22.5/ 27.8

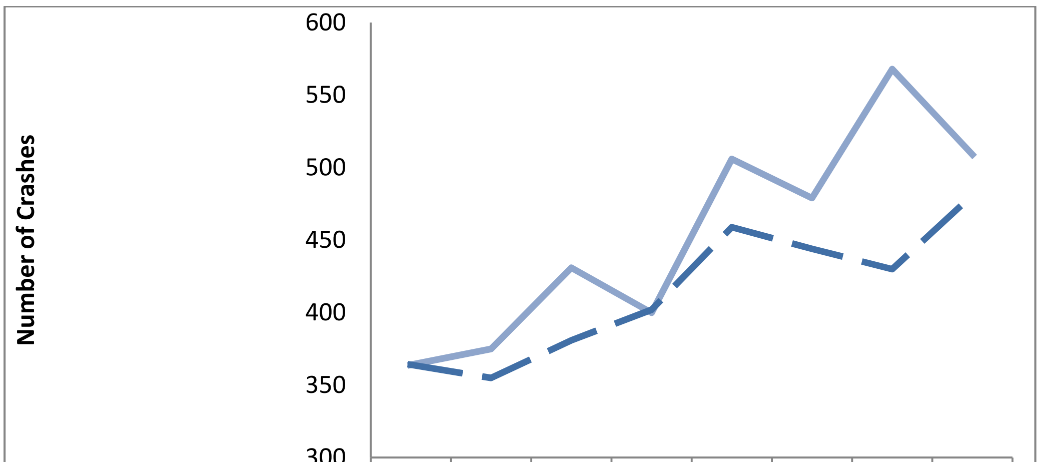
Variable	**Single-Vehicle Crash Percentage**	**Two-Vehicle Crash Percentage**
Weather conditions: Clear/Partly cloudy/Cloudy/Other	68.4/18.1/6.3/7.1	71.8/18.7/5.5/4.0
Light conditions: Daylight/Dusk/Dawn/Dark-roadway lighted/Dark-roadway not lighted/ Dark-unknown roadway lighting/ Other	60.6/4.9/1.1/13.7/17.0/0.6/ 2.1	78.7/3.2/0.5/13.0/3.1/0.4 1.1
Rural/Urban	55.0/45.0	17.2/82.8
Non-intersection/Intersection	76.5/23.5	42.5/57.5
Speed limit (mph): Under 25/25-35/40-50/55-65/ Over 65	1.6/36.3/13.0/47.7/1.5	*Motorcycle:* 2.7/69.2/11.9/16.0/0.2 *Non-motorcycle vehicle:* 3.5/69.4/11.5/15.4/0.2
Crash type: Head-on/Rear-end/Angle-oncoming left turn/Broadside/ Sideswipe-same direction/ Sideswipe-opposite direction/ Other	Non-collision (100%)	3.9/25.0/19.7/28.6/11.6/ 2.2/9.2
Driver contributing factor:	Lost control/No improper action/ Other 44.7/18.0/37.2	*Motorcycle*: Lost control/Followed too close/Exceeded authorized speed 3.13/3.1/2.8 *Non-motorcycle vehicle*: FTYROW making left turn/FTYROW from stop sign 16.3/13.7
Vehicle action: Move straight/Turning left/ Turning right/Other	75.9/6.2/4.4/13.5	*Motorcycle:* 74.8/4.6/2.4/18.1 *Non-motorcycle vehicle:* 36.4/35.0/4.2/24.4
Variable	**Mean (SD) Percentage**	**Mean (SD) Percentage**
Age of the motorcycle rider: Under 20/21-30/31-40/ 41-50/ 51-60/Over 60 years old	38.4 (15.1 SD) 12.6/23.5/18.9/23.4/ 15.9/5.7	39.8 (17.3 SD) 11.3/23.2/19.1/23.6/ 14.6/8.2
Age of the non-motorcycle vehicle driver: Under 20/21-30/31-40/41-50/ 51-60/Over 60 years old	Not applicable	43.3 (24.0 SD) 20.1/20.0/13.9/12.8/10.4/ 22.8
Helmet use: Rider without helmet/Rider with helmet	71.9/29.1	76.4/23.6

SD=standard deviation
FTYROW=Failed to yield right of way

3.3.2 Trends in the Frequency and Severity of Motorcycle Crashes

A total of 7,328 motorcycle crashes were reported during the eight-year analysis period (2001-2008). In 2008, 1,061 crashes were reported, compared to 762 crashes in 2001, representing a 39% increase. Among the total 7,328 crashes during the eight-year period, 3,632 or 50% were single-vehicle crashes, with just the one motorcycle involved; 3,316 or 45% were two-vehicle crashes, with a motorcycle and a non-motorcycle vehicle; and the remaining 5% involved two motorcycles or three or more vehicles. Given that single- and two-vehicle crashes represent 95% of the crashes, the following analysis focuses on these two types of crashes.

Figure 3.6 shows the increasing trend in the number of both single-vehicle and two-vehicle motorcycle crashes from 2001 to 2008. Note that during this time period, motorcycle registrations in Iowa increased by 34.5%, from 120,961 to 162,662. Interestingly, in the last two years of this study (2007 and 2008), single-vehicle crashes decreased by 10%, while two-vehicle crashes increased by 12%.



	2001	2002	2003	2004	2005	2006	2007	2008
Single-Vehicle Crashes	364	375	431	400	506	479	568	509
Two-Vehicle Crashes	364	355	381	402	459	444	430	481

Figure 3.6. Number of motorcycle crashes from 2001 to 2008

The analysis considered injury severity at the crash level. Crash severity was considered as fatal, major injury, minor injury, possible/unknown, and property damage only. Tables 3.4 and 3.5 present the trend in the severity of motorcycle crashes from 2001 to 2008 for single-vehicle and two-vehicle crashes.

Table 3.4. Single-vehicle motorcycle crash severity

Year	Fatal Crashes No. (%)	Major Injury Crashes No. (%)	Minor Injury Crashes No. (%)	Possible/ Unknown Crashes No. (%)	Property Damage Only Crashes No. (%)	Total Crashes No. (%)
2001	13 (4%)	90 (25%)	155 (43%)	53 (15%)	53 (15%)	364 (10%)
2002	21 (6%)	82 (22%)	151 (40%)	66 (18%)	55 (15%)	375 (10%)
2003	24 (6%)	114 (26%)	162 (38%)	91 (21%)	40 (9%)	431 (12%)
2004	15 (4%)	121 (30%)	163 (41%)	69 (17%)	32 (8%)	400 (11%)
2005	23 (5%)	111 (22%)	222 (44%)	104 (21%)	46 (9%)	506 (14%)
2006	27 (6%)	103 (22%)	186 (39%)	120 (25%)	43 (9%)	479 (13%)
2007	41 (7%)	142 (25%)	240 (42%)	102 (18%)	43 (8%)	568 (16%)
2008	26 (5%)	126 (25%)	230 (45%)	95 (19%)	32 (6%)	509 (14%)
Average	23.8 (5%)	111.1 (25%)	188.6 (41%)	87.5 (19%)	43 (10%)	454 (13%)

Table 3.5. Two-vehicle motorcycle crash severity

Year	Fatal Crashes No. (%)	Major Injury Crashes No. (%)	Minor Injury Crashes No. (%)	Possible/ Unknown Crashes No. (%)	Property Damage Only Crashes No. (%)	Total Crashes No. (%)
2001	18 (5%)	69 (19%)	127 (35%)	62 (17%)	88 (24%)	364 (10%)
2002	14 (4%)	71 (20%)	106 (30%)	78 (22%)	86 (24%)	355 (10%)
2003	19 (5%)	69 (18%)	131 (34%)	94 (25%)	68 (18%)	381 (10%)
2004	15 (4%)	82 (20%)	134 (33%)	94 (23%)	77 (19%)	402 (11%)
2005	19 (4%)	84 (18%)	156 (34%)	119 (26%)	81 (18%)	459 (13%)
2006	27 (6%)	71 (16%)	152 (34%)	100 (23%)	94 (21%)	444 (12%)
2007	14 (4%)	81 (19%)	140 (33%)	100 (23%)	95 (22%)	430 (12%)
2008	23 (5%)	69 (14%)	184 (38%)	108 (22%)	97 (20%)	481 (13%)
Average	18.6 (5%)	74.5 (18%)	141.3 (34%)	94.4 (26%)	85.8 (21%)	414.5 (11%)

Overall, single-vehicle motorcycle crashes resulted in a more severe injury outcome than crashes involving a motorcycle and a non-motorcycle vehicle, as the frequency and percentile distributions suggest. Moreover, fatal single-vehicle crashes increased by 100% from 2001 to 2008.

An analysis of the distribution of these crashes by other factors, such as weather conditions and rider and driver age, are discussed later (See Tables 3.6 through 3.9).

3.3.3 Temporal Distribution of Crashes

Figures 3.7 through 3.9 show the distribution of single-vehicle and two-vehicle crashes by month of year, day of week and time of day, respectively. As expected, most of the crashes involving motorcycles occurred between May and September, with the highest numbers occurring in June and July (See Figure 3.7).

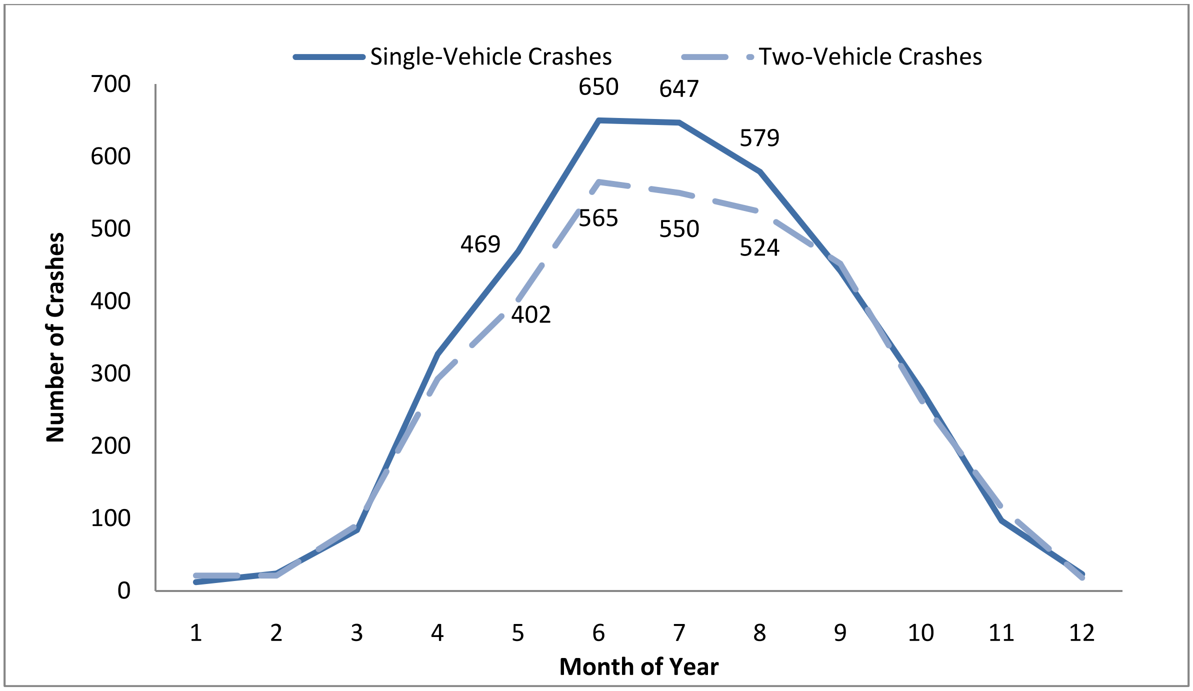


Figure 3.7. Distribution of crashes by month of year

Turning to the distribution of crashes by day of week, crashes involving motorcycles were generally more likely to occur on weekends, which suggests more recreational trips than work trips (See Figure 3.8). Public information campaigns could be beneficial to remind motorcycle riders to ride cautiously and other motorists to be more aware of motorcyclists on the road during weekends.

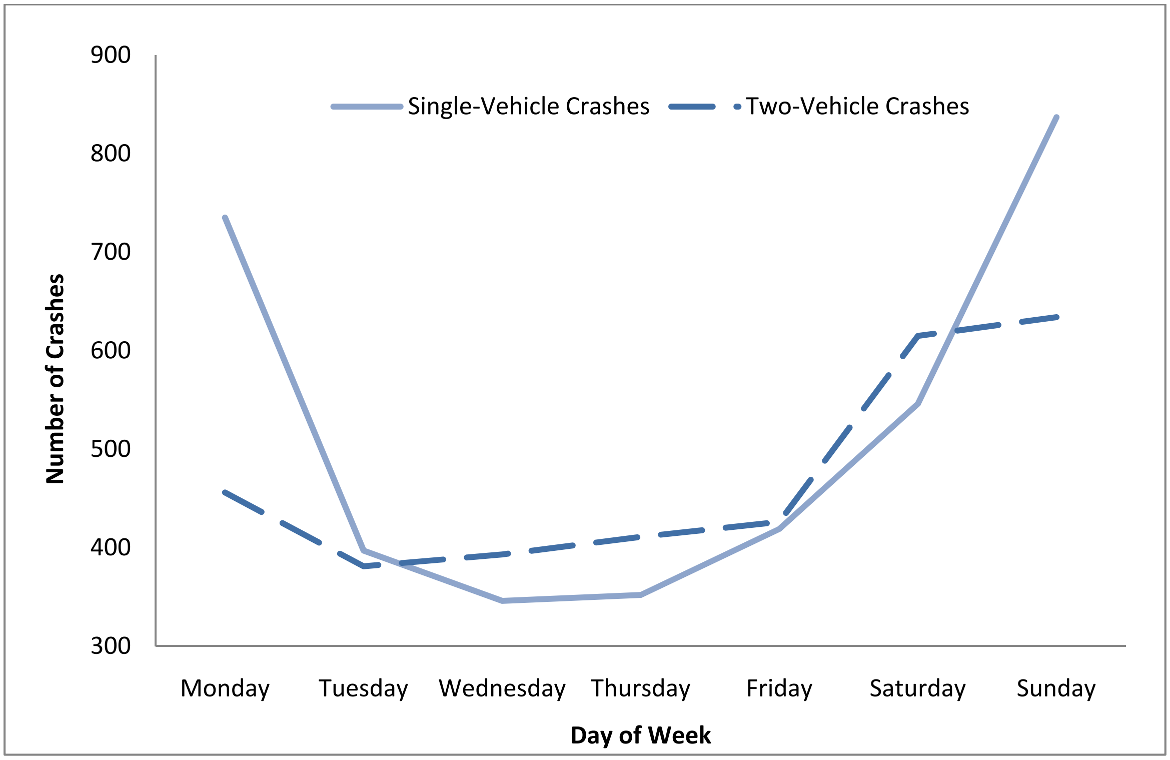


Figure 3.8. Distribution of crashes by day of week

The temporal distribution of crashes during a day (Figure 3.9) shows an increasing trend of single-vehicle crashes occurring from 8 a.m. to 7 p.m. and a decreasing trend thereafter, and an increasing trend of two-vehicle crashes occurring from 5 a.m. to 4 p.m. and a decreasing trend thereafter.

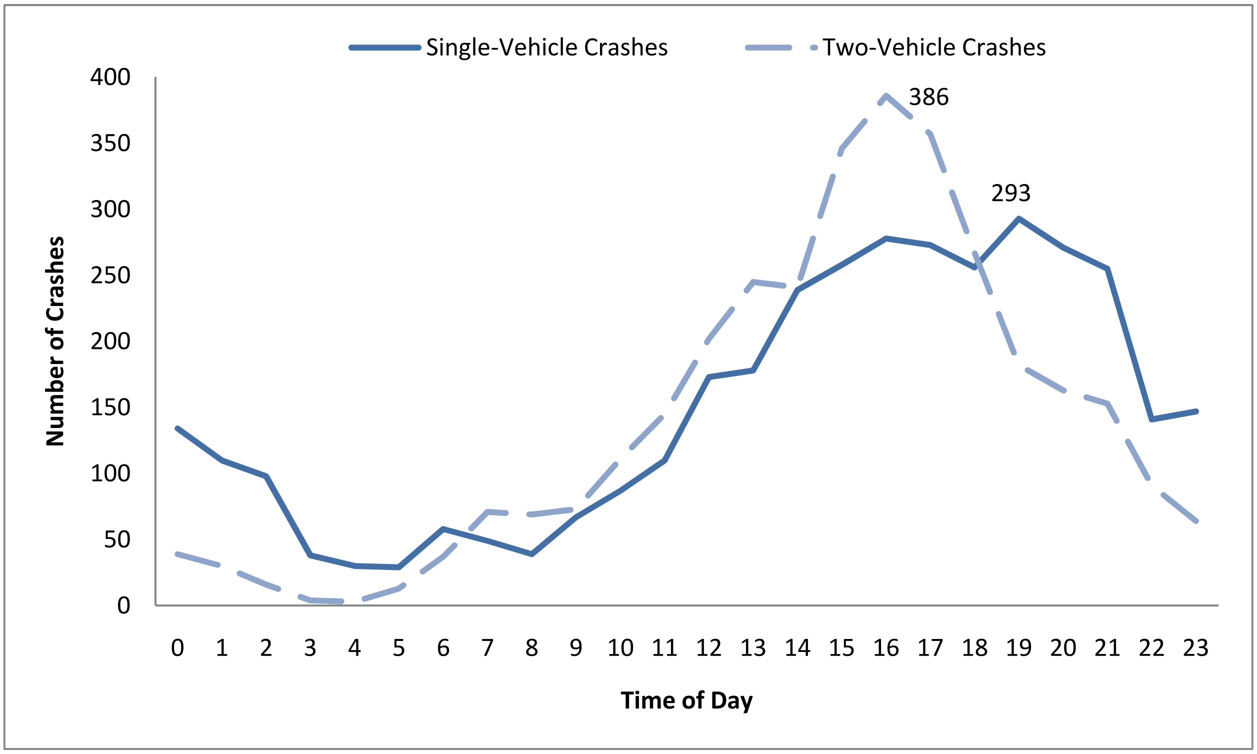


Figure 3.9. Distribution of crashes by time of day

3.3.4 Distribution of Crashes by Weather and Light Conditions

More than two-thirds of the motorcycle crashes reported were under clear weather (as clear conditions encourage motorcycle riding) and one-quarter were under cloudy or partly cloudy conditions (See Table 3.6).

Table 3.6. Distribution of crashes by weather conditions

Weather	Single-Vehicle Crashes No.	%	Two-Vehicle Crashes No.	%
Clear	2,485	68	2,380	72
Partly cloudy	659	18	620	19
Cloudy	229	6	184	6
Other	259	8	132	3
Total	3,632	100	3,316	100

Turning to the light conditions when the crash occurred, 70% of the crashes happened during daylight, while one-fifth of the crashes occurred under dark conditions (See Figure 3.10). This finding reflects the increased use of motorcycles during daylight compared to nighttime and the greater associated probability of getting involved in a crash during the day. A statistical analysis of the differences between single- and two-vehicle crashes by light conditions is presented later (See Table 4.2).

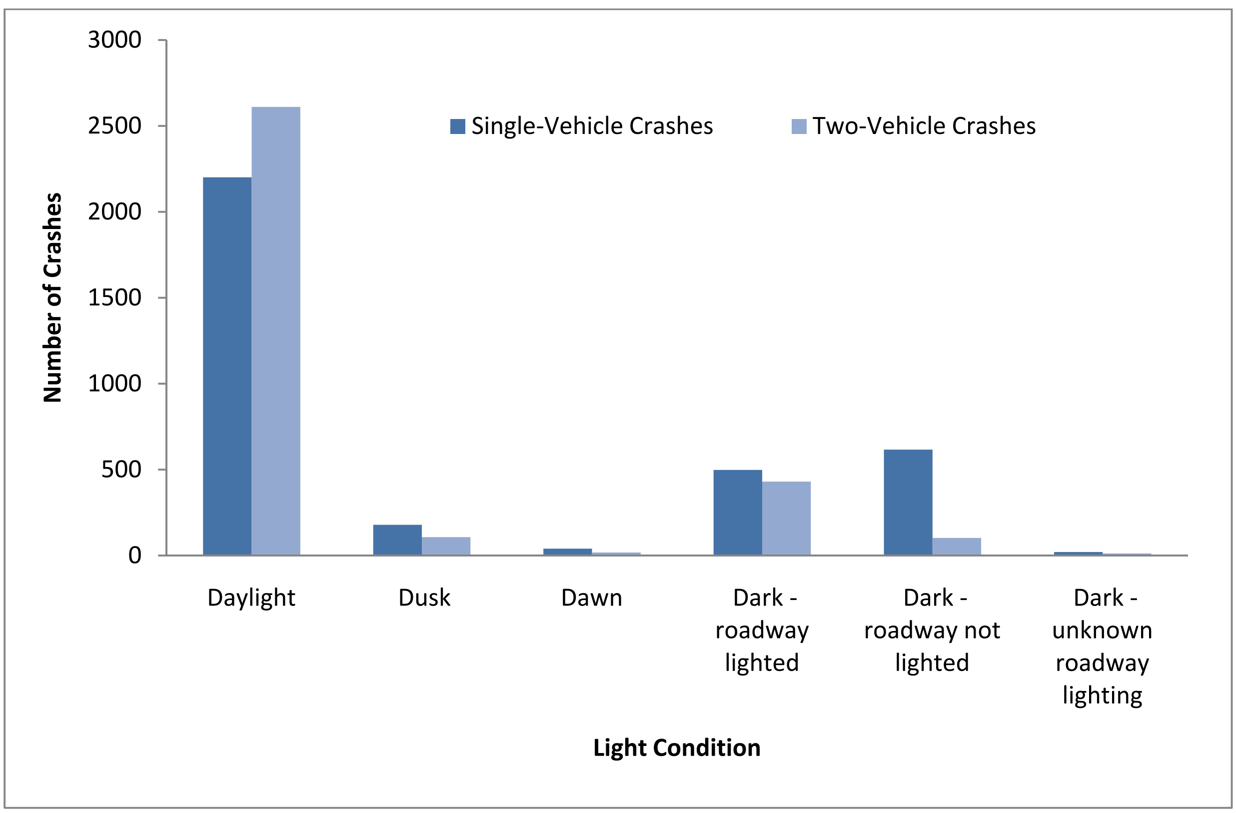


Figure 3.10. Distribution of crashes by light conditions

3.3.5 Distribution of Crashes by Rider and Driver Age

Six age groups were considered to present the age distribution of riders involved in the two types of crashes (See Figure 3.11). The percentage of riders by age group who were involved in a single-vehicle versus a two-vehicle crash was pretty similar. Moreover, half of the single- and two-vehicle crashes involved riders either between 21 and 30 years old or between 41 and 50 years old. This finding suggests taking a closer look at these two age groups.

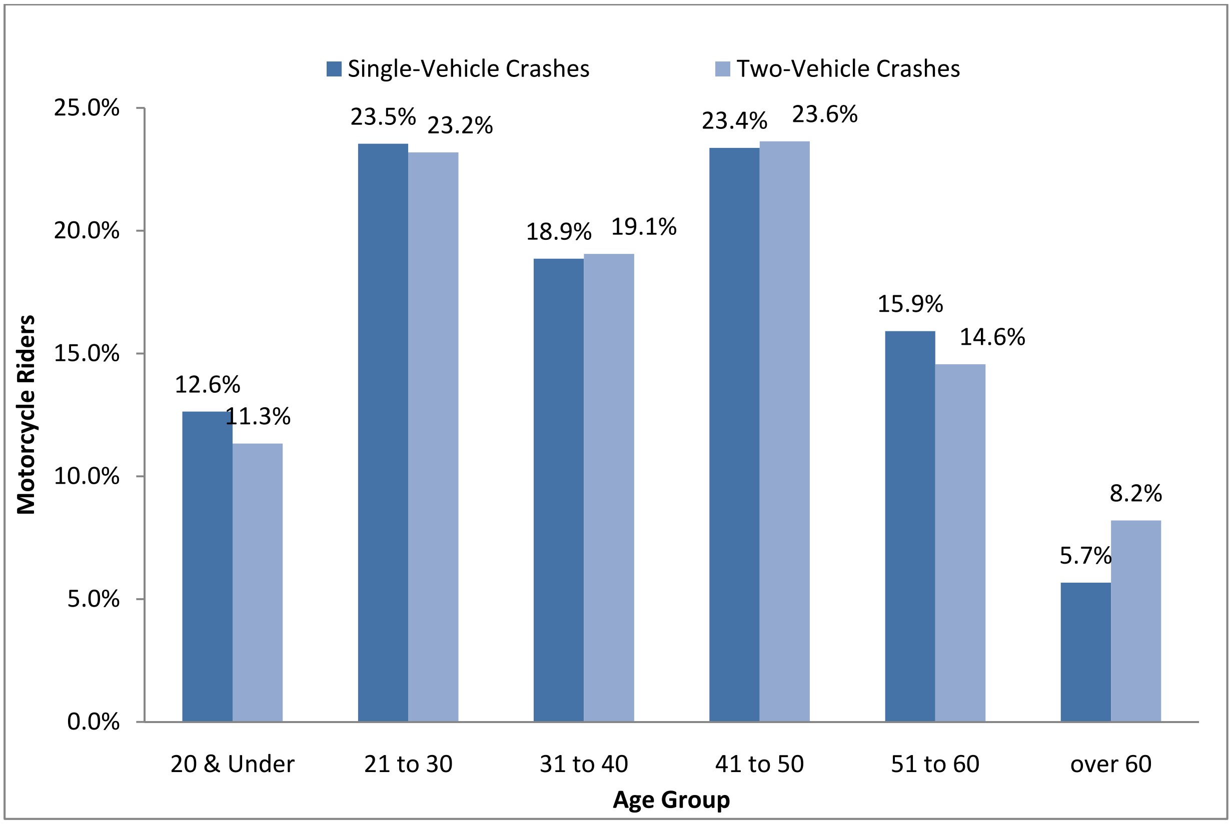


Figure 3.11. Age distribution of motorcycle riders involved in crashes

Figure 3.12 shows the distribution of crashes by the age of the non-motorcycle driver. A high percentage of older drivers (over 60), followed by younger drivers (under 30) were involved in crashes with motorcycles. This finding suggests increasing the awareness of motorcycles on the road with older and younger drivers.

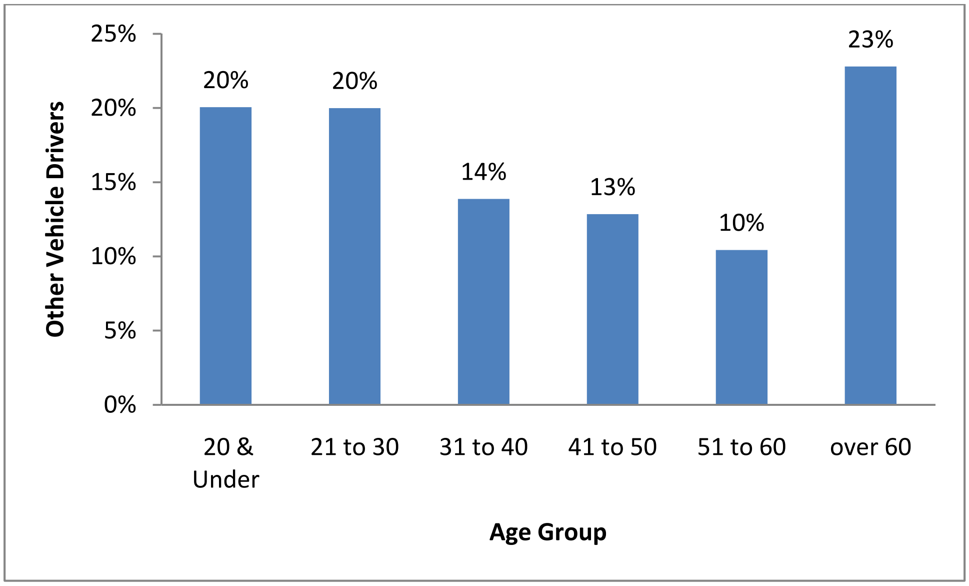


Figure 3.12. Age distribution of the non-motorcycle vehicle drivers involved in two-vehicle crashes

A comparison of the trend from 2001 to 2008 shows that younger motorcycle riders (under 40 years old) were involved in fewer crashes over time, while older riders (41 and older) were involved in more crashes (See Tables 3.7 and 3.8).

Table 3.7. Age distribution of motorcycle riders involved in single-vehicle crashes over time (percentages each year)

Age	2001	2002	2003	2004	2005	2006	2007	2008
20/under	16	14	14	12	13	11	12	11
21to 30	27	25	26	25	23	22	20	23
31 to 40	21	23	21	18	20	19	16	14
41 to 50	21	21	23	22	22	24	26	27
51 to 60	11	14	11	19	17	15	20	18
Over 60	4	3	5	5	6	9	6	6

Table 3.8. Age distribution of motorcycle riders involved in two-vehicle crashes over time (percentages each year)

Age	2001	2002	2003	2004	2005	2006	2007	2008
20/under	13	12	10	14	11	11	13	8
21to 30	24	25	23	22	27	21	22	21
31 to 40	24	24	22	21	15	19	17	13
41 to 50	24	22	27	22	25	25	20	25
51 to 60	8	12	12	15	14	17	18	19
Over 60	6	6	7	7	8	8	10	13

Turning to the non-motorcycle vehicle drivers, fewer drivers 20 years old or younger were involved in two-vehicle crashes, but more drivers between 21 and 30 were involved these crashes (See Table 3.9). Regarding the other age groups, the percentages fluctuated from year to year.

Table 3.9. Age distribution of non-motorcycle vehicle drivers involved in two-vehicle crashes over time (percentages each year)

Age	2001	2002	2003	2004	2005	2006	2007	2008
20/under	24	22	19	22	21	20	18	16
21to 30	16	20	17	19	20	20	20	26
31 to 40	16	16	15	14	14	13	13	12
41 to 50	13	14	18	12	12	12	13	10
51 to 60	9	9	11	11	12	8	13	11
Over 60	23	19	20	21	22	27	24	26

3.3.6 Helmet-Use Trend from 2001 to 2008

Helmet use by riders involved in single- or two-vehicle crashes increased from 2001 to 2008 (See Figure 3.13). However, helmet-use rates for riders involved in single-vehicle crashes were higher than those for riders involved in two-vehicle crashes. The average helmet-use rate in crashes was 25%, which is lower than the average helmet-use rate of 35% that was observed during roadside surveys (covered earlier in this report).

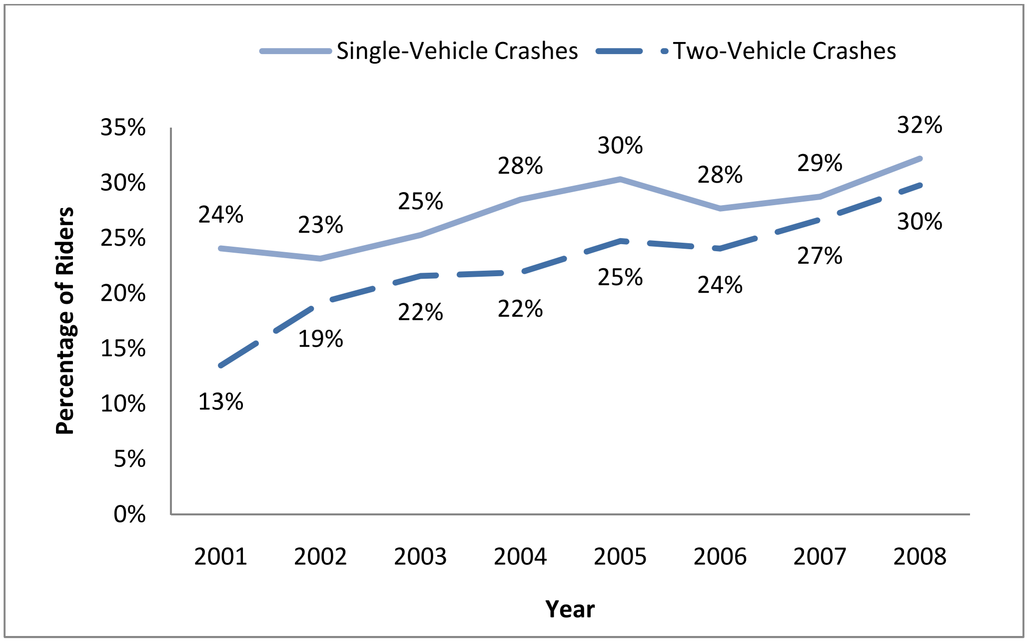


Figure 3.13. Helmet use in single- and two-vehicle crashes

3.3.7 Helmet Use on Rural and Urban Roads

Figures 3.14 and 3.15 show the distribution of helmet use in single- and two-vehicle crashes, respectively, by urban and rural classification. Most two-vehicle crashes (83%) occurred on urban roads (See Table 3.3), while the distribution of single-vehicle crashes on urban and rural roads was 45% and 55%, respectively. Interestingly, helmet use in motorcycle crashes that occurred on rural roads was 33%, while the corresponding rate on urban roads was lower, at 22%; and, the distribution is similar in single- and two-vehicle crashes. Given that 83% of two-vehicle crashes occur on urban roads, measures to increase helmet use in these locations/areas should be explored.

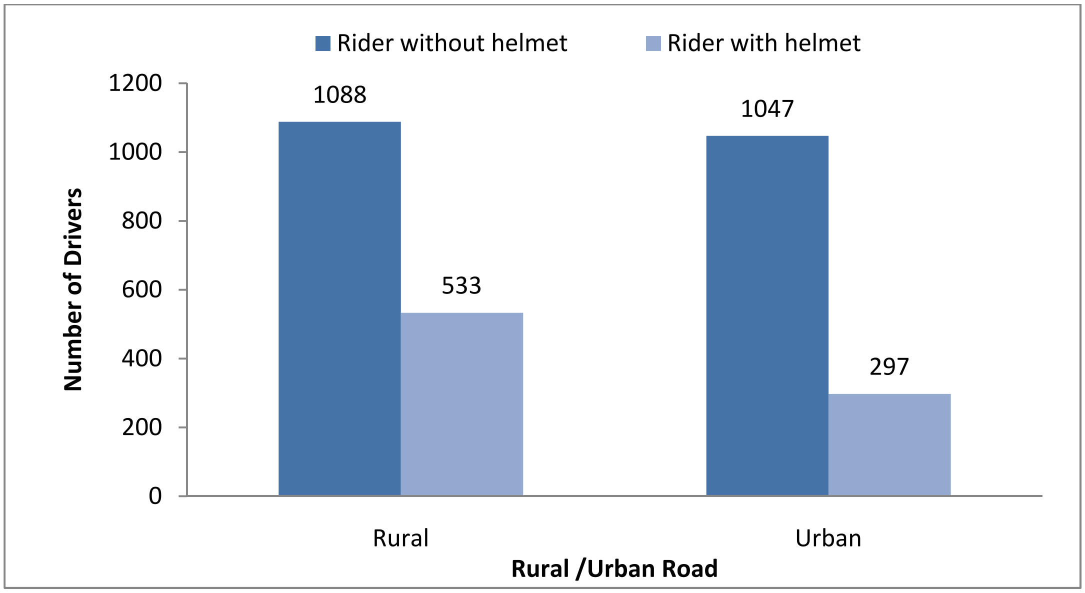


Figure 3.14. Helmet use in single-vehicle crashes by rural and urban classification

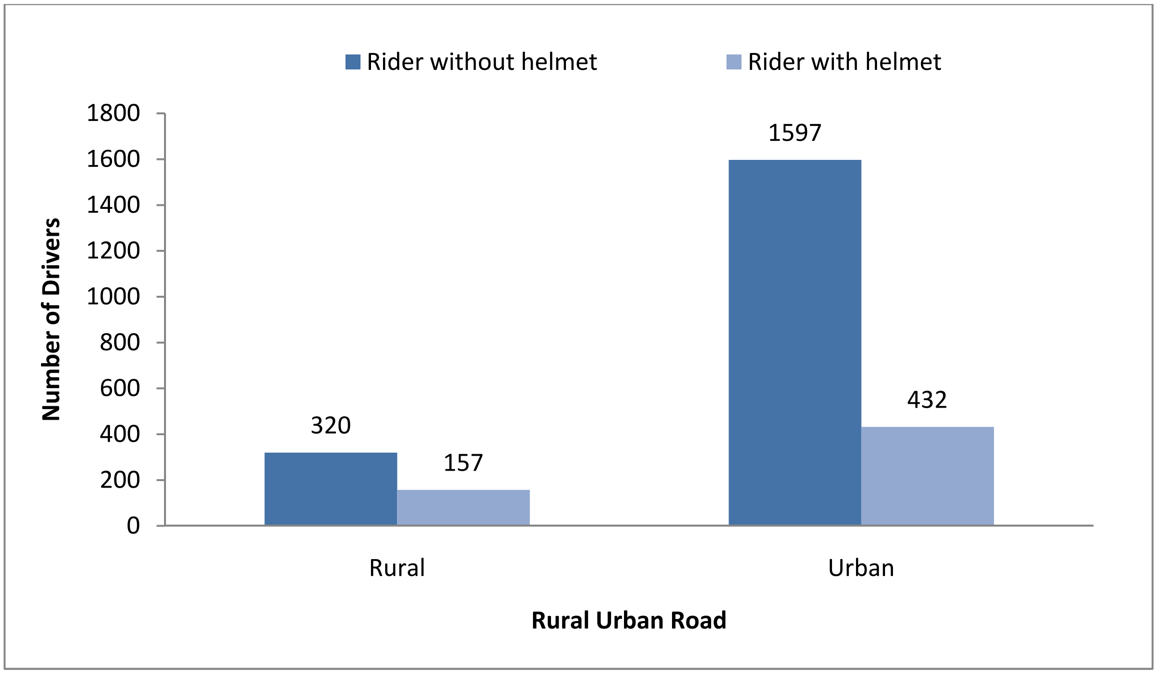


Figure 3.15. Helmet use in two-vehicle crashes by rural and urban classification

3.3.8 Helmet use in crashes by crash severity and intersection class

Figures 3.16 and 3.17 show helmet-use rates in single- and two-vehicle crashes, respectively, by crash severity and non-intersection versus intersection crashes. Helmet use was associated with lower crash severity, as anticipated. Helmet use in intersection and non-intersection two-vehicle crashes across the five severity categories was very similar.

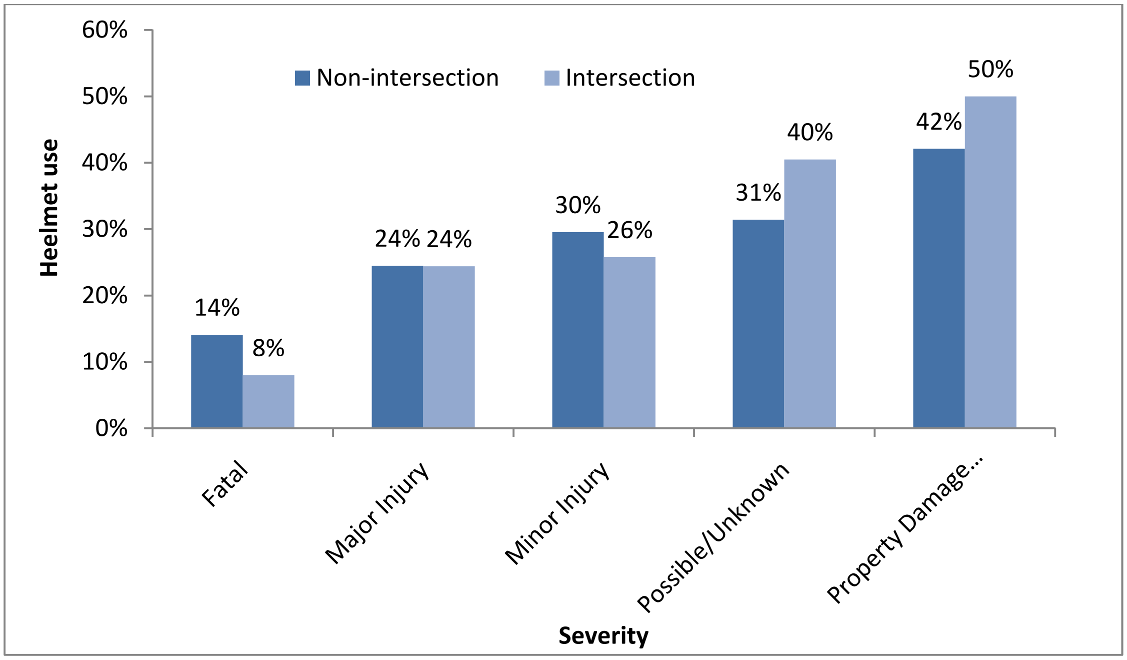


Figure 3.16. Helmet use by crash severity and intersection class in single-vehicle crashes

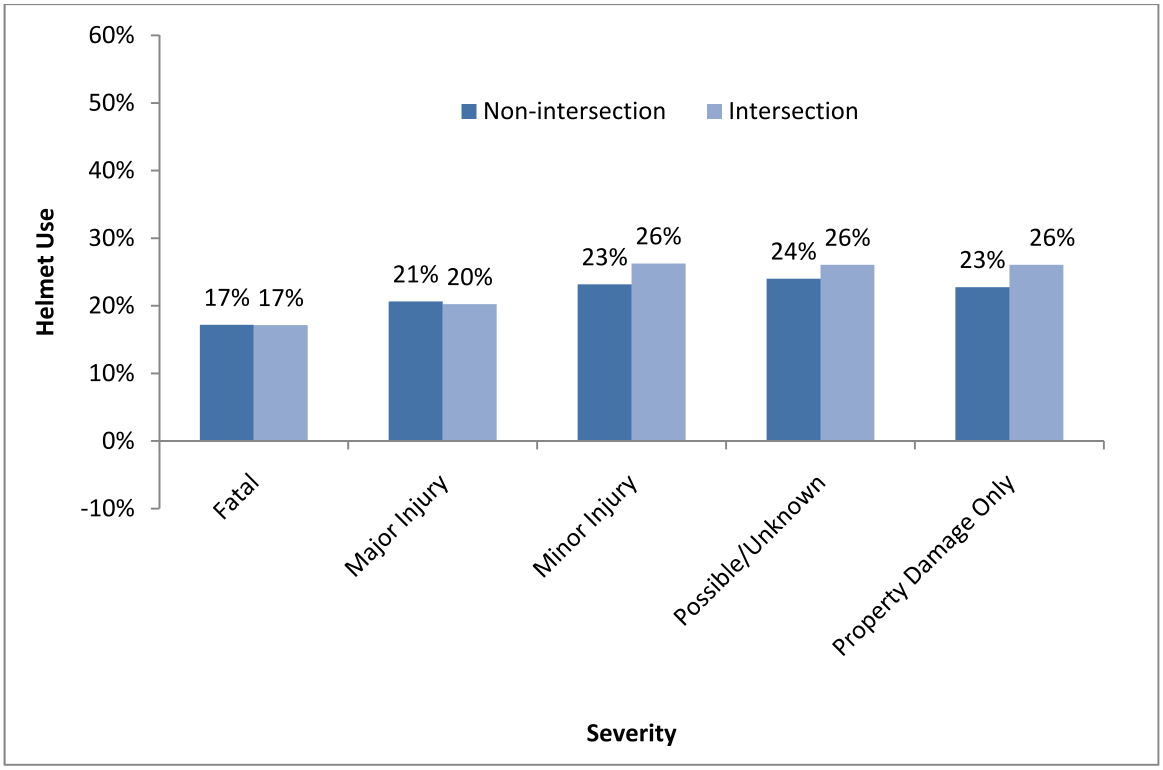


Figure 3.17. Helmet use by crash severity and intersection class in two-vehicle crashes

3.3.8 Analysis of motorcycle crashes at the driver-level

In the driver-level analysis of crashes, if the major driving contributing factor by motorcycles involved in two-vehicle crashes was "no improper action," the analysis assumed that the non-motorcycle vehicle was "at-fault." Likewise, if the major driving contributing factor by non-motorcycle vehicles involved in two-vehicle crashes was "no improper action," it was assumed that the motorcycle was "at-fault." In more than half (56%) of two-vehicle crashes, the driver of the non-motorcycle vehicle was imputed "at-fault," while in a quarter of two-vehicle crashes, motorcyclists were imputed "at-fault." This is consistent with previous work stating that in multi-vehicle crashes, motorcyclists are more likely to be victims than "at-fault" (Haque et al. 2009).

Turning to the vehicle actions that led to a crash, one-quarter of crashes involved a motorcycle and another vehicle moving straight, while one-third of crashes involved one vehicle turning left and the other going straight. The analysis of crashes where one vehicle was turning left and the other was going straight showed that in 91.4% of the cases, the motorcycle was going straight and the non-motorcycle vehicle was turning left—a finding consistent with previous work (Olson 1989). The analysis also showed one-quarter of two-vehicle crashes were rear-end crashes, 60% of which involved a motorcycle hitting the rear part of the non-motorcycle vehicle, while in 40% of the crashes, the motorcycle was rear-ended.

Table 3.10 shows the driver-contributing circumstances, major cause, speed limit range, and intersection class for single- and two-vehicle crashes. More than half of the two-vehicle crashes occurred at an intersection (of which, 67% occurred at a four-way intersection and 20% at a T-intersection), while 76% of the single-vehicle crashes occurred at a non-intersection. Note that speed limit was reported at the driver-level, and as such, for two-vehicle crashes, speed limit was reported for both the motorcycle and the non-motorcycle vehicle.

Table 3.10. Comparison of single- and two-vehicle crashes at the driver-level

	Single-Vehicle Crashes		**Two-Vehicle Crashes**	
	Non-intersection (2,711)	**Intersection** (833, 24%)	**Non-intersection** (1,392)	**Intersection** (1,881, 57%)
Driver-contributing circumstances	-Lost control (44%)	-Lost control (48%)	*Non-motorcycle vehicle:* -FTYROW making left turn (13.5%) -FTYROW from driveway (6.9%) *Motorcycle:* -Lost control (8.3%) -Followed too close (6.4%) - Exceeded authorized speed (4.5%)	*Non-motorcycle vehicle:* -FTYROW from stop sign (23.6%) -FTYROW making left turn (18.6%) *Motorcycle:* -Lost control (3.3%) -Exceeded authorized speed (3.1%) -Followed too close (2.8%)
Major cause	-Animal (18%) -Run off the road-right (18%)	-Lost control (17%) -Swerving/ evasive action (17%)	-FTYROW making left turn (14%) -Followed too close (10%)	-FTYROW from stop sign (25%) -FTYROW making left turn (20%)
Speed limit	-55mph (44%) -25 to 35mph (31%)	-25 to 35mph (50%)	-25 to 35mph (63%)	-25 to 35mph (69%)

FTYROW=Failed to yield right of way

The main driver-contributing factor to a single-vehicle crash was “lost control” for both non-intersection crashes (44% of them) and intersection crashes (48% of them), while the major cause of single-vehicle crashes at non-intersections were “animal” (18%) and “run off the road-right” (18%). 44% of the non-intersection single-vehicle crashes occurred on roads with a 55mph speed limit, while 31% occurred on lower-speed roads (25-35mph). 60% of the fatal single-vehicle crashes occurred on high-speed roads.

Turning to two-vehicle crashes, the non-motorcycle vehicle was reported as the major driving-contributing circumstance in the majority of the non-intersection and intersection crashes. “Failed to yield right of way when making left turn” is the common driver-contributing factor by non-motorcycle vehicles for both intersection and non-intersection crashes, while “failed to yield right of way from stop sign” and “failed to yield right of way from driveway” were the other two primary driver-contributing factors by non-motorcycle vehicles for intersection and non-intersection crashes, respectively.

The three primary driver-contributing factors by riders in two-vehicle crashes were “lost control” (same as in single vehicle crashes), “followed too close,” and “exceeded authorized speed.” The majority of two-vehicle crashes occurred on roads with low speed limits (25-35mph). However, 50% of the fatal two-vehicle crashes occurred on high-speed roads, which is slightly lower than the corresponding fatal percentage for single-vehicle crashes.

4. DATA ANALYSIS

4.1 Overview of the Analysis of Crash Data

This section discusses the application of contingency tables and chi-squared tests to examine potential conspicuity-related factors (such as light conditions, time of day, and helmet use). In addition, this method was used to identify locations (rural/urban and intersection/non-intersection), where motorcycle safety and conspicuity should be emphasized, and to offer recommendations for public information campaigns.

4.2 Methodology

Contingency tables were created and chi-squared test statistics were estimated to examine whether significantly different proportions of potential conspicuity-related factors (such as light conditions, time of day, and helmet use) were represented in single-vehicle crashes and two-vehicle crashes. In addition, this methodology was applied to examine the relationship between crash types and light conditions, as well as that between helmet use and light conditions in two-vehicle crashes.

Contingency tables are often used to record and analyze the relationship between two or more categorical variables, such as between light condition (daylight and dark) and crash categories (single-vehicle crashes and two-vehicle crashes). This method was first used by Karl Pearson (1904). Contingency tables display the frequency distribution of the variables in a matrix format. Table 4.1 presents the general form of a two-dimensional contingency table.

Table 4.1. General form of a two-dimensional contingency table

	Columns (variable 2)					
		1	2	. . .	c	Total
Rows (variable 1)	1	n_{11}	n_{12}		n_{1c}	$n_{1.}$
	2	n_{21}				$n_{2.}$
	r	n_{r1}			n_{rc}	$n_{r.}$
	Total	$n_{.1}$	$n_{.2}$	. . .	$n_{.c}$	$n_{..} = N$

n_{ij} is the observed frequency or count in the i category of the row variable and the j category of the column variable. The total number of observations in the ith category of the row variable is denoted by $n_{i.}$, and the total number of observations in the jth category of the column variable is denoted by $n_{.j}$. These are known as marginal totals, and calculated as equations (1) and (2).

$$n_{i.} = n_{i1} + n_{i2} + \cdots + n_{ic} = \sum_{j=1}^{c} n_{ij} \quad (1)$$

$$n_{.j} = n_{1j} + n_{2j} + \cdots + n_{rj} = \sum_{i=1}^{cr} n_{ij} \quad (2)$$

Similarly

$$n_{..} = \sum_{i=1}^{r} \sum_{j=1}^{c} n_{ij} \quad (3)$$

$$= \sum_{i=1}^{r} n_{i.} = \sum_{j=1}^{c} n_{.j} \quad (4)$$

$n_{..}$ represents the total number of observations in the sample and is usually denoted simply by N.

When the two variables are independent in a two-dimensional contingency table, the frequency is estimated using equation (5).

$$E_{ij} = \frac{n_{i.} n_{.j}}{N} \quad (5)$$

The test statistic χ^2 for a two-way contingency table is as follows (Washington et al. 2003):

$$\chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \quad (6)$$

where the differences between observed (O_{ij})and expected (E_{ij})frequencies are summed over all rows and columns (r and c, respectively).

The test statistic shown in equation (2) is approximately χ^2 distributed with degrees of freedom, $df = (r-1)(c-1)$.

4.3 Estimation Results

Table 4.2 presents the chi-squared test estimation results for the differences in potential conspicuity-related factors (light conditions, time of day, helmet use, and area/location) between single-and two-vehicle crashes. Table 4.3 presents the results for the differences in potential conspicuity-related factors by light conditions. The major findings are summarized below. Details of the calculations are presented in Appendix A.

Table 4.2. Contingency table between potential conspicuity-related factors and two categories of crashes (single-vehicle and two-vehicle crashes)

Test #	Factor	Single-vehicle crashes No. (%)	Two-vehicle crashes No. (%)	Estimated chi-squared value	Standard chi-squared value at alpha=0.05
1	Daylight	2201 (62.1%)	2611 (79.6%)	251.1	3.8
	Dark	1345 (37.9%)	670 (20.4%)		
2	Morning peak hour (7 a.m.-9 a.m.)	155 (10.9%)	213 (11.7%)	0.7	4.6
	Lunch time (11 a.m.-1 p.m.)	461 (32.4%)	592 (32.6%)		
	Evening peak hour (4 p.m.-6 p.m.)	807 (56.7%)	1010 (55.6%)		
3	Rider with helmet	846 (28.1%)	598 (23.6%)	14.0	3.8
	Rider without helmet	2167 (71.9%)	1931 (76.4%)		
4	Rural	1960 (55.0%)	558 (17.2%)	1041.8	3.8
	Urban	1604 (45.0%)	2688 (82.2%)		

Table 4.3. Contingency table between potential conspicuity-related factors and light conditions

Test #	Factor	Daylight No. (%)	Dark No. (%)	Estimated chi-squared value	Standard chi-squared value at alpha=0.05
1	*Single-vehicle crashes*				
	Rider without helmet	1255 (67.5%)	892 (79.1%)	47.3	3.8
	Rider with helmet	605 (32.5%)	235 (20.9%)		
2	*Two-vehicle crashes*				
	Rider without helmet	1531 (75.4%)	395 (80.4%)	5.6	3.8
	Rider with helmet	500 (24.6%)	96 (19.6%)		
3	*Two-vehicle crashes*				
	Rural	480 (82.5%)	102 (17.5%)	3.81	3.8
	Urban	2101 (79.5%)	563 (20.5%)		
4	*Two-vehicle crashes*				
	Rear-end	645 (78.5%)	177 (21.5%)	6.8	7.8
	Angle, oncoming left turn	493 (76.1%)	155 (23.9%)		
	Broadside	777 (82.4%)	166 (17.6%)		
	Sideswipe, same direction	316 (82.7%)	66 (17.3%)		
5	*Rear-end crash*				
	Motorcycle hit non-motorcycle vehicle	343 (80.7%)	82 (19.3%)	4.1	3.8
	Non-motorcycle vehicle hit motorcycle	211 (74.3%)	73 (25.7%)		
6	*Angle crash*				
	Motorcycle going straight, and non-motorcycle vehicle turned left	431 (75.5%)	140 (24.5%)	0.94	3.8
	Other situation	62 (76.1%)	15 (23.9%)		

4.3.1 Conspicuity-related factors

Motorcycle riders were involved in a significantly higher number of two-vehicle crashes (79.6%) than single-vehicle crashes (62.1%) in daylight ($\chi^2 = 251.1, df = 1, p < 0.05$). The estimated difference is 17.5%.This could suggest a conspicuity problem associated with motorcycles during daytime. However, turning to the time of day, the percentage of single-vehicle and two-vehicle crashes involving a motorcycle did not vary significantly across morning, lunch, and evening peak hours ($\chi^2 = 0.7, df = 2, p > 0.05$).

Helmet use was another potential conspicuity-related factor. Riders involved in two-vehicle crashes had a slightly lower helmet-use rate (23.6%) than riders involved in single-vehicle crashes (28.1%) ($\chi^2 = 14.0, df = 1, p < 0.05$). The difference is 4.5%.

As shown in Table 4.3 (Tests 1 and 2), differences in helmet use under light and dark conditions for single-vehicle and two-vehicle crashes were examined. Higher helmet use was found during daytime than under dark conditions for both categories of crashes ($\chi^2_{single-vehicle\ crash} = 43.7, df = 1, p < 0.05$, $\chi^2_{two-vehicle\ crash} = 5.6, df = 1, p < 0.05$.), but the difference in helmet-use rates in single-vehicle crashes is 11.7%, while the corresponding difference for two-vehicle crashes is 5.1%. Additional information on helmet color would provide better insights as to whether the statistically-significant, lower helmet-use rate in two-vehicle crashes (compared to single-vehicle crashes) suggests lower motorcycle conspicuity, as well. If this hypothesis holds, the motorcycle-conspicuity problem seems to be more severe under dark conditions than in daylight.

The test results for the relationship between crash type and light conditions in two-vehicle crashes are also shown in Table 4.3 (Tests 4 to 6). The crash types that were considered included those that were frequent in more than 10% of two-vehicle crashes, such as “rear-end,” “angle, oncoming left turn,” “broadside,” and “sideswipe, same direction.” Overall, the distribution of crashes in light and dark conditions did not vary significantly for different types of two-vehicle crashes ($\chi^2 = 6.8\ df = 3, p > 0.05$)

Also of interest was an examination of the specific crash type, where it is possible to impute fault to either the motorcycle or the non-motorcycle vehicle involved in the crash. For example, in “rear-end” crashes (when a vehicle was struck from behind by another vehicle), 60.0% of the crashes occurred when the motorcycle hit the rear part of the non-motorcycle vehicle (assuming motorcycle’s fault), and in 40% of the crashes, the non-motorcycle vehicle was at-fault. However, when comparing the “at-fault” percentage under light and dark conditions, a higher percentage of rear-end crashes were the non-motorcycle vehicle’s fault (25.7%) than the fault of motorcycles (19.3%) during dark conditions ($\chi^2 = 4.1\ df = 1, p < 0.05$). This suggests the need to increase driver awareness of motorcycles under dark conditions.

Lastly, the authors examined the hypothesis, adopted in previous work, that a conspicuity problem is associated with motorcycles as non-motorcycle vehicles in the traffic stream making a left turn are unable to recognize riders in daylight in comparison to non-motorcycle vehicles (Williams and Hoffmann 1979; Olson et al. 1979). However, the authors found the distribution of crashes where a vehicle was turning left and a motorcycle was going straight, when compared to other situations that led to angle crash, did not vary significantly by light conditions. As such, this analysis did not provide evidence to support the hypothesis of poor motorcycle conspicuity in daylight that has been adopted in previous work.

4.3.2 "Dangerous" sites

Table 4.2 (Test 4) shows the differences in proportions of single- and two-vehicle crashes by area/location. A significantly higher proportion of two-vehicle versus single-vehicle crashes occurred on urban roads, when compared to rural roads ($\chi^2 = 1041.8\ df = 1, p < 0.05$, the difference is 37.2%). Differences in the proportion of two-vehicle crashes under daylight and dark conditions by area/location were also examined, as shown in Table 4.3 (Test 3). This analysis showed that similar proportions of daylight two-vehicle crashes occurred on urban and rural roads ($\chi^2 = 3.81\ df = 1, p = 0.05$). A similar test was also conducted to examine the differences in proportions of single- and two-vehicle crashes by intersection and non-intersection. It was found that a higher proportion of two-vehicle crashes than single-vehicle crashes occurred at intersections, rather than non-intersections ($\chi^2 = 819.2\ df = 1, p < 0.05$, the difference is 34%), while a similar proportion of daylight two-vehicle crashes occurred at intersections and non-intersections (Test 4 in Table 4.3, $\chi^2 = 3.60\ df = 1, p > 0.05$). This suggests that low motorcycle conspicuity during daylight might not be the reason for the higher proportion of two-vehicle crashes on urban roads or at intersections. Nevertheless, increasing driver awareness of motorcycles in urban areas and at intersections, specifically, is recommended.

5. SUMMARY, LIMITATIONS, AND RECOMMENDATIONS

5.1 Summary

This research revisited the motorcycle-conspicuity problem by analysis of Iowa helmet-use survey data and motorcycle crash data.

Motorcycle helmet-use survey data were collected from three roadside observational surveys on randomly-selected roadway sites during riding season (May to September) in three regions in Iowa: Southeast region in 2006, Southwest region in 2008, and Northeast region in 2009. Observers noted the motorcycle helmet use by riders and passengers between the hours of 7 a.m. and 6 p.m. In summary, higher helmet-use rates were observed for both riders and passengers from year 2006 to 2009. However, different regions were surveyed, so the trend could be misleading. Lower helmet-use rates were observed on interstates, primary roads, and secondary roads, compared to city and urban roads, while almost half of the motorcyclists observed during the morning peak hours wore helmets.

Motorcycle crash data were obtained from the Iowa DOT for the eight-year period from 2001 to 2008. The data included information on reportable crashes on Iowa's public roadways that involved at least one vehicle that was identified as a motorcycle. These attributes were included: year, month, day and time of crash; location of crash; road surface and environmental conditions; crash type, crash severity, major cause of the crash, events contributing to the crash, and number of vehicles involved; and other information about the motorcycle rider and the driver of the non-motorcycle vehicle involved in the crash. However, potential conspicuity-related factors, such as rider clothing, color of motorcycle, helmet color, and motorcycle type, could not be collected from the crash database. The crashes occurring within one mile of the corporate city limits were defined as urban, while the crashes occurring outside the city boundaries were defined as rural.

A total of 7,328 motorcycle crashes were reported during the eight-year analysis period (2001–2008). In 2008, 1,061 motorcycle crashes were reported in Iowa, compared to 762 crashes that were reported in 2001, representing a 39% increase. Note that from 2001 to 2008, motorcycle registrations increased from 120,961 to 162,662 (34.5%). Half of the total number of crashes that were reported during the eight-year period were single-vehicle crashes (one motorcycle was involved), while 45% (3,316 crashes) were two-vehicle crashes (one motorcycle collided with a non-motorcycle vehicle), and the remaining 5% involved three or more vehicles. Since single- and two-vehicle motorcycle crashes represented 95% of the crashes, the analysis focused on these two categories of crashes.

Overall, single-vehicle crashes resulted in a more severe injury outcome than two-vehicle crashes. 60% of the fatal single-vehicle crashes and 50% of the two-vehicle crashes occurred on high-speed roads (55 mph or higher speed limit). As expected, the majority of crashes involving motorcycles occurred between May and September, with a higher number occurring in June and July. Turning to the distribution of crashes by day of week, crashes involving motorcycles were more likely to occur on a weekend, which suggests more recreational trips than work trips by motorcycles. However, a high number of single-vehicle crashes occurred on Mondays.

The temporal distribution of crashes during a day shows an increasing trend of single-vehicle crashes from 8 a.m. to 7 p.m., with a decreasing trend thereafter, and an increasing trend of two-vehicle crashes from 5 a.m. to 4 p.m., with a decreasing trend thereafter. More than two-thirds of the single- and two-vehicle motorcycle crashes that were reported occurred under clear weather (as clear conditions encourage motorcycle riding), and one-quarter occurred under cloudy or partly-cloudy conditions. 70% of the crashes occurred in daylight, while one-fifth of the crashes occurred under dark conditions. These findings are likely attributed to the higher exposure of motorcycles in daylight, compared to nighttime, and, thereby, the greater associated probability of being involved in a crash during the day.

Most two-vehicle crashes occurred on urban roads (83%), while the distribution of single-vehicle crashes on urban and rural roads was 45% and 55%, respectively. More than half of the two-vehicle crashes occurred at an intersection (of which 67% occurred at a four-way intersection and 20% at a T-intersection), while 76% of the single-vehicle crashes occurred at a non-intersection.

The main driver-contributing factor of a single-vehicle crash was “lost control” for both non-intersection and intersection crashes. 44% of the non-intersection single-vehicle crashes occurred on roads with a 55 mph speed limit, while 31% occurred on lower-speed roads (25-35 mph).

Turning to the two-vehicle crashes, the non-motorcycle vehicle driver was reported as the major contributing factor in the majority of non-intersection and intersection crashes. “Failing to yield right of way when making left turn” is the most common driver-contributing factor by non-motorcycle vehicles for both intersection and non-intersection crashes. “Failing to yield right of way from stop sign” and “failing to yield right of way from driveway” were the other two primary driver-contributing factors by non-motorcycle vehicles for intersection and non-intersection crashes, respectively. The three primary rider-contributing factors in two-vehicle crashes were “lost control” (same as in single-vehicle crashes), “following too close,” and “exceeded authorized speed.” The majority of two-vehicle crashes occurred on roads with low speed limits (25- 35 mph).

When the major contributing factor by the motorcycle rider involved in a two-vehicle crash was “no improper action,” the analysis assumed that the non-motorcycle vehicle driver was “at-fault.” Likewise, if the major contributing factor by the non-motorcycle vehicle involved in a two-vehicle crash was “no improper action,” the analysis assumed that the motorcycle was “at-fault.” Note that the crash report does not explicitly convey which driver was “at-fault.” Nonetheless, in more than half (56%) of two-vehicle crashes, the driver of the non-motorcycle vehicle was imputed “at-fault,” while in a quarter of two-vehicle crashes, motorcycle riders were imputed “at-fault.” The results are consistent with previous work stating that in multi-vehicle crashes, motorcyclists are more likely to be victims than “at-fault” (Haque et al. 2009).

Turning to the vehicle actions that led to a crash, one-quarter of crashes involved a motorcycle and a non-motorcycle vehicle moving straight, while one-third of crashes involved one vehicle turning left and the other going straight. The analysis of crashes where one vehicle was turning left and the other was going straight showed that in 91.4% of the cases, the motorcycle was going straight and the non-motorcycle vehicle was turning left—a finding consistent with previous work (Olson 1989). In addition, one-quarter of two-vehicle crashes were rear-end crashes. 60% of these involved a motorcycle hitting the rear part of the non-motorcycle vehicle, while in 40% of the crashes, the motorcycle was rear-ended.

The age distributions of motorcycle riders who were involved in single-and two-vehicle motorcycle crashes were fairly similar. Moreover, half of the single-and two-vehicle crashes involved motorcycle drivers either between 21 and 30 years old or between 41 and 50 years old. The distribution of crashes by the age of the non-motorcycle vehicle driver showed that a high percentage of older drivers (over 60), followed by younger drivers (under 30) were involved in a crash with the motorcycle.

Helmet-use rates of motorcycle riders involved in crashes during the analysis period were fairly low, as Iowa doesn't have a mandatory helmet law. More specifically, helmet-use rates for riders involved in single-vehicle crashes (27%, on average) were slightly higher than those for riders involved in two-vehicle crashes (23%, on average). Interestingly, helmet use in motorcycle crashes that occurred on rural roads was 33%, while the corresponding rate on urban roads was lower (22%); the distribution was similar in single- and two-vehicle crashes.

*Statistical methods***,** contingency tables and chi-squared test statistics were used to examine motorcycle-conspicuity factors that could potentially relate to a collision between a motorcycle and another vehicle. Conspicuity-related factors that were examined included: light conditions, time of day, helmet use, crash type (for two-vehicle crashes), and motorcycle rider actions (for two-vehicle crashes).

The analysis found that a higher proportion of two-vehicle crashes versus single-vehicle crashes occurred in daylight, rather than in dark conditions, which can be taken as evidence of low motorcycle conspicuity in daylight. However, the daylight and dark distributions of potential conspicuity-related factors in two-vehicle crashes do not necessarily support this hypothesis. For example, daylight helmet use was higher than helmet use during dark conditions. In addition, a higher percentage of rear-end crashes appeared to be caused by non-motorcycle vehicle drivers than motorcycle riders during dark conditions, rather than in daylight. Further, the distribution of crashes where a vehicle was turning left and a motorcycle was going straight, when compared to other situations that led to an angle crash, did not vary significantly by light conditions.

5.2 Limitations and Recommendations

The study found some limitations to examining motorcycle conspicuity by analysis of crash data. More specifically, potential conspicuity-related factors, such as rider clothing, color of motorcycle, helmet color, and motorcycle type, could not be collected from the crash database.

In addition, the speed information pertained to the speed limits on the roads where the collisions occurred and is likely to be imprecise, as a surrogate of the motorcycle and the non-motorcycle vehicle actual speeds. Obtaining speed information would be useful in understanding the dynamics of the motorcycle-vehicle interaction. For example, previous work stated that a motorcyclist's speed is significantly higher when compared to other vehicle speeds in motorcycle-related crashes in urban areas (Brenac et al. 2006). This could be a reason for the high number of two-vehicle crashes in urban areas in our sample, rather than low motorcycle conspicuity. Poor speed-spacing judgment could also be a contributing factor to two-vehicle motorcycle crashes.

Finally, accurate information on motorcycle-miles-traveled that would be essential in a comparison of exposure during day and night is missing, or, when available, it is of poor quality (also, indicated by Bigham et al. 2009).

If crash data collection cannot be expanded to include information on these potential conspicuity-related factors, naturalistic driving studies could provide a promising avenue for such information to be collected in future research on motorcycle conspicuity.

Recommendations related to improving motorcycle conspicuity and driver awareness in Iowa, and conspicuity-related campaigns and interventions, are summarized below.

Iowa is one of the 39 states that include conspicuity in its motorcycle manual, listing eight important ways to increase conspicuity: clothing, headlight, signals, brake lights, mirrors, head checks, horns, and riding at night. The Iowa DOT could also consider specifying the color of the helmet in the manual, such as yellow or lime yellow, since the bright color of the helmet can improve motorcycle conspicuity. Moreover, the manual could emphasize the reflectivity of the frontal area of the motorcycle/rider, and the brightness contrast between the motorcyclist and their surroundings, which have been shown to be more significant factors to enhancing motorcycle conspicuity than bright clothing and headlight use alone. Finally, the Iowa DOT could consider improving motorcycle training and education to enhance rider skills.

Safety campaigns are also considered an effective way to improve safety on the roadways. In view of the analysis results, the following important key findings are important considerations in implementing motorcycle conspicuity-related campaigns:

- A higher number of motorcycle crashes occur in June and July, on weekends, and between 5 a.m. and 4 p.m.
- 83% of two-vehicle crashes occur on urban roads and more than half of two-vehicle crashes occur at intersections.
- The major driver-contributing factors to two-vehicle crashes are as follows:
    - *Non-motorcycle vehicle drivers*
        - Intersection crashes: “Failed to yield right of way when making left turn” and “failed to yield right of way from stop sign ”
        - Non-intersection crashes: “Failed to yield right of way when making left turn ” and “failed to yield right of way from driveway”
    - *Motorcycle riders* “lost control,” “followed too close,” and “exceeded authorized speed limits”

- The driver groups most involved in two-vehicle crashes are either younger (under 30) or older (over 60). Awareness programs targeted specifically to younger and older drivers should be considered. Motorcycle training programs targeted specifically to riders between 21 and 30 years old and between 41 and 50 years old are also desirable.
- Helmet-use rates in both single- and two-vehicle crashes are very low on urban roads (22%). Since helmet use could improve motorcycle conspicuity, safety campaigns could encourage drivers to wear helmets, especially when traveling in high motorcycle crash locations.

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APPENDIX A. CONTINGENCY TABLES

Table A.1. Contingency calculation table for Table 4.2

	Single-vehicle crashes	Two-vehicle crashes	Row total
Daylight (observed)	2201	2611	4812
Expected	2499.39	2312.61	
Observed- Expected	-298.39	298.39	
(Observed- Expected)^2	89038.03	89038.03	
(Observed- Expected)^2/Expected	35.62	38.50	
Dark (observed)	1345	670	2015
Expected	1046.61	968.39	
Observed- Expected	298.39	-298.39	
(Observed- Expected)^2	89038.03	89038.03	
(Observed- Expected)^2/Expected	85.07	91.94	
Column total	3546	3281	6827
Chi-squared value	**251.14**		

	Single-vehicle crashes	Two-vehicle crashes	Row total
Morning peak hour(observed) 7 a.m. – 9 a.m.	155	213	368
Expected	161.72	206.28	
Observed- Expected	-6.72	6.72	
(Observed- Expected)^2	45.22	45.22	
(Observed- Expected)^2/Expected	0.28	0.22	
Lunch Time (observed) 11 a.m.-1 p.m.	461	592	1053
Expected	462.76	590.24	
Observed- Expected	-1.76	1.76	
(Observed- Expected)^2	3.10	3.10	
(Observed- Expected)^2/Expected	0.01	0.01	
Evening peak hour (observed) 4 p.m. – 6 p.m.	807	1010	1817
Expected	798.51	1018.49	
Observed- Expected	8.49	-8.49	
(Observed- Expected)^2	72.00	72.00	
(Observed- Expected)^2/Expected	0.09	0.07	
Column total	1423	1815	3238
Chi-squared value	**0.67**		

	Single-vehicle crashes	**Two-vehicle crashes**	**Row total**
Rider without helmet (observed)	2167	1931	4098
Expected	2227.95	1870.05	
Observed- Expected	-60.95	60.95	
(Observed- Expected)^2	3714.35	3714.35	
(Observed- Expected)^2/Expected	1.67	1.99	
Rider with helmet (observed)	846	598	1444
Expected	785.05	658.95	
Observed- Expected	60.95	-60.95	
(Observed- Expected)^2	3714.35	3714.35	
(Observed- Expected)^2/Expected	4.73	5.64	
Column total	3013	2529	5542
Chi-squared value	**14.02**		

	Single-vehicle crashes	**Two-vehicle crashes**	**Row total**
Rural (observed)	1960	558	2518
Expected	1317.79	1200.21	
Observed- Expected	642.21	-642.21	
(Observed- Expected)^2	412433.29	412433.29	
(Observed- Expected)^2/Expected	312.97	343.63	
Urban (observed)	1604	2688	4292
Expected	2246.21	2045.79	
Observed- Expected	-642.21	642.21	
(Observed- Expected)^2	412433.29	412433.29	
(Observed- Expected)^2/Expected	183.61	201.60	
Column total	3564	3246	6810
Chi-squared value	**1041.82**		

Table A.2. Contingency calculation table for Table 4.3

Single-vehicle crashes	**Daylight**	**Dark**	**Row total**
Rider without helmet (observed)	1255	892	2147
Expected	1336.93	810.07	
Observed- Expected	-81.93	81.93	
(Observed- Expected)^2	6713.08	6713.08	
(Observed- Expected)^2/Expected	5.02	8.29	
Rider with helmet (observed)	605	235	840
Expected	523.07	316.93	
Observed- Expected	81.93	-81.93	
(Observed- Expected)^2	6713.08	6713.08	
(Observed- Expected)^2/Expected	12.83	21.18	
Column total	1860	1127	2987
Chi-squared value	**47.32**		

Two-vehicle crashes	**Daylight**	**Dark**	**Row total**
Rider without helmet (observed)	1531	395	1926
Expected	1551.03	374.97	
Observed- Expected	-20.03	20.03	
(Observed- Expected)^2	401.33	401.33	
(Observed- Expected)^2/Expected	0.26	1.07	
Rider with helmet (observed)	500	96	596
Expected	479.97	116.03	
Observed- Expected	20.03	-20.03	
(Observed- Expected)^2	401.33	401.33	
(Observed- Expected)^2/Expected	0.836169241	3.45877745	
Column total	2031	491	2522
Chi-squared value	**5.62**		

Two-vehicle crashes	Daylight	Dark	Row total
Rural (observed)	480	102	582
Expected	462.77	119.23	
Observed- Expected	17.23	-17.23	
(Observed- Expected)^2	296.97	296.97	
(Observed- Expected)^2/Expected	0.64	2.49	
Urban (observed)	2101	563	2664
Expected	2118.23	545.77	
Observed- Expected	-17.23	17.23	
(Observed- Expected)^2	296.97	296.97	
(Observed- Expected)^2/Expected	0.14	0.54	
Column total	2581	665	3246
Chi-squared value	**3.82**		

Two-vehicle crashes	Daylight	Dark	Row total
Rear-end (observed)	645	177	822
Expected	656.13	165.87	
Observed- Expected	-11.13	11.13	
(Observed- Expected)^2	123.87	123.87	
(Observed- Expected)^2/Expected	0.19	0.75	
Angle, oncoming left turn (observed)	493	155	648
Expected	517.24	130.76	
Observed- Expected	-24.24	24.24	
(Observed- Expected)^2	587.62	587.62	
(Observed- Expected)^2/Expected	1.14	4.49	
Broadside (observed)	777	166	943
Expected	752.71	190.29	
Observed- Expected	24.29	-24.29	
(Observed- Expected)^2	589.86	589.86	
(Observed- Expected)^2/Expected	0.78	3.10	
Sideswipe, same direction (observed)	316	66	382
Expected	304.92	77.08	
Observed- Expected	11.08	-11.08	
(Observed- Expected)^2	122.84	122.84	
(Observed- Expected)^2/Expected	0.40	1.59	
Column total	2231	564	2795
Chi-squared value	**6.82**		

Rear-end crashes	Daylight	Dark	Row total
Motorcycle hit other vehicle (observed)	343	82	425
Expected	332.09	92.91	
Observed- Expected	10.91	-10.91	
(Observed- Expected)^2	119.08	119.08	
(Observed- Expected)^2/Expected	0.36	1.28	
Other vehicle hit motorcycle (observed)	211	73	284
Expected	221.91	62.09	
Observed- Expected	-10.91	10.91	
(Observed- Expected)^2	119.08	119.08	
(Observed- Expected)^2/Expected	0.54	1.92	
Column total	554	155	709
Chi-squared value	**4.09**		

Angle crashes	Daylight	Dark	Row total
Motorcycle straight, and other vehicle turn left (observed)	431	140	571
Expected	434.42	136.58	
Observed- Expected	-3.42	3.42	
(Observed- Expected)^2	11.68	11.68	
(Observed- Expected)^2/Expected	0.03	0.09	
Other situation (observed)	62	15	77
Expected	58.58	18.42	
Observed- Expected	3.42	-3.42	
(Observed- Expected)^2	11.68	11.68	
(Observed- Expected)^2/Expected	0.20	0.63	
Column total	493	155	648
Chi-squared value	**0.95**		