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MEDIAN CROSSOVER CRASHES IN THE VICINITY OF INTERCHANGES ON UTAH INTERSTATES

by

Katherine E. Winters

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

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BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

Katherine E. Winters

This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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Date	Mitsuru Saito
Date	Travis M. Gerber

BRIGHAM YOUNG UNIVERSITY

As chair of the candidate’s graduate committee, I have read the thesis of Katherine E. Winters in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

MEDIAN CROSSOVER CRASHES IN THE VICINITY OF INTERCHANGES ON UTAH INTERSTATES

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Master of Science

While not accounting for a significant proportion of overall crashes, median crossover crashes in the state of Utah do account for a significant proportion of interstate fatalities. Due to the seriousness of median crossover crashes in the state of Utah, the need exists to evaluate the impact of median crossover crashes in the state, to identify locations where median crossover crashes may be occurring at particularly high rates, and to identify methods to help mitigate these crashes. Previous research has noted that median crossover crash rates appear to increase in the vicinity of interchanges. The purpose of this research, therefore, is to develop a strategy to mitigate median crossover crashes statewide and determine the role that the interchanges play in contributing to median crossover crashes.

Fourteen years of crash data spanning the years 1992 through 2005 on Interstates 15, 70, 80, 84, and 215 were used to determine overall characteristics of median crossover crashes in Utah and determine the relationship between median crossover crashes and other types of crashes. Using a chi-square goodness of fit test, the distributions of median crossover crashes and all types of interstate crashes in the vicinity of interchanges were compared. Three-year median crossover crash rates spanning the years 2003 through 2005 for rural and urban areas were then used to identify which sections of Utah interstates are most prone to median crossover crashes. Finally, recommendations were made concerning appropriate median barrier installation for the 37 critical sections as identified by the three-year analysis.

ACKNOWLEDGMENTS

The author would like to acknowledge the extensive contributions of Dr. Grant Schultz to the research presented herein. Scott Jones, UDOT Crash Studies Engineer, has been very helpful in assisting with data acquisition and interpretation. Additional thanks goes to Dr. Mitsuru Saito and Dr. Travis Gerber who, as members of the advisory committee, offered constructive input to the project.

The author would also like to thank her husband, Kevin Winters, for all his patience and support through this process.

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1 INTRODUCTION

A median crossover crash is defined as a crash that occurs when a vehicle departs its travel lane to the left, crosses over the median, and collides with a vehicle traveling the opposite direction (Davis 2008, Donnell et al. 2002, Miaou et al. 2005, Nystrom 1997). Because of the high relative speeds involved, median crossover crashes tend to be far more severe than other types of crashes (Noyce 2006). The purpose of this thesis is to present the results of research conducted to assess median crossover crashes in the vicinity of interchanges on Utah interstates. To understand the background of median crossover crashes in the state of Utah and to identify the purpose and outline of this thesis, this chapter is divided into four sections including a problem statement section, a background section, an objectives section, and a thesis organization section.

1.1 Problem Statement

Based on crash data from 1992 through 2005 on Utah interstates, an average of seven median crossover crashes on Utah interstates each year were fatal, out of an average total of 86 fatal crashes (8.2 percent). In contrast, median crossover crashes only accounted for an average of 48 crashes each year out of an average of 7,600 total crashes (0.63 percent). While median crossover crash rates in the vicinity of interchanges have not been the primary focus of previous research, some studies have suggested that median crossover crash rates may increase around highway interchanges (Bane 2008, Donnell et al. 2002). Because of the high rate of severity of median crossover crashes, this research seeks to determine if median crossover crash rates do, in fact, differ at freeway interchanges, what the zone of influence of the interchange is, how the crash rates might be decreased by appropriate installation of median barriers, and which locations along Utah interstates are most in need of median barrier installation.

1.2 Background

For this introduction, background information will first be presented on median crossover crashes, followed by background information on median barrier treatments. The final section will focus on a brief background of interchange safety.

1.2.1 Median Crossover Crashes

As mentioned previously, median crossover crashes tend to be far more severe than other types of highway crashes. Studies in Pennsylvania and North Carolina similarly found that median crossover crashes represented a seemingly insignificant proportion of all crashes but a very significant proportion of fatal crashes (Donnell et al. 2002, Lynch 1998). The high severity of median crossover crashes has been reported to be attributable to the high relative speeds of the vehicles at the time of collision. The predominant cause of median crossover crashes has not been agreed upon, but a variety of contributing factors have been proposed, such as weather, driver error, and driver avoidance of other incidents to name a few (Miaou et al. 2005).

Prior research has shown that overall crash rates on interstates are likely to increase near interchanges, primarily because of the conflicts that occur between entering and exiting traffic and driver error as the driver attempts to navigate the interchange (Lunenfeld 1993). However, the functional area of the interstate impacted by an interchange has been defined differently by each study. The area has been defined as narrowly as 100 to 800 feet downstream of a ramp terminus, or as widely as 1.0 mile from ramp termini for a total of 1.5 miles from the center of the interchange in each direction, and this area has generally been based upon observation (Bane 2008, Donnell et al. 2002). Little has been published regarding the change in overall crash rates in the vicinity of interchanges, and only Donnell et al. have addressed median crossover crashes near interchanges. In that study, only 20 crashes were studied, and therefore the statistical significance of the findings is questionable (Donnell et al. 2002).

1.2.2 Median Barrier Treatments

The American Association of State Highway Transportation Officials (AASHTO) has published guidelines that most states follow to determine where the placement of median barriers would be appropriate, based on the median width and volume of traffic on the roadway (AASHTO 2002). Further research has suggested that this guideline is insufficient, and some states have moved to install barriers in wider medians and lower traffic areas (Lynch 1998, Nystrom 1997).

Three major types of barriers are currently in service to prevent vehicles from crossing the median: concrete barrier, W-beam barrier, and three-strand cable barrier. Median barriers have been shown to decrease the occurrence of severe injury and fatal median crossover crashes, but the rate of less severe crashes often increases as more vehicles collide with the barrier (AASHTO 2002).

1.2.3 Interchange Safety

Because of the conflicts between through traffic and drivers that merging or exiting the roadway, crash rates on interstates tend to increase sharply near interchanges (Lunenfeld 1993). The tighter spacings of urban areas accentuate the conflicts, and result in much higher crash rates at urban interchanges than at rural interchanges (Twomey et al. 1993). Most of the studies conducted on interchange spacing thus far have focused on operational issues, and most studies on interchange safety have focused solely on safety issues on ramps and cross streets.

1.3 Objectives

Due to the seriousness of median crossover crashes in the state of Utah, the need exists to evaluate the impact of median crossover crashes in the state, to identify locations where median crossover crashes may be occurring at particularly high rates, and to identify methods to help mitigate these crashes. The purpose of this research, therefore, is to develop a strategy to mitigate median crossover crashes statewide and determine the role that the interchanges play in contributing to median crossover crashes. The first step in this process is to identify locations with high crash rates where the presence of an interchange may be a significant contributing factor. The next step is to propose and evaluate possible engineering solutions to mitigate the concerns at the identified locations. Recommendations will then be provided for mitigation measures at the identified locations.

The results of this research will provide direction and guidance to the Utah Department of Transportation (UDOT) on the identification and prioritization of corridors in which median crossover crashes are more likely to occur. UDOT will benefit from this research by implementing engineering mitigation measures at high crash locations identified to reduce median crossover crashes. The documented results will also aid UDOT in understanding how to best understand the effects of interchanges on urban and rural median crossover crash rates.

1.4 Thesis Organization

This thesis is organized into the following five chapters: 1) Introduction; 2) Literature Review; 3) Analysis Procedure; 4) Results; 5) Conclusions. A References section and an Appendix follow the indicated chapters.

Chapter 2 is a literature review that defines median crossover crashes, their contributing factors, rates of occurrence and severity. Past studies about median crossover crashes and state and national guidelines for median barriers are discussed, as are barrier types and studies on interchange safety. The background of the UDOT crash database is also given.

Chapter 3 documents the steps followed during the analysis using the UDOT crash database. The data collection, reduction, and analysis procedures followed in using the crash database are presented in detail so that the procedures may be replicated for similar future analyses. The statistical analysis procedures for determining the effect of interchanges on median crossover crashes and determining critical crash rates are also explained.

Chapter 4 presents the results of the analyses including tables and figures to aid in the presentation of the results. The chapter contains crash data for the highway corridors prone to have median crossover crashes based upon corridors found to have crash rates in excess of a critical crash rate. The results are divided into urban and rural sections, and the impact of interchanges on median crossover crash rates is given for both. Median crossover crash statistics pertinent to each highway are identified. Examples of these statistics include the time of day, day of the week, weather and roadway conditions, and severity of median crossover crashes. Median crossover countermeasures are recommended for the critical interstate sections identified. Appropriate barrier types are identified for each critical section.

Chapter 5 provides conclusions of the research. The chapter also recommends future research possibilities related to the effectiveness of yet to be installed countermeasures.

Appendix A contains tables detailing the results of the chi-square analysis of crash distributions.

2 LITERATURE REVIEW

This literature review will introduce median crossover crashes, with the major contributing factors, common rates, and levels of severity. Previous studies concerning median crossover crashes and recommended median barrier warrants will be summarized, followed by a discussion of the three most common median barrier types: concrete barriers, W-beam barriers, and three-strand cable barrier systems. Interchange safety issues will also be presented, followed by a brief introduction to the UDOT crash database tool.

2.1 Median Crossover Crashes

Median crossover crashes have been defined as crashes that occur when the driver departed its traveled way to the left, traversed the entire median, entered oncoming traffic, and collided with an oncoming vehicle (Davis 2008, Donnell et al. 2002, Miaou et al. 2005, Nystrom 1997). Some studies have removed the requirement that a vehicle collided with another vehicle in the opposing lanes from the definition of median crossover crashes (Lynch 1998, Noyce 2006). Another study simply evaluated whether or not crashes involved vehicles traveling in opposing directions in order to determine the need for and benefit of median barriers (Tarko et al. 2008).

In this section, various proposed contributing factors to median crossover crashes will be presented, followed by a discussion on the observed rates of occurrence and severities of median crossover crashes.

2.1.1 Contributing Factors

Although the predominant cause of median crossover crashes has not been agreed upon, a variety of contributing factors have been proposed, such as driver error, reckless driving, inclement weather, and driver avoidance maneuvers (Miaou et al. 2005). Research shows that the majority of drivers involved in median crossover crashes were intending to travel straight ahead at the time of the crash, but lost control of the vehicle. In a Wisconsin study, the percentage of drivers that lost control on dry pavement was comparable to the percentage that lost control due to weather (Noyce 2006). In contrast, a Florida study found that only 25 percent of crashes occurred in adverse weather (Bane 2008). Donnell et al. found that 71 percent of median crossover crashes in Pennsylvania began with a driver losing control in his own lane and crossing the median, 20 percent began with a collision between two or more vehicles in the same direction of travel, and 8 percent resulted from a driver attempting to avoid a vehicle in the same direction of travel (Donnell et al. 2002). Similarly, about 78 percent of Florida crashes were attributable to driver error or avoidance maneuvers, while many North Carolina crashes also began with a driver avoiding an incident in the driver’s own direction of travel (Bane 2008, Lynch 1998). Nineteen percent of median crossover crashes in a Florida study were attributed to alcohol, while speed did not appear to be a major factor, since in 78 percent of crashes the crossing vehicle’s speed was estimated to be within 5.0 miles per hour (mph) of the posted speed limit (Bane 2008). Other studies have identified driver inattention, fatigue, improper lane changes, medical emergencies, and equipment failure as possible contributors to median crossover crashes (Strasburg and Crawley 2005, Zeitz 2003).

2.1.2 Rates of Occurrence

In a study of median crossover crashes over three years in Wisconsin, Noyce found that 4.2 percent of all crashes on Wisconsin interstates and expressways were median crossover crashes, with an average rate of 0.142 crashes per mile per year (Noyce 2006). However, the definition of median crossover crashes in the Wisconsin study included crossovers by vehicles that did not strike opposing vehicles, so the occurrence of median crossover crashes corresponding to the standard definition would be less frequent (Noyce 2006). Of 6,000 crashes reviewed in Florida, 134, or 2.2 percent, were found to be median crossover crashes (Bane 2008). From 1994 through 1998, 276 of the 44,113 crashes, or 0.69 percent, occurring on Pennsylvania interstates and expressways were median crossover crashes (Donnell et al. 2002). Because of these low rates of occurrence, statistical predictions of median crossover crashes are difficult, and simulation packages openly state that they cannot simulate median crossover crashes (Davis 2008).

2.1.3 Severity

Despite their low frequency, median crossover crashes tend to be much more severe than other collisions, sometimes up to three times as severe (Strasburg and Crawley 2005). During a three-year period in Wisconsin, 53.2 percent of median crossover crashes resulted in personal injury and 6.5 percent resulted in one or more fatality. As the number of vehicles involved in the crash increased, the percentages of fatal crashes increased dramatically, from 3.0 percent of single vehicle crashes to 23 percent of crashes involving three or more vehicles (Noyce 2006). Similarly, Donnell et al. found the 15.0 percent of median crossover crashes in Pennsylvania involved a fatality, while an additional 71.9 percent of median crossover crashes resulted in injury. Median crossover crashes represented only 0.69 percent of crashes on Pennsylvania interstates and expressways over a five-year study period, but 7.3 percent of the fatalities (Donnell et al. 2002). Similarly, median crossover crashes in North Carolina were found to account for less than 5.0 percent of all freeway crashes, but over 20.0 percent of all fatalities (Lynch 1998). The high severity of median crossover crashes can be attributed to the high relative speed of the vehicles at the time of collision (Miaou et al. 2005). A summary of the rates of occurrence and severity of median crossover crashes for selected states are shown in Table 2-1.

Table 2-1. Comparison of Crash Frequency and Severities

State	Percent of All Highway Crashes	Percent of all Highway Fatalities	Fatal Percent of Median Crossover Crashes	Injury Percent of Median Crossover Crashes
Florida	2.2	--	--	--
North Carolina	Less than 5.0	Over 20.0	--	--
Pennsylvania	0.7	7.3	15.0	71.9
Wisconsin	4.2	--	6.5	53.2

2.2 Median Barrier Studies

In 2002, AASHTO published guidelines for median barrier installation that most states follow based on average daily traffic (ADT) and median width (AASHTO 2002). Recent studies, however, suggest that these guidelines are not sufficient (Noyce 2006, Strassburg and Crawley 2005). Two separate studies found that between 12 and 27 percent of all median crossover crashes occurred in locations where AASHTO recommended median barriers be considered, with the remaining crashes occurring in locations where barriers are “optional” or “not normally considered” (Donnel et al. 2002, Lynch 1998). Consequently, several states have begun studies to create better models of median crossover crash frequency and to develop their own median barrier guidelines (Davis 2008, Donnell et al. 2002, Miaou et al. 2005). This section will first present the AASHTO guidelines and then discuss research that has occurred at the state level for median barriers. Specific sates identified include California, Florida, Georgia, Minnesota, North Carolina, Pennsylvania, South Carolina, Texas, Washington, and Wisconsin.

2.2.1 AASHTO Guidelines

The 2002 AASHTO Roadside Design Guide provides suggested guidelines for the consideration of median barriers on high-speed, controlled-access roadways with relatively flat, traversable medians. Median barriers should only be installed when the expected consequence of striking a barrier is less severe than if the barrier had not existed. The AASHTO guidelines are “based on a limited analysis of median crossover crashes” (AASHTO 2002 p. 6-1), and are only suggested for use in the absence of current and/or site-specific data. The guidelines are based solely on ADT and median width, and are shown in Figure 2-1 (AASHTO 2002). At low ADTs, fewer vehicles will enter the median and the chance of an entering vehicle contacting an oncoming vehicle is low, so median barriers are only recommended for sites with a history of median crossover crashes when the ADT is less than 20,000 vehicles per day (vpd). Similarly, wide medians provide opportunity for a vehicle to safely come to a stop and therefore the probability of vehicle completely crossing the median is low (AASHTO 2002).

According to Donnell et al. (2002), nearly all states have adopted the AASHTO guidelines.

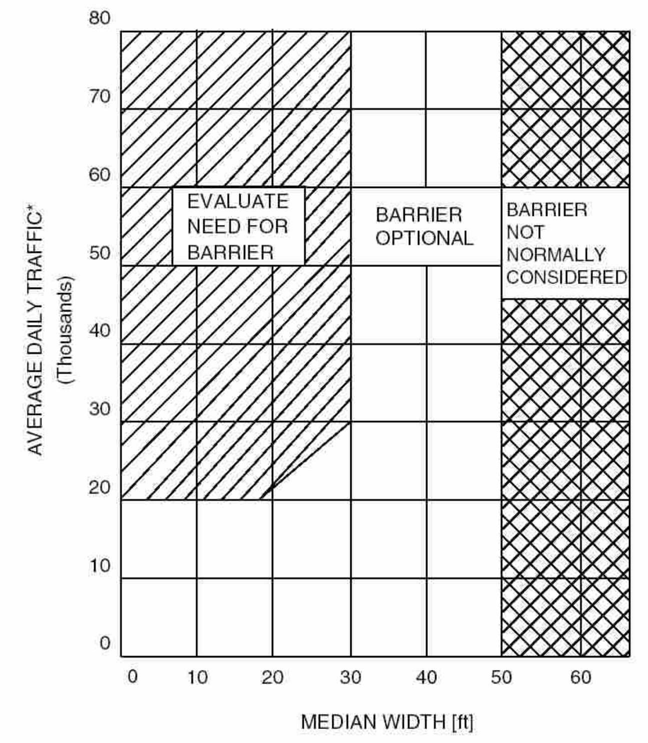


Figure 2-1. AASHTO median barrier guidelines (AASHTO 2002) (*Based on five-year projection).

2.2.2 California Study

Beginning in 1947, the California Department of Transportation (Caltrans) conducted a series of studies to determine the effects of median barriers and to develop guidelines for barrier installation (Nystrom 1997). After observing an increasing number of median crossover crashes occurring at locations with median widths greater than 45 feet, Caltrans made the decision to revise their median barrier warrant. Like the

AASHTO warrant, the current Caltrans warrant is based on combinations of traffic volume and median width, as illustrated in Figure 2-2. Unlike the AASHTO guidelines, the Caltrans warrant helps engineers identify where safety studies to judge the appropriateness of barriers may be warranted based on site characteristics. Caltrans also uses a crash study warrant of 0.50 median crossover crashes per mile per year of any severity, or 0.12 fatal median crossover crashes per mile per year, based on at least three crashes occurring within a five-year period. This combination of a volume/width warrant and a crash study warrant allows engineers to utilize greater judgment in selecting appropriate sites for barrier installation, based on more data than just traffic volume, width, and crash history.

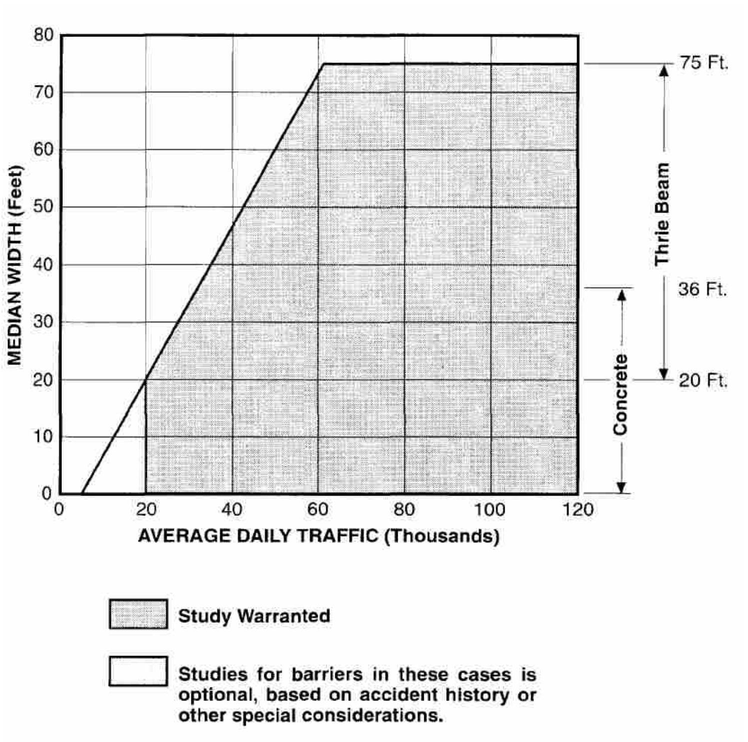


Figure 2-2. Caltrans freeway median barrier volume/width study warrant (Nystrom 1997).

2.2.3 Florida Study

The Florida Department of Transportation initiated a project to study median crossover crashes in an effort to determine what size barriers would be needed to adequately prevent crossover crashes (Bane 2008). The study found that, in 98 percent of the crashes, the crossing vehicle was a passenger car. Consequently, the review panel determined that test level three barriers would be sufficient. Details on the barrier ratings can be found in the literature and will not be summarized here (Ross et al. 1993).

In addition to results previously mentioned, the study also found that 62 percent of median crossover crashes occurred within 0.5 miles of a ramp terminus, and 82 percent occurred with 1.0 mile (Bane 2008). This led to a recommendation that median barriers be installed for 1.5 miles on either side of all highway interchanges. Interchanges with crash histories were prioritized first, and median barriers were constructed at all prioritized interchanges between 2004 and 2006.

2.2.4 Georgia

The Georgia Department of Transportation recommends positive barrier separation for all urban interstates, and 44-foot depressed medians for all arterial highways with speed limits greater than 55 mph or design speeds greater than 50 mph. If the depressed median is not feasible, a positive median barrier system must be installed. (Donnell et al. 2002).

2.2.5 Minnesota Study

Reviewing models produced by researchers for the Pennsylvania and Texas Departments of Transportation, researchers for the Minnesota Department of Transportation found that the results of the predictive crash models differed by up to a factor of two for similar conditions (Davis 2008). Researchers were unsure if the variation was due to differences in crash patterns in the states, difference in data collection, or other reasons. Because of these differences, Davis determined that models from other states could not be reliably applied to Minnesota highways. The author then developed a model based on fatal and injury-producing Minnesota crashes that was roughly consistent with Pennsylvania and Texas model results. The model was not deemed reliable for absolute estimates of median crossover crash frequencies, but could be used for comparing relative effectiveness of various proposed median highway treatments.

2.2.6 North Carolina Study

The North Carolina Department of Transportation (NCDOT) conducted median crash studies in 1993, 1997, and 1998 in an attempt to develop a model to assist in the identification of potentially hazardous sections of North Carolina interstates (Strasburg and Crawley 2005). Despite a large body of data studied, researchers were not able to develop a sufficient predictive model. The final study, conducted in 1998, did identify more than 1,200 miles of freeway in North Carolina that were candidates for median barriers. As a result of the this study, median barriers were placed first on freeways with histories of median crossover crashes, then on all freeway sections with median widths less than 70 feet, resulting in the installation of over 1,000 miles of barrier. Finally, NCDOT policies were also revised to prohibit the future construction of freeway sections with unprotected narrow medians. The newly installed median barriers are now credited with saving an estimated 25 to 30 lives each year, and for preventing many more serious injuries (Lynch 1998).

2.2.7 Pennsylvania Study

The work by Donnell et al. in Pennsylvania notes high percentages of crashes in areas that do not warrant median barriers according to AASHTO guidelines. When median crossover crashes were plotted against AASHTO warrant, 12 percent occurred where AASHTO suggested evaluating the need for a barrier, 31 percent where evaluation was optional, and 57 percent where median barriers are not normally considered (Donnell et al. 2002). To better protect medians, Donnell and Mason (2006) suggest moving towards a warrant evaluation based on crash history similar to California. Alternatively, the installation of concrete or single W-beam barriers were found to always be cost effective when the median is less than 70 feet wide and the one-way annual ADT (AADT) is greater than 20,000 vpd, using Pennsylvania data. Donnell and Mason conclude that the need for a median barrier should still be analyzed for facilities with medians between 70 feet and 100 feet wide that have one-way AADTs greater than 20,000 vpd, but barriers may not always be cost effective (Donnell and Mason 2006).

2.2.8 South Carolina Study

As part of a larger project aimed to decrease highway fatality rates, South Carolina installed cable median barriers on all medians narrower than 60 feet. In the two-year study period before the barriers were installed, 70 fatalities were attributed to 57 separate median crossover crashes. The South Carolina Department of Transportation installed three-strand cable median barriers on a total of 314.5 miles of highway, at a total cost of 18.5 million dollars. In the six months immediately following the completion of the project, the barriers were hit over 3,000 times, 15 vehicles penetrated the barrier, and eight fatalities resulted from median crossover crashes. Most of the penetrations involved collisions that the barrier was not designed to withstand, such as vehicles contacting the barrier at high speeds or at angles greater than 25 degrees, or heavy vehicles hitting the barrier. Based on this data, the barriers were determined to be effective and efficient in reducing median crossover crashes (Zeitz 2003).

2.2.9 Texas Study

Texas researchers studied three years of crash data on interstates, freeways, and expressways with four or more lanes and speed limits of 55 mph or greater to develop a predication model for median crossover crashes. Nearly 800 potential median crossover crashes were identified, and 443 were determined to be true median crossover crashes. A random sample of non median crossover crashes was also collected. Of the cross median crashes, 42.2 percent involved fatal or incapacitating injuries, while only 6.2 percent of median related crashes in the presence of median barrier were fatal or incapacitating. The authors attempted to create a model to explain the severity of median crossover crashes, but could not identify any statistically significant explanatory variables. Further study with more data was recommended (Miaou et al. 2005).

2.2.10 Washington Study

In order to test the effectiveness of cable median barriers, the Washington Department of Transportation installed cable median barriers over 25 miles of test sites on I-5. Researchers observed decreases in crash rates from 16 crashes per year in the 25 miles of test sites before installation to 3.42 crashes per year after installation. Crash rates for fatal and disabling crashes decreased from 3.8 per year to 0.33 per year (Noyce 2006).

2.2.11 Wisconsin Study

Noyce conducted a study of median crossover crashes in Wisconsin from 2001 to 2003 and found that of 631 crashes over three years, 514 (81.5 percent) occurred at locations where median barrier was not warranted according to the AASHTO guidelines. The Wisconsin Department of Transportation requires median barriers on all facilities with design speeds greater than 65 mph, traffic volumes greater than 7,000 vpd, speed limits greater than 55 mph, and medians narrower than 60 feet. However, 416 crashes (65.9 percent) during the study period occurred in locations where the median width was greater than 60 feet, suggesting further study may be needed to expand the warrant for wider medians (Noyce 2006).

2.2.12 Summary

Multiple studies have shown that the AASHTO warrant may be too lenient in prescribing median barrier treatments. Large proportions of crashes have occurred at sites not warranting median barriers according to AASHTO guidelines (Donnell et al. 2002, Nystrom 1997). All states that have installed additional median barriers have seen noticeable decreases in median crossover crashes since the installation of barriers (Bane 2006, Noyce 2006, Zeitz 2003).

2.3 Barrier Types

Median barriers are designed to redirect vehicles striking the barrier back into the travel lanes. Past research has shown that crash rates often increase after median barrier installation, but that median crossover crashes are virtually eliminated (Miaou et al. 2005, Nystrom 1997). One proposed reason for the increase in crashes is that errant vehicles that could have recovered and successfully merged back into traffic instead strike a barrier. Therefore, median barriers should only be used when the expected consequence of striking the barrier is less severe than if the barrier had not been installed (AASHTO 2002). The three main categories of median barriers used in Utah, and therefore discussed in this thesis, are the three-strand cable, W-beam, and concrete barriers.

2.3.1 Three-Strand Cable Barriers

Three-strand cable barriers allow approximately 12 feet of lateral movement, therefore a median width of at least 24 feet is recommended for installation, if the barrier is to be placed in the center of the median. An example of three-strand cable barrier installed on I-15 is shown in Figure 2-3. Three-strand cable barrier systems are effective on a moderate slope, generally no more than 1V:6H (16.7 percent slope). Since the barrier must repaired after each hit in order to maintain effectiveness, three-strand cable barriers are not appropriate in areas where they will be hit frequently. However, three-strand cable barrier systems are fairly inexpensive to install and perform well when they are hit. Three-strand cable barriers are rated as TL-3 longitudinal barriers, as outlined in National Cooperative Highways Research Program (NCHRP) Report 350: *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (AASHTO 2002, Ross et al. 1993). Details on the barrier ratings can be found in the literature and will not be summarized here.

Figure 2-3. Three-strand cable barrier (UDOT 2008a).

2.3.2 W-Beam Barriers

W-beam median barriers are available in two main types: weak post and strong post (AASHTO 2002). W-beam median barriers, in contrast to W-beam guardrails, have steel W-beams installed on both sides of the wood or metal post. Figure 2-4 shows a W-beam median guardrail in service.

Figure 2-4. W-beam median barrier (UDOT 2008a).

The weak-post, W-beam barrier system has a recommended mounting height of 33 inches and a 7.0-foot design deflection. The barrier is sensitive to height variation, and is therefore suitable only for flat, traversable medians where frost heave or erosion are not likely to alter the mounting height. Weak-post, W-beam barriers are classified as TL-2 longitudinal barriers outlined in NCHRP Report 350 (AASHTO 2002, Ross et al. 1993).

The strong-post, W-beam system provides a more rigid barrier and has been used extensively to prevent median crossover crashes in relatively narrow medians. With a design deflection distance of 2.0 to 4.0 feet, the barriers have been typically used in medians wider than 10.0 feet. Depending on the setup, strong-post, W-beam barriers can be rated as either TL-2 or TL-3 longitudinal barriers outlined in NCHRP Report 350 (AASHTO 2002, Ross et al. 1993).

2.3.3 Concrete Barriers

Concrete barrier are manufactured in four different primary shapes: Jersey, F-shape, single slope, and vertical wall. These rigid barriers are the most durable, and all are rated as TL-4 longitudinal barriers at 32 inch height and TL-5 longitudinal barriers at 42 inch and greater heights according to NCHRP Report 350 (Ross et al. 1993). As the barriers are not designed to deflect when properly anchored, they are most suitable for narrow medians (AASHTO 2002). The most common concrete barriers on Utah interstates are Jersey shape and single slope.

Jersey barriers, as shown in service in Figure 2-5, have a shallower slope near the base of the barrier and a steep slope near the top. According to UDOT specifications, Jersey barriers can be placed a minimum of 2.0 feet from the end of the shoulder. The Jersey barrier is 32.0 inches in height, 24.0 inches wide at the base, and 6.0 inches wide at the crown (UDOT 2008b).

Single slope barriers are often used on interstate curves to prevent vehicles from tipping and crossing the median. According to 2008 UDOT specifications, cast-in-place single slope barriers are constructed to height of 42.0 inches, tapering from a 24.0 inch base to an 8.0 inch crown (UDOT 2008b). A single slope barrier is shown in service in Figure 2-6.

Figure 2-5. Jersey barrier (photo by Katherine Winters 2008).

Figure 2-6. Single slope concrete barrier (photo by Katherine Winters 2008).

2.4 Interchange Safety

Incidents on interstates are most likely to occur near interchanges, primarily because of the conflict that occurs between entering and exiting traffic and driver error as the driver attempts to navigate the interchange (Lunenfeld 1993). Crash rates at urban interchanges have been shown to be much greater than at rural interchanges, and to increase sharply as interchange spacing decreases in urban areas (Twomey et al. 1993). This difference in crash rates necessitates separate analysis of urban and rural interchanges.

Despite the documented increase in crash rates as interchange spacing decreases, the bulk of published research regarding interchange spacing has focused on operations and traffic flow issues. With all other factors held constant, Bared et al. (2006) developed a model based on California and Washington data that predicted six additional fatal or injury crashes per mile per year upon tightening urban interchange spacing from 3.0 miles to 1.0 mile. For a model developed based on three years of crash data in Tennessee and North Carolina, interstate segments within 1,500 feet of an interchange were predicted to have crash rates two to three times as large as the crash rates of non-interchange segments (Kiattikomol et al. 2008). Neither of these models differentiated between types of crashes.

In a median crossover crash study by Donnell et al. (2002), it was noted that six of the 20 studied crash sites occurred with an entrance ramp 100 to 800 feet upstream of the crash site. Based on freeway characteristics, 1.7 crashes were expected. Therefore, there appeared to be higher crash rates downstream from an entrance ramp. The sample size however, was rather small, making it difficult to report the true significance of the findings. An unpublished Florida study with a very large sample size found that 82 percent of median crossover crashes occurred with a mile of a ramp terminus, and consequently recommended median barriers for 1.5 miles on either side of every interchange (Bane 2008).

As has been shown, the functional area of the interstate impacted by an interchange has been defined differently by each study. The area has been defined as narrowly as 100 to 800 feet downstream of a ramp terminus, or as widely as 1.0 mile from ramp termini for a total of 1.5 miles from the center of the interchange, and generally based upon observation (Bane 2008, Donnell et al. 2002).

2.5 Background of the UDOT Crash Database Tool

The research conducted in this thesis is the first such investigation of median crossover crashes and of the variation in median crossover crash rates around interchanges in the state of Utah. To determine the location and distribution of median crossover crashes, crash data were evaluated. Crash records were retrieved from the UDOT crash database and used to analyze crash statistics for all interstate freeways in Utah.

The UDOT crash database is designed to allow users to rapidly and remotely retrieve and analyze basic transportation data. The database facilitates data investigation in six ways (Anderson et al. 2006):

1. Custom tables and reports are created with only selected parameters, leaving off unneeded data. This simplifies the analysis by focusing on what is important to each individual user.

2. Placing the data on a “smart map” allows the decision-maker to visually identify hot spots or deficient areas. The analysis can be further refined by extracting selected information from the map as needed.
3. Simple statistical processes can be applied to the data by location using “Fixed Segment,” “Floating Segment,” or “Cluster” analysis.
4. Providing information from multiple databases in one web site allows users to conduct “loose” integration of the data. Information extracted through a series of queries from different data sources can be saved into a single spreadsheet for analysis. For example wet weather crashes, skid index, and AADT could be acquired for a site from three different databases.
5. Decision-makers will have more time to analyze the data since it takes less time to gather and compile the information. This will enhance the identification of problem areas, program delivery, and improved designs.
6. The system is designed to quickly down-load data for performance measurement. The effectiveness of improvements can be monitored over time in an efficient manner.

Crash analysis is a critical tool in evaluating the safety conditions of a roadway. Crash reports in the UDOT crash database include information not only on crash location, type, and severity, but also weather conditions, roadway conditions, contributing factors to the crash, and data about all drivers and passengers involved in the crash. Through actual crash histories, researchers can obtain a wealth of data to facilitate an in-depth understanding of the relationship between roadway characteristics and driver behavior.

Several research projects have been conducted using data available from the UDOT crash database, including studies on drowsy driving crashes (Schultz and Young 2007), access management (Saito et al. 2005, Schultz and Braley 2007, Schultz and Lewis 2006), and animal-vehicle crashes (Perrin and Disegni 2003).

2.6 Literature Review Summary

In this chapter, a literature review was presented containing relevant information regarding median crossover crashes and interchange safety on interstate highways. Median crossover crashes were defined as occurring when a driver departs his traveled way to the left, traverses the entire median, enters oncoming traffic, and collides with an oncoming vehicle; and typical contributing factors, rates, and severities were discussed. Previous studies and existing guidelines on median barrier installation and types were reviewed. Research on interstate safety concerns in the vicinity of interchanges was summarized, and the UDOT crash database was introduced as an effective resource for pertinent information on crashes in Utah. The next chapter of this report will present the procedure used to analyze median crossover crashes in the vicinity of Utah interstate interchanges.

3 ANALYSIS PROCEDURE

To determine which corridors on Utah interstates have had high numbers of median crossover crashes in years past, and to calculate the influence of interchanges on median crossover crash rates, data were obtained from the UDOT crash database. The manner in which crash records were retrieved from the database is set forth, along with the data preparation and analysis procedures. The functional area of interchanges was determined based on median crossover crash distribution, and that distribution was compared to the distribution of all types of crashes using a chi-square goodness of fit test. Crash rates in terms of crashes per mile per year and crashes per million vehicle miles travelled (VMT) were calculated based on data collected from 2003 through 2005 and used to identify critical sections.

3.1 Data Retrieval from UDOT Crash Database

Data for this study were obtained through the UDOT crash database. The crash database is comprised of records and statistics obtained from police reports for crashes occurring on interstate freeways, U.S. routes, and Utah state route highways. Crash data and statistics are available dating back through 1992. At the time of this study, data were available through 2005.

From the UDOT database website, the crash database can be accessed by selecting “Accidents” from the “Select Application” drop-down menu in the upper right corner of the screen, as is shown in Figure 3-1.

" Go to the Preferences section to change your

Figure 3-1. UDOT crash database homepage.

At the top of the next screen are five tabs that enable the user to access different sections of the crash database. The third tab, “Filters,” allows the user to create a custom set of criteria by which to obtain a subset of crash records. By selecting the “Filters” tab, the filters screen opens. The user can either access a previously created filter through the “Filter Management” option, as shown in Figure 3-2, or to create a new filter using the “Create a Filter” option.

Filter: MedianCrossoverType1

Figure 3-2. Example of “filters” tab in UDOT crash database.

To create a filter, the user must first select which criteria will be included in the filter. The database contains 66 available parameters by which to construct a filter. The “Year” parameter is automatically included in the filter, which utilizes Boolean operators to sort through all the crash records in the database and return applicable results. The filters use the “AND” Boolean operator to combine terms. If an “OR” operator is necessary, the user must select the parameter multiple times. For this study, data were needed for all five interstates, so the “Route_Num” parameter was selected five times as shown in Figure 3-3.

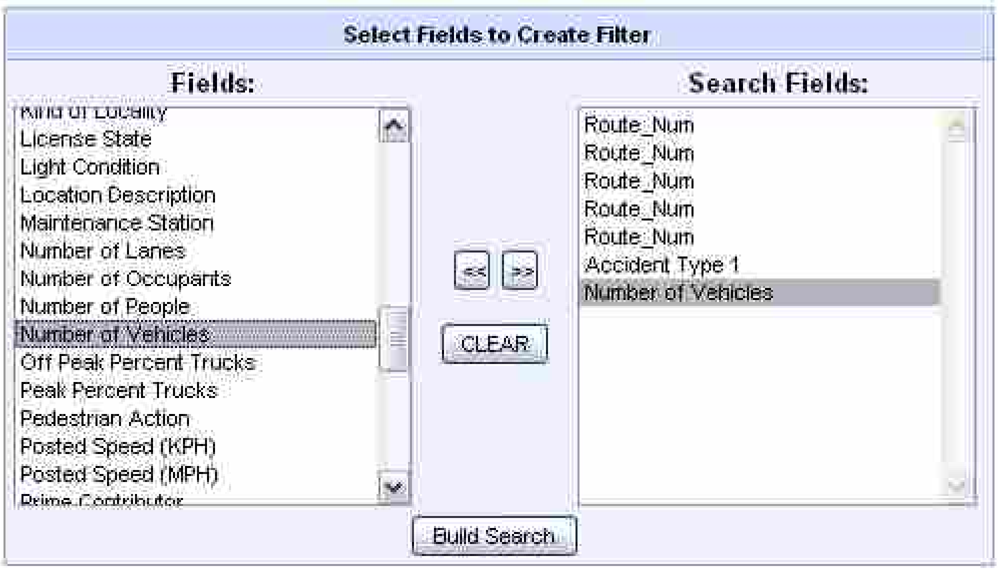


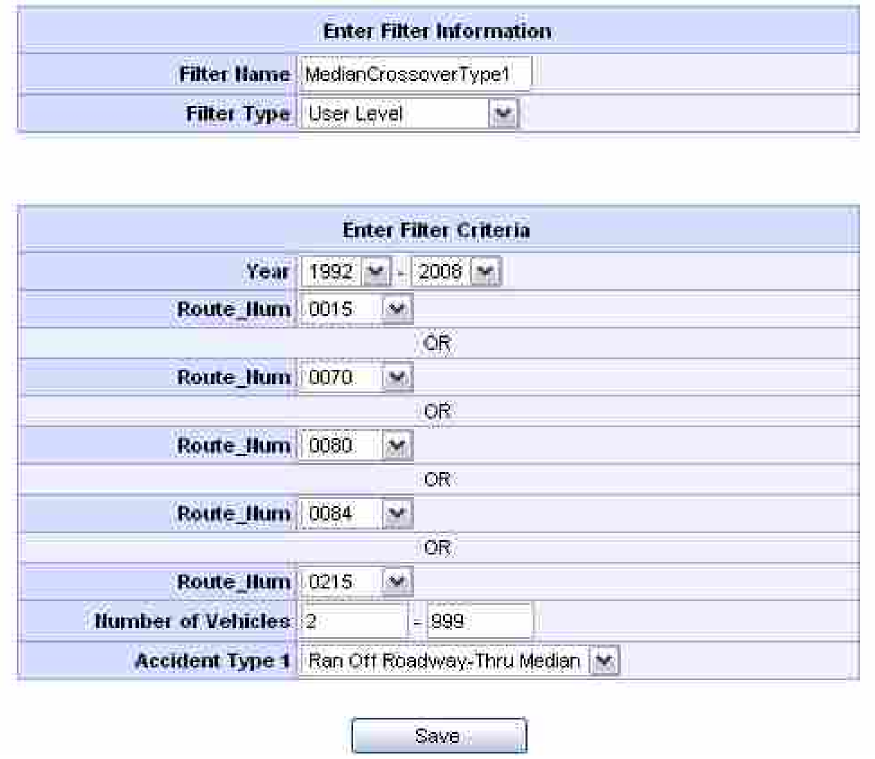
Figure 3-3. Example of creating a filter with Boolean operator capabilities.

After selecting all of the parameters needed for the search, the “Build Search” button takes the user to the next screen. The first input box allows the user to name the filter, and then determine the filter type. Filters designated as “User Level” are only available when the creating user logs into the database, while selecting “Add to Filter

Library" allows all users to access the filter. The user then enters the filter criteria in the next box. As can be seen in Figure 3-4, "Year," "Route_Num," and "Accident Type 1" parameters can be selected from drop-down lists of available values, while "Number of Vehicles" requires a numerical input. The database allows users to select years through 2008, although no data is available after 2005. All five interstates are then selected individually, and the Boolean "OR" operator can be seen between them. Since median crossover crashes involve multiple vehicles by definition, the number of vehicles range is set between 2 and 999. The crash type of "Run Off Roadway-Thru Median" is also selected. The user can then save the filter, which will also run a search on the database for crash records meeting the filter criteria.

Upon completion of the search, the results are displayed in a new window, as shown in Figure 3-5. The search criteria are displayed, along with the year, route, mile point, number of vehicles, and a link to the crash record for each crash that met the search criteria. The crashes are sorted by route and then mile point.

By selecting the "Info" link next to a crash record, the complete crash report opens as is shown in Figure 3-6. This page contains a wealth of information pertaining to the conditions at the time of the crash. By selecting the "Vehicle" tab at the top of the page, another table opens with information about each vehicle involved in the crash. An example of the vehicle information is shown in Figure 3-7.



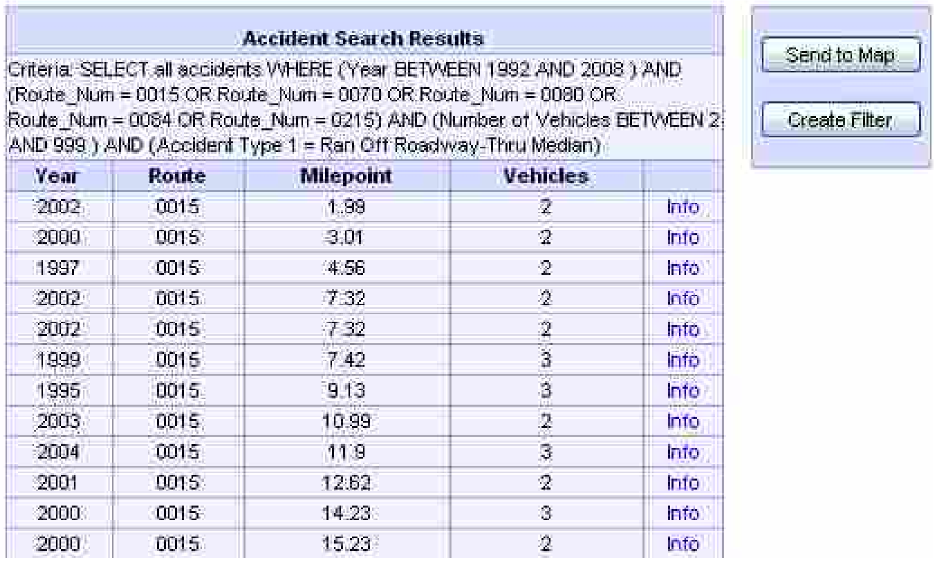
Enter Filter Information

Filter Name: MedianCrossoverType1
Filter Type: User Level

Enter Filter Criteria

Year: 1992 - 2008
Route_Num: 0015
OR
Route_Num: 0070
OR
Route_Num: 0080
OR
Route_Num: 0084
OR
Route_Num: 0215
Number of Vehicles: 2 - 999
Accident Type 1: Ran Off Roadway-Thru Median

Figure 3-4. Example of entering filter criteria.



Accident Search Results

Criteria: SELECT all accidents WHERE (Year BETWEEN 1992 AND 2008) AND (Route_Num = 0015 OR Route_Num = 0070 OR Route_Num = 0080 OR Route_Num = 0084 OR Route_Num = 0215) AND (Number of Vehicles BETWEEN 2 AND 999) AND (Accident Type 1 = Ran Off Roadway-Thru Median)

Year	Route	Milepoint	Vehicles	
2002	0015	1.99	2	Info
2000	0015	3.01	2	Info
1997	0015	4.56	2	Info
2002	0015	7.32	2	Info
2002	0015	7.32	2	Info
1999	0015	7.42	3	Info
1995	0015	9.13	3	Info
2003	0015	10.99	2	Info
2004	0015	11.9	3	Info
2001	0015	12.62	2	Info
2000	0015	14.23	3	Info
2000	0015	15.23	2	Info

Figure 3-5. Example of crash search result using a filter.

Accident Information	
Year	2000
Accident Control Number	595
Milepoint	40.3
Date	1/2/2000
Day of Week	Sunday
Time	1/2/2000 10:00:00 AM
County	Washington
Ramp Number	NULL
Route_Num	NULL
Location Description	NULL
Severity	No Injury
Traffic Control	Traffic Lanes Marked
Alignment	Straight and Level
Weather	Snowing
Surface Condition	Snowy
Roadway Condition	NULL
Light Condition	Daylight
Kind of Locality	Open Country
Number of Vehicles	2
Collision Type	NULL
Accident Type 1	Ran Off Roadway-Thru Median
Accident Type 2	MV-MV
Accident Type 3	NULL
EMS Report Number	NULL
Time Called	1/2/2000 10:05:00 AM
Time Arrived	1/2/2000 10:20:00 AM
Time Completed	1/2/2000 11:30:00 AM
Region District	Cedar
Maintenance Station	22
Functional Class	Principal Arterial-Interstate
AADT	11870
Future AADT	25138
Year Future AADT	2020
Number of Lanes	4
Speed Limit (MPH)	65
Peak Percent Trucks	19
Off Peak Percent Trucks	19

Figure 3-6. Example of crash information.

Accident Information	
Vehicle Number	1
Vehicle Year	1995
Vehicle Type	Pickup or Panel
Direction	S
Collision with Object	NULL
Estimated Travel Speed (MPH)	60
Estimated Travel Speed (KPH)	NULL
Estimated Impact Speed (MPH)	20
Estimated Impact Speed (KPH)	NULL
Posted Speed (MPH)	75
Posted Speed (KPH)	NULL
Prime Contributor	NULL
Secondary Contributor	NULL
Driver Intent	Go Straight Ahead
Number of Occupants	1
License State	CA
Driver Vision	Not Obscured
Altered Vehicle	None

Vehicle Number	2
Vehicle Year	1998
Vehicle Type	Passenger Car - Compact
Direction	N
Collision with Object	NULL
Estimated Travel Speed (MPH)	50
Estimated Travel Speed (KPH)	NULL
Estimated Impact Speed (MPH)	20
Estimated Impact Speed (KPH)	NULL
Posted Speed (MPH)	75
Posted Speed (KPH)	NULL
Prime Contributor	Did Not Contribute
Secondary Contributor	NULL
Driver Intent	Go Straight Ahead
Number of Occupants	1
License State	ZZ
Driver Vision	Not Obscured
Altered Vehicle	None

Figure 3-7. Example of vehicle information.

As previously described, when a search parameter is selected multiple times while creating a filter, the Boolean operator is set to “OR.” Because of this, a filter could not be created to only search for crashes involving vehicles traveling in different directions. Each crash report that met the previously listed requirements was opened and individually analyzed to determine if the vehicles were traveling in different directions as was shown in Figure 3-7. Also, the crash database contains multiple options for the crash type. Depending on the reporting officer, a median crossover crash could be classified either as a “Run Off Roadway-Thru Median” or “Run Off Roadway-Left” crash classification. Also, the database allows up to three crash types for each crash, which are input as “Accident Type 1,” “Accident Type 2,” and “Accident Type 3.” Since selecting multiple crash type parameters would result in the “AND” operator being used in the filter, a separate filter had to be created for each crash type, as well as each crash classification, resulting in a total of six filters for this study.

In total, the six filters returned 4,662 crash records for the years 1992 through 2005. Of these, 830 involved vehicles traveling in opposing directions and were considered to be median crossover crashes. The crash information for these crash records was then copied and incorporated into a computer spreadsheet to aid in the analysis. Table 3-1 shows the number of records obtained from each filter for each interstate. As can be seen from the table, the bulk of the median crossover crashes occurred on I-15, and very few median crossover crashes occurred on I-70 and I-84. Since the bulk of traffic in Utah is on I-15 in urban areas with narrow medians, I-15 is the longest interstate in Utah, and I-70 and I-84 have much lower AADTs and wider medians, comparatively, these numbers are as expected.

Table 3-1. Median Crossover Crashes Obtained from the UDOT Database

		I-15	I-70	I-80	I-84	I-215	Total
Accident Type 1	Thru Median	272	6	48	8	48	382
Accident Type 2	Thru Median	134	2	21	4	12	173
Accident Type 3	Thru Median	20	0	2	0	1	23
Accident Type 1	Left	92	4	15	6	14	131
Accident Type 2	Left	65	4	12	2	12	95
Accident Type 3	Left	19	0	5	1	1	26
	Total	602	16	103	21	88	830

3.2 Data Reduction

The first step in data reduction was to eliminate duplicate data records. Some crash records were added to the analysis spreadsheet twice because they appeared under a “Run Off Roadway-Thru Median” filter and a “Run Off Roadway-Left” filter. Crashes that occurred in construction zones or access ramps were also removed, as were crashes that were caused as a result of intentional median crossings. The total number of median crossover crashes was thus reduced from 830 to 667, a nearly 20 percent reduction. A breakdown of the number of crashes removed from the data set for each interstate is shown in Table 3-2, and the total number of median crossover crashes for each year is shown in Figure 3-8. The annual number of median crossover crashes decreased from 2000 through 2005, a trend likely due to increased safety measures on Utah interstates.

Table 3-2. Summary of Median Crossover Crash Total Calculations

	I-15	I-70	I-80	I-84	I-215	Total
Initial Selected Crossover Crashes	602	16	103	21	88	830
Duplicate Crashes	-55	0	-11	-1	-5	-72
Construction Zone Crashes	-32	-1	-4	-1	-6	-44
Ramp Crashes	-22	0	-6	0	-2	-30
Intentional Crossover Crashes	-13	0	-1	0	-3	-17
Final Selected Crossover Crashes	480	15	81	19	72	667

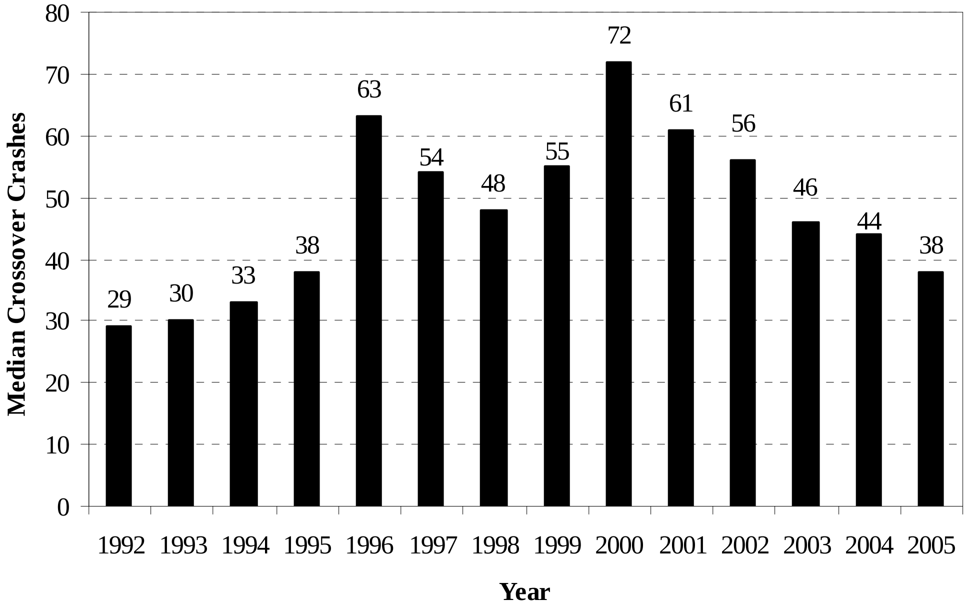


Figure 3-8. Median crossover crashes by year.

3.3 Data Preparation

To facilitate the analysis, missing information needed to be added to the crash records, such as blank fields for county or day of the week. The nearest interchange to each crash was also identified, and the distance to that interchange was recorded. Each crash was then labeled as occurring in an urban or rural location. The functional area of each interchange was determined by analyzing the distribution of crashes, and crashes occurring outside of the functional area were removed from the data set.

3.3.1 *Filling in Missing Data*

Several crashes in the data set had missing data, such as the day of the week or county. For all crashes without a listed day of the week, the day was determined from the date of the crash and entered into the appropriate column. To determine the county where each crash took place, the UDOT Roadview Explorer (UDOT 2008a) tool was used. This tool consists of photographs of every Interstate, U.S. Route, and S.R. highway in Utah taken every 0.01 mile, as well as the county, heading, the date the photograph was taken, latitude and longitude, and altitude of the site. Using this tool, users can search through the photographs by interstate, milepost, and direction. A picture of the site is then displayed along with information about the site, as illustrated in Figure 3-9. This information was used to supplement information missing from the crash record, such as the county where the crash took place.

Route_nr: 0015
Direction: +
District: 5
Countyname: WASHINGTON
Heading: N
Logdate: 06/07/2007
Session_name: 5_0015_N
Frame: 3731
Milepost: 37.123
Latitude: 37.413904
Longitude: -113.234209
Altitude: 1428
☑ GPS On

Figure 3-9. Example of Roadview Explorer on I-15 at Milepost 37.123 (UDOT 2008a).

3.3.2 Locating the Nearest Interchange

A list of interchange locations, as published in UDOT's *2005 Annual Average Daily Traffic*, was used to determine the nearest interchange to each crash (UDOT 2006). For each interstate, a computer spreadsheet was created listing all the crashes in one column and all the interchanges in one row. The distance from each crash to each interchange was calculated in terms of the absolute value of the difference between the crash milepost and the interchange milepost. The spreadsheet was then programmed to identify the minimum distance value, and copy that value to a designated column. The closest interstate was also identified by a program that referenced the column containing the minimum distance value and returned the name of the interchange. Since the crash data did not identify which vehicle crossed the median, it could not be determined if a crash occurred upstream or downstream of an interchange. Interchange characteristics are generally similar on either side of interchanges, so this was determined to be acceptable for this analysis.

3.3.3 Urban vs. Rural

Urban and rural interstates have several different characteristics. Urban interstates are more likely to have narrow paved medians with barriers, while rural interstates frequently have wide unpaved medians with barriers. Because of higher traffic volumes, a crossing vehicle in urban areas is also more likely to strike an opposing vehicle. Vehicles that run into the median in rural areas have more time and space to recover safely. Interchanges also are spaced further apart in rural areas, and often have longer ramps, resulting in different relationships between crash rates and the distance to the nearest interchange. For these reasons, crashes were separated into urban and rural categories.

The boundaries between urban and rural areas were indentified as the locations where the speed limit changes from 75 mph to 65 mph, as identified through the Roadview Explorer (UDOT 2008a). To facilitate the process of determining the nearest interchange to each crash, urban and rural boundaries were then shifted to the midpoint between successive interchanges. Boundaries were determined based on the conditions near the end of the study period. It is important to note that development that has occurred since 2005 may result in current urban and rural boundaries that are different from the boundaries used in this study.

Two urban areas were identified on Utah interstates: I-15 in the St. George area in Washington County, and I-15, I-80, and I-215 in the greater Salt Lake City area in Utah, Salt Lake, Weber, and Davis Counties. The starting and ending mileposts (M.P.) for each urbanized area are listed in Table 3-3. All interstate sections not located within the boundaries described in Table 3-3 were assumed to be rural, including all of I-70 and I-84.

Table 3-3. Rural-Urban Boundaries

Highway	Beginning Urban M.P.	Ending Urban M.P.	Urbanized Area
I-15	0.00	13.42	St. George
I-15	255.43	345.86	Provo/Salt Lake City
I-80	112.29	132.78	Salt Lake City
I-215	0.00	28.95	Salt Lake City

3.3.4 Interchange Functional Area

To best prioritize locations for median barrier installation on Utah interstates, the functional area of the interchange had to be determined. The functional area was defined as the area of the interstate impacted by the presence of an interchange. Figure 3-10 shows the distribution of urban and rural crashes with the distance from the crash to the nearest interchange. From this figure, it was determined that 90.0 percent of urban median crossover crashes occurred within 1.0 mile of an interchange, and 90.0 percent of rural median crossover crashes occurred with 3.0 miles of an interchange. This resulted in a maximum functional area of an urban interchange of 2.0 miles, or 1.0 mile on each side of the interchange, and the maximum functional area of a rural interchange of 6.0 miles, or 3.0 miles on either side of the interchange. However, many interchanges were more closely spaced than 2.0 miles in urban areas and 6.0 miles in rural areas. The downstream functional area was then recorded as the minimum of the downstream tributary area and 1.0 miles if urban and 3.0 miles if rural, where the tributary area was calculated as half of the distance from the center of the interchange in question to the center of the upstream or downstream interchange. The upstream functional area was calculated as the minimum of the upstream tributary area and 1.0 miles if urban and 3.0 miles if rural. The total functional area was then the sum of the upstream and downstream functional areas.

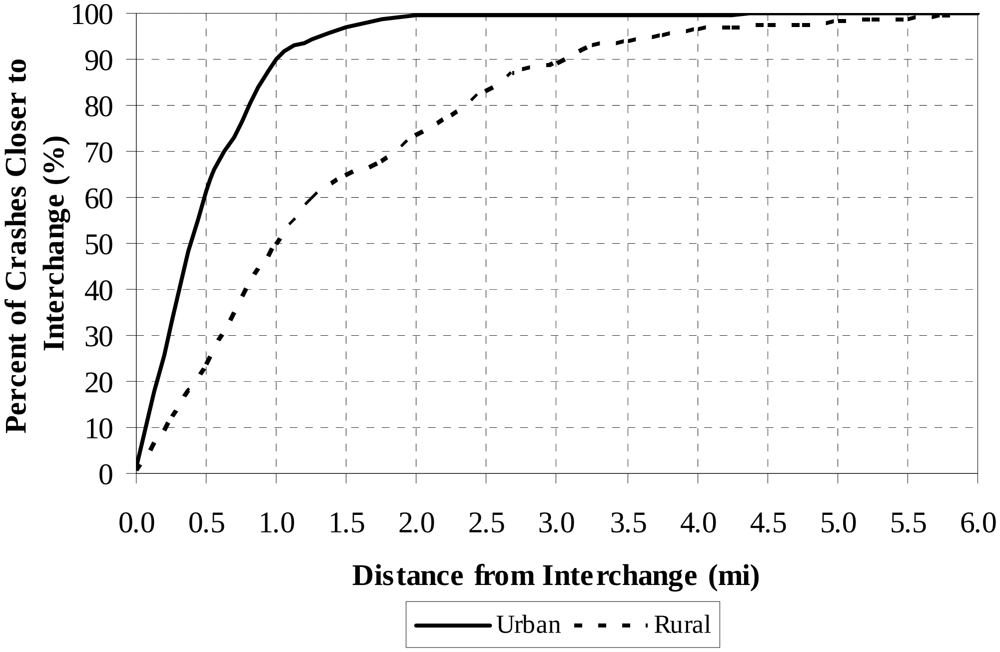


Figure 3-10. Crash distribution for urban and rural median crossover crashes.

Once the functional area of interchanges was determined, the data set was reduced to only include crashes that occurred within the functional area of interchanges. For the 2003 through 2005 analysis period, 10 rural crashes were removed from the data set. All of the urban crashes were within the interchange functional area. Table 3-4 shows the number of crashes within the interchange functional area for each interchange during the 2003 through 2005 analysis period.

Table 3-4. Median Crossover Crashes within Interchange Functional Area by Highway, 2003 through 2005

	I-15	**I-70**	**I-80**	**I-84**	**I-215**	**Total**
Urban	59	0	3	0	8	70
Rural	23	5	11	9	0	48
Total	82	5	14	9	8	118

3.4 Crashes in the Vicinity of Interchanges

In order to determine if median crossover rates occur in a different pattern around interchanges than other types of crashes, a chi-square goodness of fit test was used. The chi-square goodness of fit test compares the distribution of a sample with an expected distribution (Brase and Brase 1995). For this study, the expected distribution was calculated as the distribution of all types of crashes around interchanges. This was accomplished by sorting crashes obtained from the UDOT crash database by their distance from the nearest interchange. Median crossover crashes were summed into quarter-mile increments, and the chi-square test statistic was calculated according to Equation 3-1.

$$\chi^2 = \sum \frac{(O-E)^2}{E} \tag{3-1}$$

where: χ^2 = chi-square test statistic,

O = observed number of crashes in segment, and

E = expected number of crashes in segment.

The test statistic was calculated separately for urban and rural median crossover crashes, and then compared to critical values to determine significance and the 0.05 confidence level. If the test statistic exceeded the critical value, it was determined that the distribution of median crossover crashes was statistically different from the expected distribution at the 0.05 confidence level. If the test statistic did not exceed the critical value, then there was insufficient evidence to reject the null hypothesis that the distribution of median crossover crashes was the same as the distribution of all crashes.

3.5 Calculating Crash Rates and Identifying Critical Sections

Crash rates were calculated based on the most recent three years of data available, 2003 through 2005. Of the 667 median crossover crashes that occurred from 1992 through 2005, 128 crashes occurred between 2003 and 2005. Of the 128 crashes, 70 were in urban areas and 58 in rural areas. Using information on AADT, length of functional area, and number of crashes for each interchange, crash rates in terms of crashes per million VMT and crashes per mile per year were calculated. Critical crash rates for rural and urban areas were then calculated, and interchanges with crash rates exceeding the critical crash rate were identified.

3.5.1 Crashes per Million Vehicle Miles Traveled

Exposure based crash rates in terms of crashes per million VMT are commonly used to compare roadway sections with differing levels of traffic. Exposure-based rates allow for a simple quantification of the overall risk to drivers. Median crossover crash rates were calculated for each interchange according to Equation 3-2 (Roess et al. 2004). The AADT values, in units of vpd, used for this calculation were obtained from *2005 Annual Average Daily Traffic*, which includes AADT data for 2003 through 2005 (UDOT 2006).

$$RMVM = \frac{1{,}000{,}000 \times A}{365 \times V \times L} \tag{3-2}$$

where: $RMVM$ = crash rate for the segment (crashes per million VMT),

A = number of reported crashes for the time period,

V = total AADT for the analysis segment (vpd), and

L = length of segment (miles).

3.5.2 Crashes per Mile per Year

Crash rates expressed in terms of crashes per mile per year do not take traffic volumes into account. However, calculating the number of crashes per mile per year can identify locations with high number of crashes where median barriers may be most effective, even if the overall exposure rate is not critical. Crash rates were calculated according to Equation 3-3.

$$RSEG = \frac{A}{T \times L} \tag{3-3}$$

where: $RSEG =$ crash rate for the segment (crashes per mile per year),

$A =$ number of reported crashes for the time period,

$T =$ number of years being analyzed, and

$L =$ length of segment in (miles).

3.5.3 Identifying Critical Sections

Critical sections were identified as interchange locations with crash rates significantly higher than the average crash rate. The mean and standard deviation were first calculated for both urban and rural crash rates. Critical crash rates were then calculated according to Equation 3-4, based on the assumption that approximately 5.0 percent of crash rates lie on the upper end of the distribution (Roess et al. 2004). A confidence level of 95.0 percent in one tail ($Z = 1.645$) was used for the analysis. Interchanges with crash rates exceeding the critical value were then identified and flagged for further study, and are presented and discussed in Chapter 4. It is important to note that this method of analysis will always yield critical crash rates, so engineering judgment must be used to distinguish between statistical and practical significance.

$$C = \bar{x} + (Z \times \sigma_s) \tag{3-4}$$

where: C = critical crash rate for portion of facility considered,

$\bar{x}$ = mean crash rate the portion of facility considered,

Z = constant corresponding to a confidence level (Z = 1.645), and

σ_s = sample standard deviation for portion of facility considered.

3.6 Analysis Procedure Summary

In order to identify critical locations of median crossover crashes, data were obtained from the UDOT crash database, assembled into a computer spreadsheet, and reduced to include only true median crossover crashes. The selected crash records were then augmented to included additional data critical to the analysis. The functional areas of interchanges were then determined, and the distribution of median crossover crashes and all types of crashes were compared. Crash rates in terms of crashes per million VMT and crashes per mile per year were calculated for crashes occurring within the functional areas of interchanges between 2003 and 2005. The critical crash rates were determined and interchanges with crash rates exceeding critical rates were identified for further discussion in Chapter 4.

4 RESULTS

The results of the analysis are presented in four sections. First, overall crash characteristics are presented and discussed, including driver characteristics, site characteristics, temporal distribution of crashes, and crash severity. Crashes in the vicinity of interchanges are then addressed. Finally, critical sections are identified and limited recommended remediation measures are presented. The limited recommendations provided in this thesis reflect the views of the author and not the official views or policies of UDOT.

4.1 Crash Characteristics

The overall crash characteristics were calculated based upon 14 years of data, 1992 through 2005, in order to maximize the sample size. Driver characteristics and crash severity are summarized for all crashes, while site characteristics and temporal distributions are presented for rural and urban crashes.

The following subsections present statistics on primary driver characteristics as listed in the crash record, followed by statistics concerning the characteristics of the site where the crash occurred. The temporal distribution of crashes by hour, day, and month are illustrated, followed by a report on the severity of median crossover crashes.

4.1.1 Driver Characteristics

Driver characteristics were summarized based on the first driver listed in the crash report. While crash reports obtained from the UDOT crash database do not explicitly identify the driver at fault for the crash, it was assumed that the first driver was at fault. Figure 4-1 supports this assumption, showing that reporting police officers were far less likely to report that the first driver did not contribute to the crash. Based on the assumption that the first driver was the driver at fault for the crash, summary statistics were calculated for the prime contributors to median crossover crashes, vehicle types involved in median crossover crashes, and speed data.

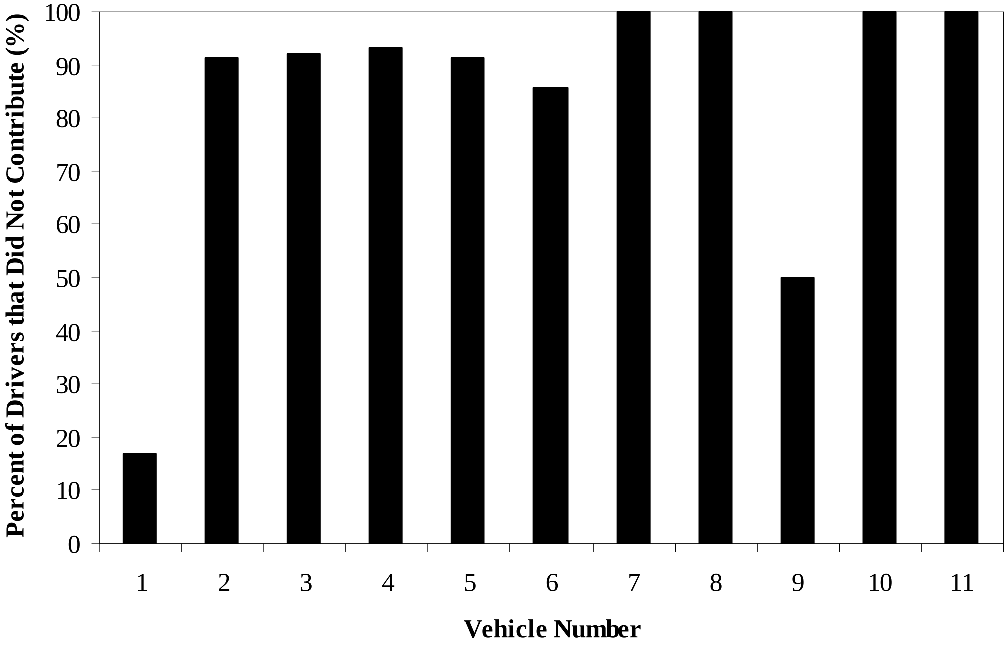


Figure 4-1. Percentage of drivers that did not contribute to the crash.

Table 4-1 shows the prime contributors recorded for each crash. As can be seen from the table, the reporting police officer failed to report a prime contributor in 43.2

percent of the crashes analyzed. The remaining data show that some form of improper driving was a major contributor to crashes, further supplemented by improper lookouts. A significant proportion of drivers were also asleep, fatigued, or driving under the influence of alcohol or drugs.

Table 4-1. Prime Contributors to Median Crossover Crashes

Prime Contributor for First Vehicle Involved in Crash	Number of Vehicles	Percent of Vehicles
Improper Driving	124	18.6%
Did Not Contribute	66	9.9%
Asleep or Fatigued	49	7.3%
DUI or Under the Influence of Drugs	37	5.5%
Improper Lookout	33	4.9%
Other Defective Condition of Vehicle	19	2.8%
Non-Contact Vehicle Involved	19	2.8%
Tires Defective	15	2.2%
Separation of Units	8	1.2%
Cargo Loss or Shifted	6	0.9%
Jackknife	2	0.3%
Hit and Run	1	0.1%
No Prime Contributor Recorded	288	43.2%
Total	667	100.0%

Table 4-2 details the vehicle types involved with median crossover crashes. Consistent with previous studies, the vast majority of vehicles were passenger cars or pickups (Lane et al. 1995, Noyce 2006). Vehicle types were not recorded in 6.7 percent of crashes.

Table 4-2. Vehicle Types Involved in Median Crossover Crashes

Vehicle Type of First Vehicle Involved in Crash	Number of Vehicles	Percent of Vehicles
Passenger Car/Pickup	552	82.8%
Truck/Tractor and Trailer	37	5.5%
Passenger Car/Pickup with Trailer	28	4.2%
Hit and Run Vehicle	2	0.3%
Dump Truck	1	0.1%
Farm Tractor and/or Equipment	1	0.1%
Motor Driven Bicycle (Scooter or Moped)	1	0.1%
No Vehicle Type Recorded	45	6.7%
Total	667	100.0%

To determine if excessive speed was a factor in median crossover crashes, the travel speed and impact speed of crashes were analyzed. Table 4-3 shows the average, median, and standard deviation of the travel speed, impact speed, and difference between travel speed and speed limit for the first vehicle involved in the crash. Figure 4-2 shows the distribution of the difference between travel speed and the posted speed limit. From this figure, it can be seen that the average driver was not speeding at the time of the median crossover crash.

Table 4-3. Speed Summary Statistics

Statistic	Travel Speed (mph)	Impact Speed (mph)	Difference Between Travel Speed and Speed Limit (mph)
Average	62.93	50.19	-2.87
Median	65.00	55.00	0.00
Standard Deviation	13.63	19.55	12.67

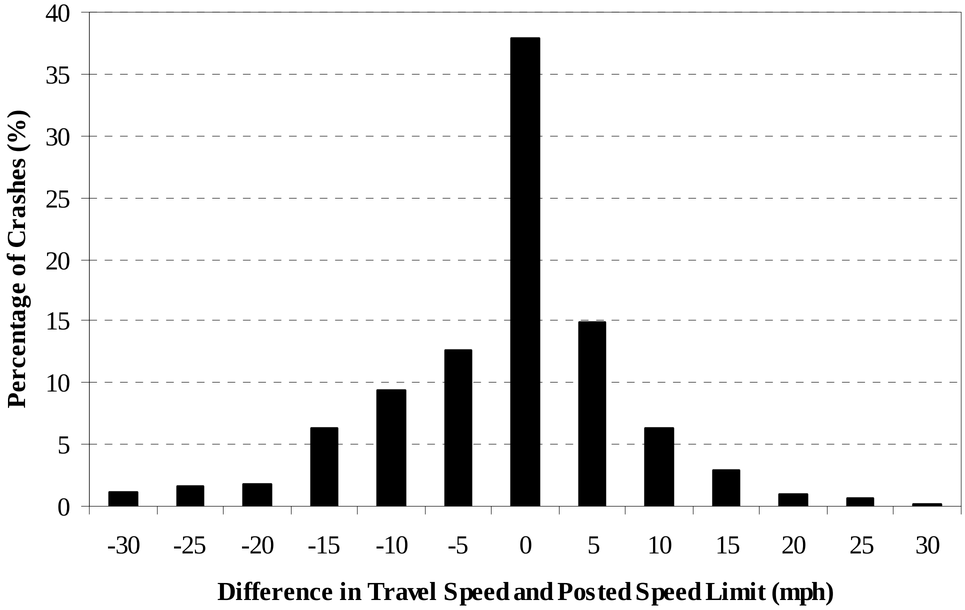


Figure 4-2. Difference between travel speed and posted speed limit for median crossover crashes.

4.1.2 Site Characteristics

Site characteristics reported in the crash records include the roadway alignment at the crash location, lighting conditions at the time of the crash, weather condition at the time of the crash, and pavement surface condition at the time of the crash. As can be seen in Table 4-4, Table 4-5, Table 4-6, and Table 4-7, the majority of median crossover crashes occurred on straight and level alignments, during daylight, in clear conditions, and on dry pavement.

Table 4-4. Roadway Alignment at Crash Location

	Total		Rural		Urban	
Alignment	**Number of Vehicles**	**Percent of Vehicles**	**Number of Vehicles**	**Number of Vehicles**	**Number of Vehicles**	**Number of Vehicles**
Straight and Level	418	62.67%	122	55.20%	296	66.37%
Grade Straight	97	14.54%	46	20.81%	51	11.43%
Curve Level	83	12.44%	17	7.69%	66	14.80%
Curve Grade	45	6.75%	26	11.76%	19	4.26%
Hillcrest Straight	11	1.65%	3	1.36%	8	1.79%
Curve Hillcrest	8	1.20%	6	2.71%	2	0.45%
Dip Straight	4	0.60%	1	0.45%	3	0.67%
Dip Curve	1	0.15%	0	0.00%	1	0.22%
Total	667	100%	221	100%	446	100%

Table 4-5. Lighting Conditions at Time of Crash

	Total		Rural		Urban	
Light Condition	**Number of Vehicles**	**Percent of Vehicles**	**Number of Vehicles**	**Percent of Vehicles**	**Number of Vehicles**	**Percent of Vehicles**
Daylight	456	68.37%	147	66.52%	309	69.28%
Darkness Street or Highway Not Lighted	157	23.54%	61	27.60%	96	21.52%
Dawn	22	3.30%	6	2.71%	16	3.59%
Dusk	17	2.55%	3	1.36%	14	3.14%
Darkness Street or Highway Lighted	15	2.25%	4	1.81%	11	2.47%
Total	667	100%	221	100%	446	100%

Table 4-6. Weather Condition at Time of Crash

	Total		Rural		Urban	
Weather	**Number of Vehicles**	**Percent of Vehicles**	**Number of Vehicles**	**Percent of Vehicles**	**Number of Vehicles**	**Percent of Vehicles**
Clear	373	55.92%	109	49.32%	264	59.19%
Snowing	112	16.79%	48	21.72%	64	14.35%
Cloudy	102	15.29%	40	18.10%	62	13.90%
Raining	56	8.40%	14	6.33%	42	9.42%
Sleeting	10	1.50%	6	2.71%	4	0.90%
Fog	9	1.35%	2	0.90%	7	1.57%
Other or Not Recorded	5	0.75%	2	0.90%	3	0.67%
Total	667	100%	221	100%	446	100%

Table 4-7. Surface Condition at Time of Crash

	Total		Rural		Urban	
Surface Condition	**Number of Vehicles**	**Percent of Vehicles**	**Number of Vehicles**	**Percent of Vehicles**	**Number of Vehicles**	**Percent of Vehicles**
Dry	438	65.67%	131	59.28%	307	68.83%
Wet	104	15.59%	31	14.03%	73	16.37%
Snowy	78	11.69%	34	15.38%	44	9.87%
Icy	47	7.05%	25	11.31%	22	4.93%
Total	667	100%	221	100%	446	100%

4.1.3 Temporal Distribution

The temporal distributions of median crossover crashes were evaluated to determine if median crossover crashes exhibit different trends than the overall traffic on Utah interstates. The data are presented in the following subsections by month, day of the week, and hour of the day. Traffic distribution values are based on rural and urban aggregates of UDOT volume data collected from traffic counters present on all Utah interstates (Virgen 2008). Due to different traffic patterns in rural and urban areas, graphs are presented separately for urban crashes and rural crashes.

4.1.3.1 Monthly Distribution

The monthly distributions of median crossover crashes for rural and urban areas are show in Figure 4-3 and Figure 4-4, respectively. In addition, the percentages of highway traffic volume by month are also included. Rural traffic volumes slightly increased during the summer months, but urban traffic volumes remained fairly constant throughout the year. In contrast, both figures show median crossover crash rates fluctuating throughout the year.

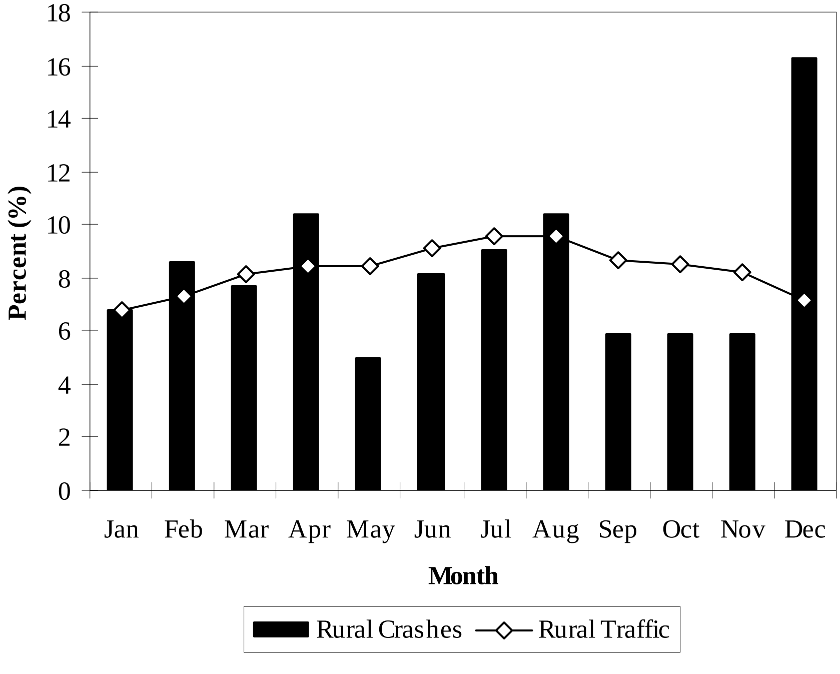


Figure 4-3. Month of crash occurrence for rural crashes.

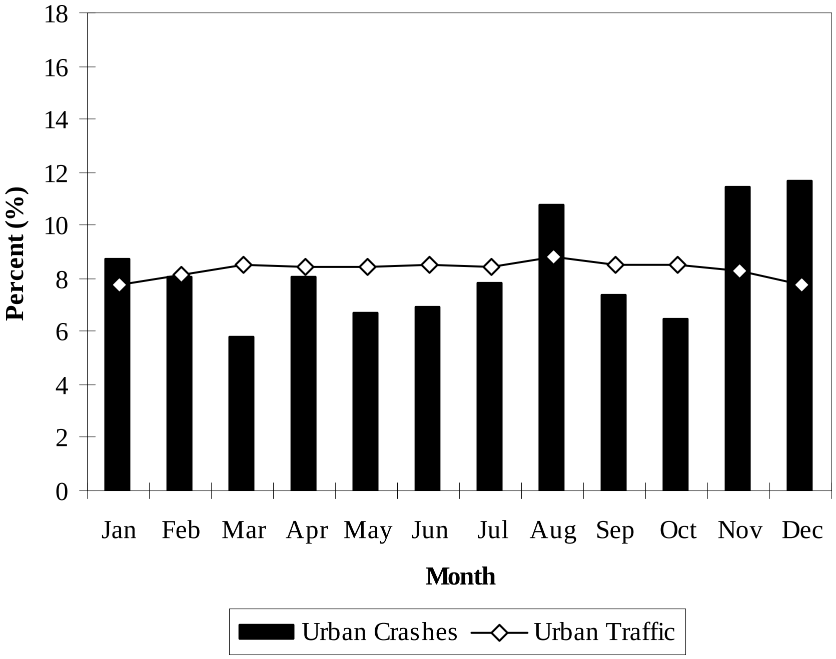


Figure 4-4. Month of crash occurrence for urban crashes.

The monthly rural crash distribution shown in Figure 4-3 shows a significantly higher percentage of crashes occurring in December than would be expected based solely on the overall traffic volume. Figure 4-4 shows a similar, though less severe spike in December on urban interstates. In the previous section, Section 4.1.2, Table 4-7 presented the total percentages of crashes sorted by surface conditions. Using that distribution and the assumption that one twelfth of the 667 median crossover crashes should have occurred in December if all factors were equal, Table 4-8 shows the expected number of crashes by surface condition for one month. The actual surface conditions for the 88 crashes that occurred in December are also given. While December has about the same number of crashes on dry pavement as would be expected, many more crashes occurred on wet and snowy pavement than would be anticipated in an average month, resulting in a greater total number of crashes. Therefore, the spike in numbers of crashes can likely be attributed to weather conditions in December.

Table 4-8. Average and December Surface Conditions at Time of Crash

	Expected Monthly		**December**	
Surface Condition	**Number of Vehicles**	**Percent of Vehicles**	**Number of Vehicles**	**Percent of Vehicles**
Dry	37	65.67%	32	36.36%
Wet	9	15.59%	21	23.86%
Snowy	7	11.69%	28	31.82%
Icy	4	7.05%	7	7.95%
Total	56	100%	88	100%

4.1.3.2 Daily Distribution

Figure 4-5 and Figure 4-6 display the variation of median crossover crashes by day of the week, as are traffic patterns by day of the week. Both urban and rural crash distributions closely follow the traffic patterns. Minor variations can likely be attributed to random variation in the data set due to the limited number of crashes analyzed.

4.1.3.3 Hourly Distribution

The hourly distributions of rural and urban median crossover crashes are presented in Figure 4-7 and Figure 4-8, respectively, as well as expected traffic trends. From these figures it can be seen the hourly crash trends generally follow traffic trends. The rural crash distribution follows the traffic distribution closely. The urban crash distribution shows some variation from the traffic pattern, but this variation is minor. Again, any difference can likely be attributed to random variation in the sample.

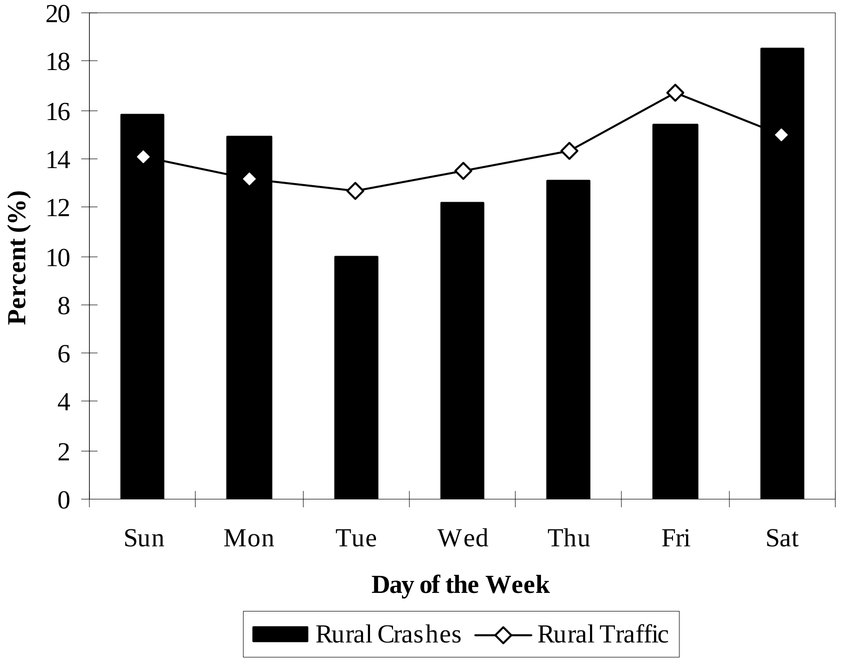


Figure 4-5. Day of crash occurrence for rural crashes.

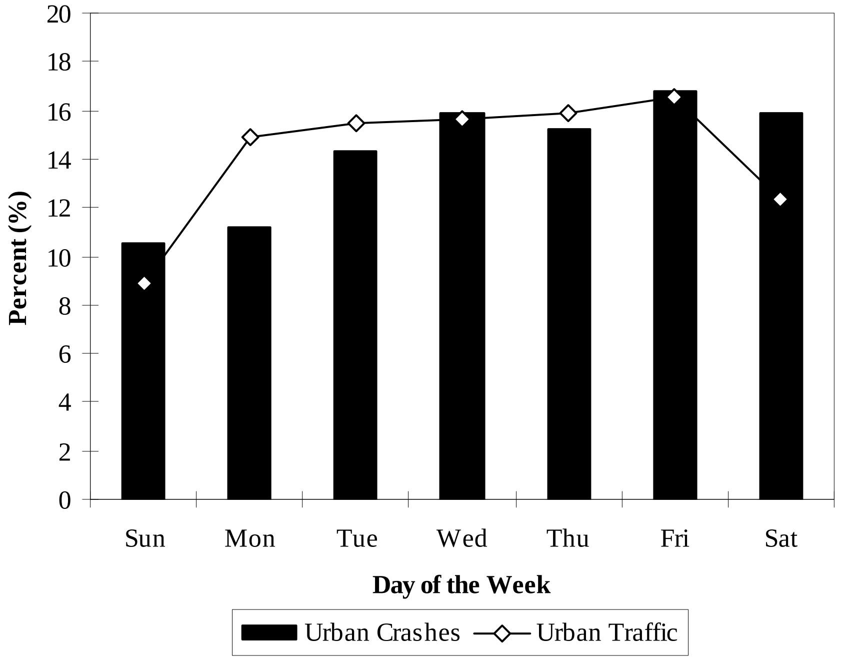


Figure 4-6. Day of crash occurrence for urban crashes.

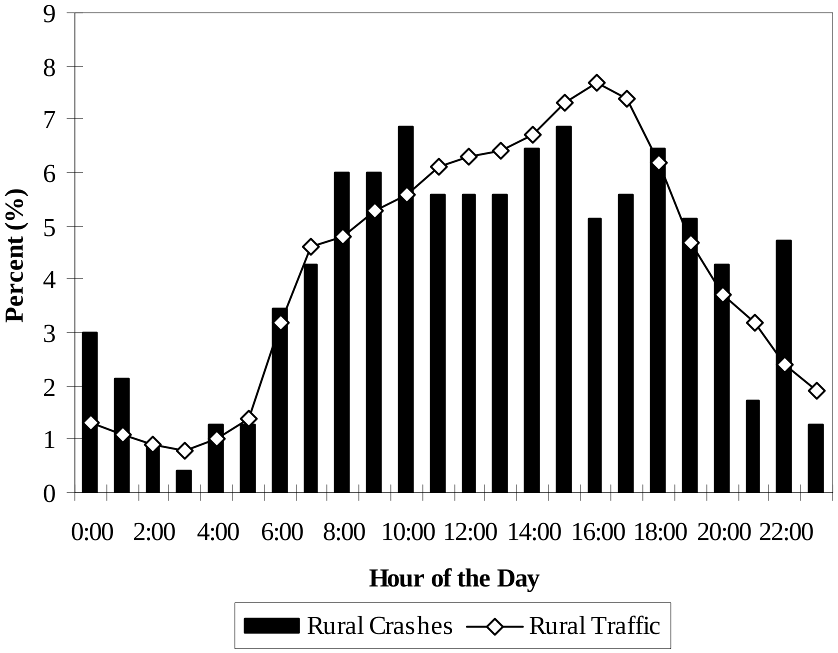


Figure 4-7. Hour of crash occurrence for rural crashes.

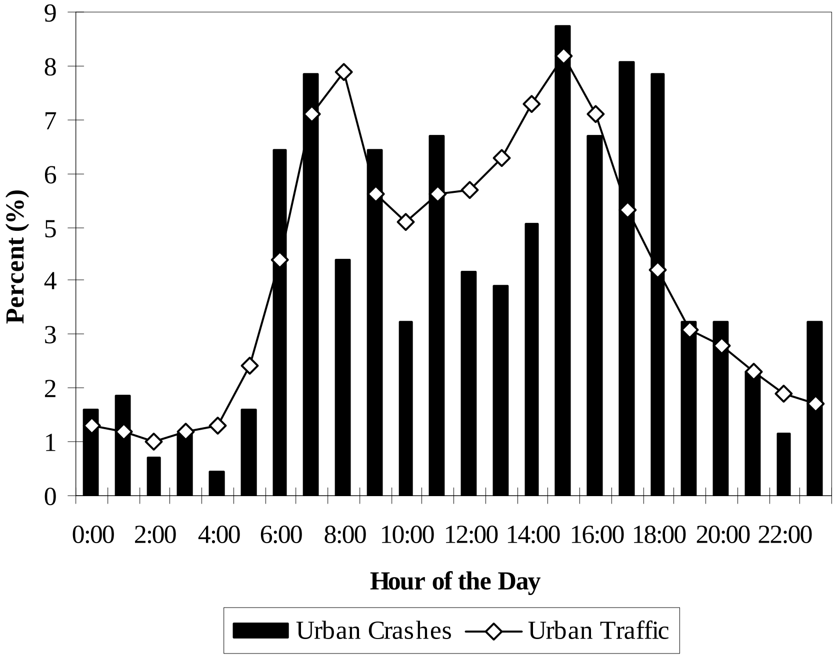


Figure 4-8. Hour of crash occurrence for urban crashes.

4.1.4 Crash Severity

The severity of all median crossover crashes sorted by the number of vehicles involved in the crash is shown in Figure 4-9. As can be seen from the figure, the severity of a crash tends to increase as more vehicles are involved in the crash. Crashes with no reported injury make up 31.1 percent of crashes involving two vehicles, but only 10.0 percent of crashes involving five or more vehicles. In contrast, the percentage of fatal crashes increases from 13.6 percent when two vehicles are involved to 23.3 percent when five or more vehicles are involved in the crash. This finding is consistent with trends noted in the literature (Noyce 2006).

Figure 4-10 and Figure 4-11 show the severities of rural and urban crashes, respectively. As there were only seven rural crashes involving four vehicles and four crashes involving five or more vehicles, the categories are grouped together in a “4+” category for the rural graph. Due to the very small sample size, the trend for rural crashes is not entirely as expected, with only 1 of the 11 crashes resulting in a fatality. However, it is expected that a larger sample size of rural crashes involving four or more vehicles may result in a trend more like Figure 4-9. The urban crashes shown in Figure 4-11 do follow the expected trend of increasing severity with increasing vehicle involvement.

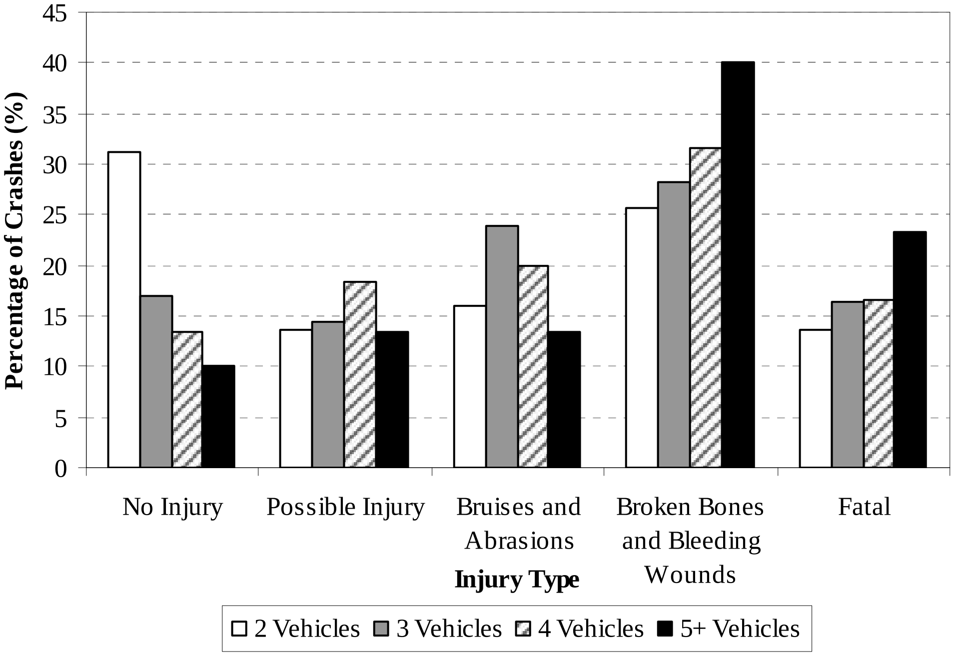


Figure 4-9. Severity of all crashes sorted by number of vehicles involved.

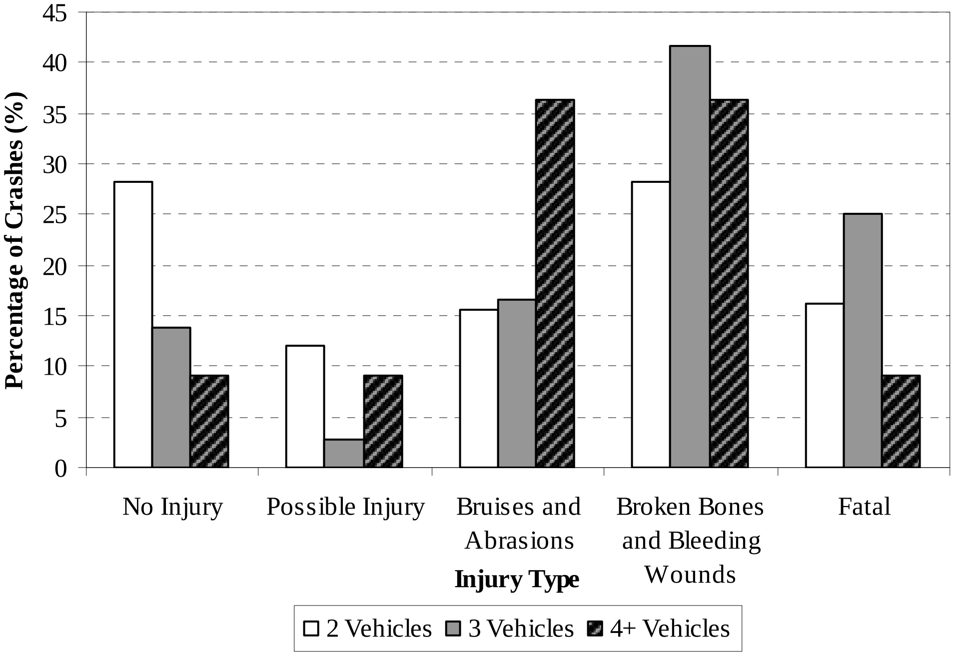


Figure 4-10. Severity of rural crashes sorted by number of vehicles involved.

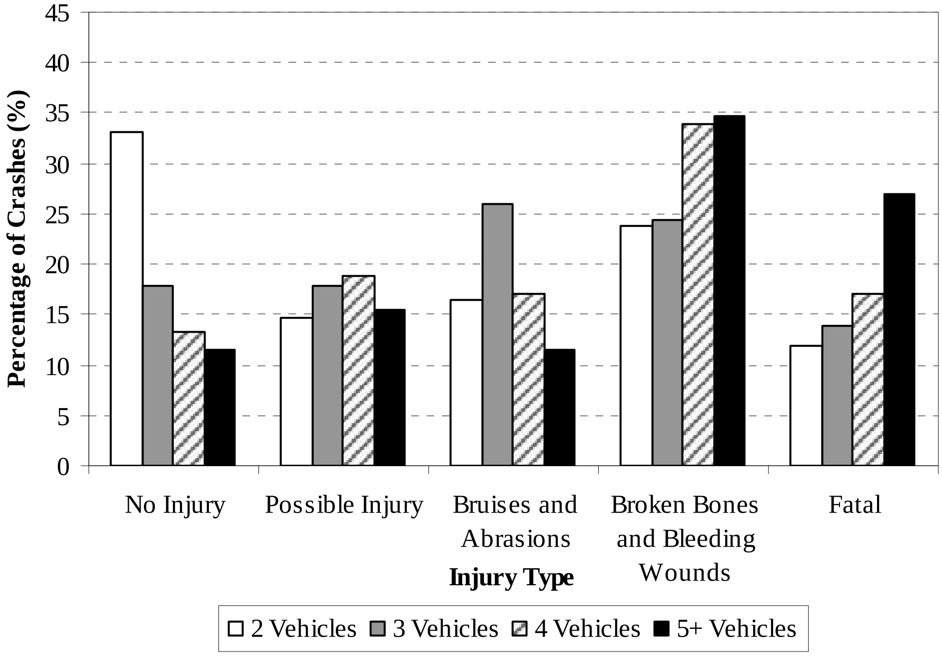


Figure 4-11. Severity of urban crashes sorted by number of vehicles involved.

4.2 Crashes in the Vicinity of Interchanges

In order to determine if median crossover crashes exhibit different patterns of occurrence in the vicinity of interchanges, the distribution of median crossover crashes was compared to the distribution of all types of crashes on Utah interchanges. Both distributions were plotted to aid in comparison. A chi-square goodness of fit test was also conducted for both urban and rural crash data and results are presented herein.

4.2.1 Rural

The distribution of median crossover crashes and all types of crashes in rural areas appears to be fairly similar within 1.0 mile of an interchange. After that point, median crossover crashes became clustered somewhat closer to interchanges than all crash types. All median crossover crashes occurred within 6.0 miles of an interchange, while the furthest distance from an interchange for a non-median crossover crash was almost 19.0 miles. Based on a chi-square goodness of fit test, shown in Table A-1 in Appendix A, the hypothesis that the distribution of median crossover crashes is the same as the distribution of all crashes could not be rejected at the 0.05 confidence level. The *p*-value for the test was calculated as 0.99998, which provides evidence that the distributions are similar. The distributions of both types of crashes are shown in Figure 4-12.

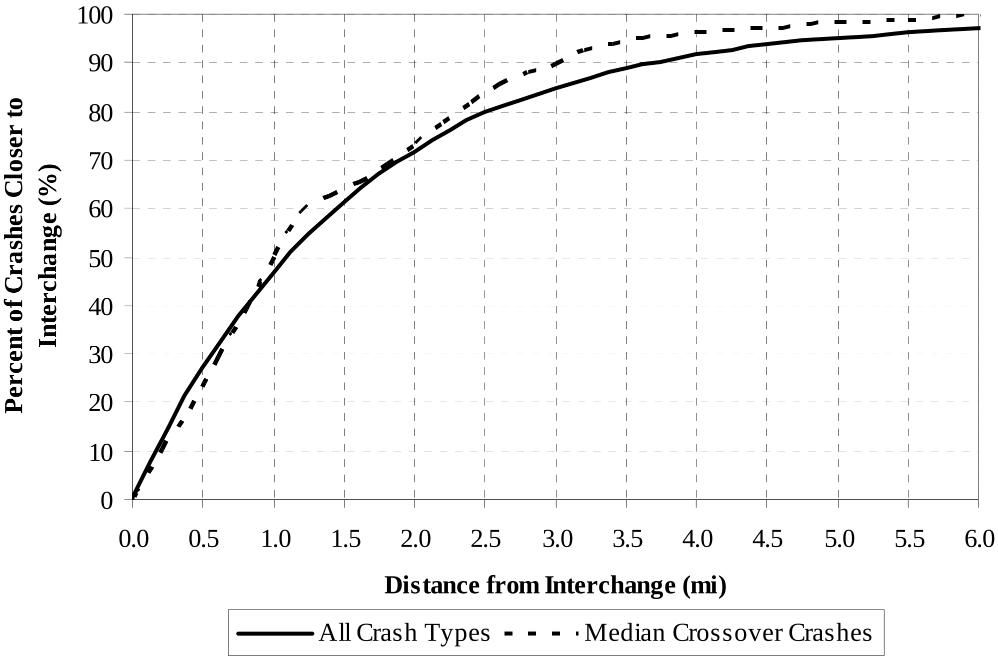


Figure 4-12. Rural crash distributions.

4.2.2 Urban

Urban median crossover crashes appeared to occur somewhat further from interchanges when compared to all types of crashes. The difference grows until about 85 percent of crashes have been accounted for, and then the two trend lines begin to merge back together. This is likely due to weaving and merging movements before off-ramps and after on-ramps. Based on a chi-square goodness of fit test, shown in Table A-2 in Appendix A, the hypothesis that the distribution of median crossover crashes is the same as the distribution of all crashes was rejected at the 0.05 confidence level, and it was determined that the two distributions are different. The *p*-value for the test was calculated as 9.28×10^{-8}, which provides convincing evidence that the distributions are different. The distributions of both types of crashes are shown in Figure 4-13.

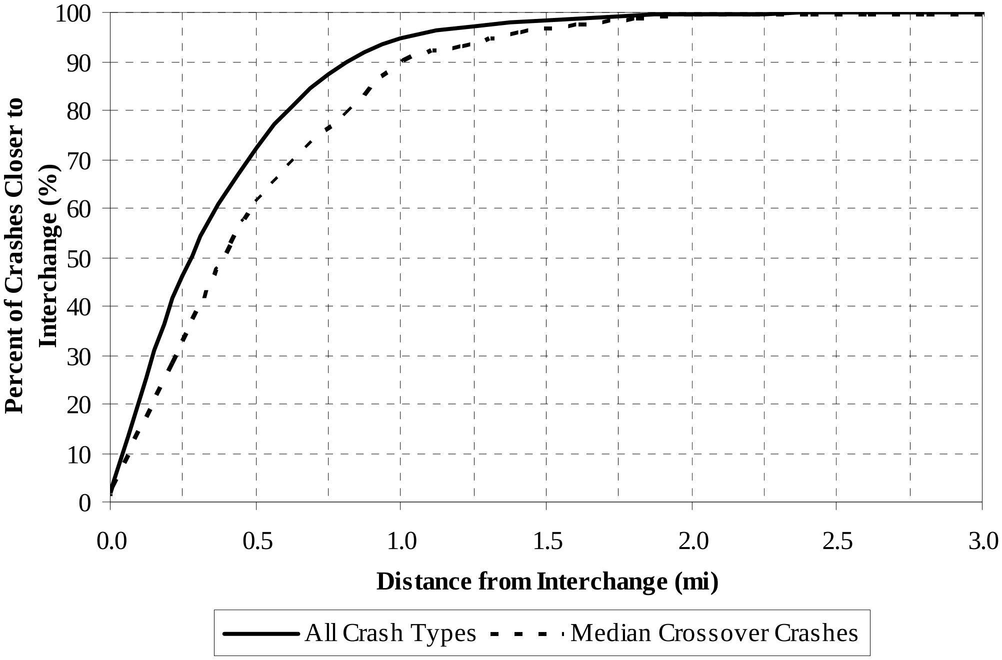


Figure 4-13. Urban crash distributions.

4.3 Critical Sections

Critical sections were identified according to the procedure outlined in Section 3.4, using data for 2003 through 2005. The statistics used to identify the critical crash rates and interchange locations exceeding the critical crash rates are presented in this section. Rural crashes and urban crashes were evaluated separately, and total crashes and fatal crashes were also analyzed for each, for a total of four sets of analyses. Crash rates in terms of crashes per million VMT and crashes per mile per year are listed and ranked. Traversable and non-traversable medians were included in the analysis.

Crash rates in terms of crashes per million VMT provide a simple quantification of overall risk to drivers adjusted for traffic volume, while crash rates in terms of crashes per mile per year can be useful in identifying locations where median barriers could be most effective. In some cases one crash rate, either crashes per million VMT or crashes per mile per year, exceeded the critical rate but the other did not, so the non-critical (N.C.) crash rate is listed in italics and given a ranking of N.C. Since both crash rates provide important information about the crash characteristics of the site in question, all sections flagged as critical by one or both crash rates were evaluated and are presented here.

4.3.1 Rural

This section presents the critical crash rates and critical sections for rural areas for all severities of median crossover crashes, followed by the critical crash rates and critical sections for fatal median crossover crashes.

4.3.1.1 All Crashes

Sixteen interchange locations were identified as exceeding the critical crash rate shown in Table 4-9. These intersections are listed in Table 4-10. While all 16 interchanges were determined to be critical locations, only four of the interchanges were determined to be critical by both crash rates in terms of crashes per million VMT and crashes per mile per year. Since the equation for crashes per million VMT uses AADT values, it is quite sensitive to widely varying AADT in rural areas. Consequently, some interchanges with very low AADT and only one crash were flagged as critical. Similarly, the North Willard Interchange on I-15 had the highest number of crashes, but it is not flagged as critical based on crashes per million VMT because of a relatively high AADT compared to the other rural sections.

4.3.1.2 Fatal Crashes

As mentioned previously, no rural interchange experienced more than one fatal crash, and a total of seven fatal crashes were recorded during the three-year study period. All seven interchanges where a fatal crash occurred were determined to be critical according to crashes per mile per year, and six of the seven were critical according to crashes per million VMT. The seventh barely failed to meet the threshold due to a much larger AADT than the other locations. Three of the critical fatal crash interchanges were also identified as critical interchanges in the total crash analysis. The crash statistics are shown in Table 4-11, and the critical sections are identified in Table 4-12.

Table 4-9. Rural Total Crash Statistics

	Crashes per Million VMT	**Crashes per Mile per Year**
Average Rate	0.005	0.029
Standard Deviation	0.010	0.062
Critical Rate	0.022	0.130

Table 4-10. Rural Critical Sections

Route	**Interchange**	**Interchange Milepost**	**Segment Length**	**Crashes**	**Crashes per Million VMT**		**Crashes per Mile per Year**	
					Rate	**Rank**	**Rate**	**Rank**
15	Black Ridge Int./ Ranch	36.8	3.42	3	0.042	3	0.293	2
15	New Harmony Int.	42.2	3.95	2	0.024	9	0.169	6
15	N. Beaver Int.	111.8	4.52	2	0.025	8	0.147	10
15	N. Ogden Int./ 450 N./ Harrisville	346.7	2.19	2	*0.017*	*N.C.*	0.304	1
15	Plain City/ 27th N./ Farr West/ Pleasant View	349.4	2.56	2	*0.017*	*N.C.*	0.261	4
15	N. Willard Int.	357.6	5.08	4	*0.019*	*N.C.*	0.262	3
70	Jct. SR 10/ Price/ Loa	91.0	5.13	1	0.035	5	*0.065*	*N.C.*
70	Jct. SR 6 W. of Green River	157.9	4.24	1	0.030	6	*0.079*	*N.C.*
70	Floy Int./Ranch	175.6	6.00	1	0.024	10	*0.056*	*N.C.*
80	Tooele Int.	98.6	4.46	2	*0.012*	*N.C.*	0.150	9
80	7200 W. Int.	111.3	4.00	2	*0.017*	*N.C.*	0.167	8
80	Summit Park Int./ Parley's Summit	139.4	2.86	2	*0.015*	*N.C.*	0.233	5
84	Ranch Exit	12.0	4.35	1	0.027	*7*	*0.077*	*N.C.*
84	Hansel Valley Int./ Ranch	15.8	2.70	1	0.043	2	*0.123*	*N.C.*
84	Howell Int.	26.6	3.98	2	0.059	1	0.168	7
84	W. Morgan Int.	103.4	3.29	1	0.038	4	*0.101*	*N.C.*

"N.C." denotes a crash rate that was not critical.

Table 4-11. Rural Fatal Crash Statistics

	Fatal Crashes per Million VMT	**Fatal Crashes per Mile per Year**
Average Rate	0.001	0.004
Standard Deviation	0.004	0.018
Critical Rate	0.007	0.033

Table 4-12. Rural Fatal Critical Sections

Route	Interchange	Interchange Milepost	Segment Length	Crashes	Fatal Crashes per Million VMT		Fatal Crashes per Mile per Year	
					Rate	Rank	Rate	Rank
15	Kolob Canyon Int.	40.3	2.70	1	0.017	2	0.123	1
70	Sigurd Int.	48.9	6.00	1	0.014	5	0.056	7
70	Jct. SR 6 W. of Green River*	157.9	4.24	1	0.030	1	0.079	3
80	Tooele Int.*	98.6	4.46	1	*0.006*	*N.C.*	0.075	5
80	7200 W. Int.*	111.3	4.00	1	0.009	6	0.083	2
80	Coalville Int.	162.6	5.37	1	0.014	4	0.062	6
84	Mtn Green Int.	92.4	4.36	1	0.016	3	0.077	4

"N.C." denotes a crash rate that was not critical.

*Also identified as critical in Table 4-10.

4.3.2 Urban

Urban crashes occurred with greater frequency than rural crashes, which can generally be attributed to higher traffic volumes and narrower medians in urban areas. This section presents the critical crash rates and critical sections for urban areas for all severities of median crossover crashes, followed by the critical crash rates and critical sections for fatal median crossover crashes.

4.3.2.1 All Crashes

Seven interchanges were identified as exceeding the critical crash rates shown in Table 4-13, and are listed in Table 4-14. The higher AADT in urban areas resulted in crash rates per million VMT being comparable to rural crash rates, but the critical crash rates per mile per year were many times greater than rural crash rates. All seven critical sections are located on I-15; one interchange is located on the north end of the St. George urbanized area, three are located in Utah County, and three are located near the Weber and Davis County line. The Washington interchange in St. George and the

1600 North/Lindon/Pleasant Grove interchange in Utah County were each only identified as critical by one crash rate.

Table 4-13. Urban Total Crash Statistics

	Crashes per Million VMT	Crashes per Mile per Year
Average Rate	0.005	0.170
Standard Deviation	0.010	0.287
Critical Rate	0.021	0.643

Table 4-14. Urban Critical Sections

Route	Interchange	Interchange Milepost	Segment Length	Crashes	Crashes per Million VMT		Crashes per Mile per Year	
					Rate	Rank	Rate	Rank
15	Washington Int.	10.9	2.00	3	0.039	2	*0.500*	*N.C.*
15	Center St. Int., Orem	270.7	1.31	5	0.028	4	1.272	2
15	1600 N. Int./Lindon/ Pleasant Grove	272.9	1.60	4	*0.019*	*N.C.*	0.836	5
15	W. American Fork Int./Main St.	278.6	1.57	5	0.026	5	1.062	3
15	Syracuse Int./ SR 108	332.9	1.24	3	0.023	6	0.806	6
15	Riverdale Rd Int.	339.1	0.88	4	0.057	1	1.515	1
15	31st St. Int., Ogden	342.0	1.44	4	0.032	3	0.929	4

“N.C.” denotes a crash rate that was not critical.

4.3.2.2 Fatal Crashes

Eight fatal crashes occurred at seven interchanges during the three-year study period. All of these interchanges were identified as critical interchanges during the statistical analysis. Six of the interchanges were on I-15, and the other was on I-215 near the I-80 interchange. Three of the interchanges were also identified as critical in the overall crash rate analysis. The crash statistics are shown in Table 4-15, and the critical sections are identified in Table 4-16. The critical fatal crash rate for crashes per million VMT is about half the critical rate for rural crashes, while the fatal crash rate for crashes per mile per year is nearly quadruple the rural crash rate. Again, this can likely be attributed to high AADT values.

Table 4-15. Urban Fatal Crash Statistics

	Fatal Crashes per Million VMT	Fatal Crashes per Mile per Year
Average Rate	0.001	0.019
Standard Deviation	0.002	0.073
Critical Rate	0.004	0.139

Table 4-16. Urban Fatal Critical Sections

					Fatal Crashes per Million VMT		Fatal Crashes per Mile per Year	
Route	Interchange	Interchange Milepost	Segment Length	Crashes	Rate	Rank	Rate	Rank
15	12th S. Int./ University Parkway	269.1	1.81	1	0.004	7	0.185	7
15	1600 N. Int./ Lindon/ Pleasant Grove*	272.9	1.60	1	0.005	6	0.209	6
15	W. American Fork Int./ Main St.*	278.6	1.57	1	0.005	5	0.212	5
15	600 N. Int.	309.3	1.12	1	0.009	3	0.298	3
15	Jct. SR 273, Kaysville	328.7	1.68	2	0.011	2	0.397	1
15	N. Layton Int./ SR 232	331.6	1.43	1	0.007	4	0.233	4
215	I-80 Southbound Ramp	1.5	0.96	1	0.012	1	0.347	2

"N.C." denotes a crash rate that was not critical.
*Also identified as critical in Table 4-14

4.4 Recommendations

Recommendations are presented in this section by rural and urban area for the appropriate type of median barrier installation, if any, for each interchange identified as a critical crash location. Since some critical sections only experienced one crash during the study period, continued monitoring for future trends may be recommended. Several sites in the urban areas have had median barriers installed since the study period, and therefore are expected to have experienced a decrease in median crossover crashes in the years since the barrier was installed. The limited recommendations provided in this section reflect the view of the author and not the official views or policies of UDOT. As such, UDOT representatives should review these recommendations and accompanying justification and make their own conclusions based on the results.

4.4.1 Rural

Of the 16 interchange locations identified as exceeding the critical crash rate shown previously in Table 4-9, six interchange locations observed only one crash within the interchange functional area. For these interchanges, continued observation is recommended along with further evaluation once addition data are available. Table 4-17 outlines recommendations for barrier installations at the remaining 10 interchanges. All of the medians in the critical sections were observed to be between 30 feet and 50 feet wide, therefore three-strand cable barrier is recommended as the most cost effective form of mitigation for the rural interchanges with flat terrain and no current median barriers.

Since no rural interchange experienced more than one fatal crash during the three-year period, no barrier installations are currently recommended based on fatal crash rates. However, it is recommended that the sites be monitored for future crashes and reevaluated as additional data become available.

Table 4-17. Recommendations for Rural Critical Sections

Route	Interchange	Interchange Milepost	Existing Median Type	2005 AADT	Recommendation
15	Black Ridge Int./ Ranch	36.8	Grade separated and flat with median barrier	19,560	No additional barrier needed
15	New Harmony Int.	42.2	Flat and open	20,185	Install three-strand cable barrier
15	N. Beaver Int.	111.8	Flat and open	16,140	Install three-strand cable barrier
15	N. Ogden Int./ 450 N./ Harrisville	346.7	Flat with median barrier	47,900	No additional barrier needed
15	Plain City/27th N./ Farr West/ Pleasant View	349.4	Flat with median barrier south of interchange	41,645	Install three-strand cable barrier north of interchange
15	N. Willard Int.	357.6	Flat and open	37,690	Install three-strand cable barrier
80	Tooele Int.	98.6	Flat and open	33,685	Install three-strand cable barrier
80	7200 W. Int.	111.3	Flat and open	26,885	Install three-strand cable barrier
80	Summit Park Int./ Parley's Summit	139.4	Grade separated and moderately sloped	44,760	Install three-strand cable barrier if slope is sufficient, or install W-beam barriers
84	Howell Int.	26.6	Flat and open	7,945	Install three-strand cable barrier

4.4.2 Urban

Seven interchanges were identified as exceeding the critical crash rates and were listed previously in Table 4-14. Of these, the six in the Provo/ Salt Lake City urbanized area have had median barriers installed as part of interstate reconstruction projects since the end of the study period in 2005. Three-strand cable median barriers were installed during the three-year study period around the Center St., Orem, 1600 North/Lindon/ Pleasant Grove, and West American Fork/Main St. interchanges. The majority of the crashes that occurred during the study period occurred before the barriers were installed. Since that time, however, the roadway has been widened and concrete median barriers have been installed. Therefore, no further remediation is recommended at this time.

The Washington interchange in the St. George urbanized area, according to pictures from the UDOT Roadview Explorer dated 27 June 2007, has not had median barriers installed (UDOT 2008a). The medians on both sides of the interchange are fairly flat and approximately 40 feet wide. Therefore, three-strand cable median barrier is recommended to protect the medians around the Washington interchange.

All seven of the urban interchanges identified as critical interchanges in terms of fatal crash rates presented previously in Table 4-16 currently have median barriers in place. No further remediation in recommended at this time.

4.5 Results Summary

Overall crash characteristics based on data collected from 1992 through 2005 were presented and discussed, including driver characteristics, site characteristics, temporal distribution of crashes, and crash severity. Crashes in the vicinity of interchanges were then addressed. Rural median crossover crashes occur with the same distribution as all types of crashes, while urban median crossover crashes occur further from interchanges than other types of crashes. Based on a three-year analysis encompassing the years 2003 through 2005, 37 critical sections were identified and recommended remediation measures were proposed. The limited recommended remediation measures reflect the view of the author and not the official views or policies of UDOT.

5 CONCLUSIONS

The preceding chapters have outlined the background of median crossover crash studies and barrier warrants in the United States, as well as addressed median barrier types and interchange safety studies. The analysis procedure using the UDOT crash database has been set forth as well as the methods for determining the impact of interchanges on median crossover crashes and for identifying critical crash sections during the years 2003 through 2005. The results identify 37 critical segments distributed over all five interstate facilities in the state of Utah, with the majority of critical sections located on I-15. This chapter provides conclusions and outlines future research possibilities aimed at reducing median crossover crashes.

5.1 Conclusions

The results of the research indicate that median crossover crashes occur in both rural and urbanized areas. While median crossover crashes represent less than 1.0 percent of all crashes in Utah, they are responsible for approximately 8.2 percent of all fatal crashes on Utah interstates. The number of critical sections was somewhat greater in rural areas, with nine of the 10 most critical sections occurring in areas with AADT values between 19,000 and 48,000 vpd. The median crossover crash statistics calculated from Utah interstates reaffirm many median crossover crash statistics found in the literature.

For example, the severity of median crossover crashes increased sharply as the number of vehicles involved in the crash increased. Approximately 14 percent of median crossover crashes involving two vehicles were fatal, while approximately 23 percent of crashes with five or more vehicles were fatal. Similarly, 69 percent of crashes involving two vehicles resulted in at least one injury, while injury crashes made up 90 percent of crashes involving five or more vehicles.

The results of the chi-square goodness of fit analysis in Chapter 4 showed that rural median crossover crashes do not differ significantly in their distribution around interchanges compared to all types of rural crashes. While urban crossover crashes tend to occur closer to interchanges than rural crossover crashes, they occur farther from interchanges than all types of urban crashes. Overall, median crossover crashes are more likely to occur in the vicinity of interchanges, with 90 percent of urban and rural crashes occurring within 1.0 mile and 3.0 miles of an interchange, respectively.

Critical interchanges were also identified in Chapter 4. Of the 37 sections identified, 16 were rural, seven were based on rural fatal crash rates, seven were urban, and seven were based on urban fatal crash rates. Locations with only one crash during the 2003 through 2005 study period were recommended for further study as additional data becomes available, including all rural segments identified as critical due to fatal crash rates. Three-strand cable barrier was determined to be the most appropriate for the remaining eight rural critical interchanges that do not presently have barriers installed. Only one critical urban segment has not had median barriers installed since the end of the study period, and three-strand cable barrier is also recommended for that site since the median is wide and flat. All urban segments identified as critical due to fatal crash rates have had median barriers installed since the end of the study period. It is important to note that these limited recommendations reflect the view of the author and not the official views or policies of UDOT.

5.2 Future Research

Future research is highly recommended for the area of median crossover crashes in Utah and median crossover crashes in the vicinity of interchanges. As the population in Utah continues to increase, medians will likely be narrowed to allow additional interstate lanes, and crash rates will likely increase. The urban areas analyzed in this study will expand, and more miles of barrier will be needed. Further research would also be beneficial in analyzing the impact of the median barriers that have been installed on Utah interstates since the conclusion of this study to determine the effectiveness of those barriers. Finally, more data from more states would allow for a more accurate analysis of median crossover crashes in the vicinity of interchanges to determine if the conclusions drawn in this study are valid in other jurisdictions.

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APPENDIX A: CHI-SQUARE TESTS RESULTS

Table A-1. Rural Chi-square Test Results

Starting Milepost	Ending Milepost	Expected Distribution	Observed Count	Expected Count	Chi-square Statistic
0.00	0.00	0.45%	1	1	0.00
0.01	0.25	14.56%	26	32	1.19
0.26	0.50	12.15%	25	27	0.13
0.51	0.75	10.77%	33	24	3.55
0.76	1.00	8.95%	25	20	1.37
1.01	1.25	7.92%	22	18	1.16
1.26	1.50	6.47%	11	14	0.76
1.51	1.75	5.71%	7	13	2.50
1.76	2.00	4.63%	12	10	0.31
2.01	2.25	4.32%	10	10	0.02
2.26	2.50	3.81%	12	8	1.53
2.51	2.75	2.62%	10	6	3.07
2.76	3.00	2.48%	3	5	1.13
3.01	3.25	2.07%	9	5	4.28
3.26	3.50	2.07%	2	5	1.46
3.51	3.75	1.34%	2	3	0.31
3.76	4.00	1.40%	3	3	0.00
4.01	4.25	1.07%	1	2	0.78
4.26	4.50	1.05%	1	2	0.74
4.51	4.75	0.72%	0	2	1.60
4.76	5.00	0.48%	2	1	0.83
5.01	5.25	0.61%	1	1	0.09
5.26	5.50	0.51%	0	1	1.12
5.51	5.75	0.55%	2	1	0.50
5.76	6.00	0.37%	1	1	0.04
6.01	6.25	0.33%	0	1	0.74
6.26	6.50	0.30%	0	1	0.66
6.51	6.75	0.25%	0	1	0.55
6.76	7.00	0.16%	0	0	0.36
7.01	7.25	0.11%	0	0	0.24
7.26	7.50	0.11%	0	0	0.25
7.51	7.75	0.11%	0	0	0.24
7.76	8.00	0.10%	0	0	0.23

Table A-1. (cont.)

Starting Milepost	Ending Milepost	Expected Distribution	Observed Count	Expected Count	Chi-square Statistic
8.01	8.25	0.09%	0	0	0.19
8.26	8.50	0.07%	0	0	0.15
8.51	8.75	0.13%	0	0	0.28
8.76	9.00	0.05%	0	0	0.10
9.01	9.25	0.02%	0	0	0.04
9.26	9.50	0.03%	0	0	0.06
9.51	9.75	0.02%	0	0	0.04
9.76	10.00	0.04%	0	0	0.08
10.01	10.25	0.05%	0	0	0.12
10.26	10.50	0.02%	0	0	0.05
10.51	10.75	0.03%	0	0	0.07
10.76	11.00	0.03%	0	0	0.07
11.01	11.25	0.03%	0	0	0.07
11.26	11.50	0.05%	0	0	0.12
11.51	11.75	0.04%	0	0	0.09
11.76	12.00	0.03%	0	0	0.06
12.01	12.25	0.03%	0	0	0.07
12.26	12.50	0.03%	0	0	0.08
12.51	12.75	0.04%	0	0	0.08
12.76	13.00	0.03%	0	0	0.07
13.01	13.25	0.03%	0	0	0.07
13.26	13.50	0.03%	0	0	0.06
13.51	13.75	0.03%	0	0	0.06
13.76	14.00	0.03%	0	0	0.08
14.01	14.25	0.02%	0	0	0.04
14.26	14.50	0.03%	0	0	0.06
14.51	14.75	0.02%	0	0	0.05
14.76	15.00	0.03%	0	0	0.06
15.01	15.25	0.03%	0	0	0.07
15.26	15.50	0.05%	0	0	0.11
15.51	15.75	0.03%	0	0	0.07
15.76	16.00	0.03%	0	0	0.06
16.01	16.25	0.04%	0	0	0.10
16.26	16.50	0.02%	0	0	0.04
16.51	16.75	0.03%	0	0	0.06
16.76	17.00	0.03%	0	0	0.06
17.01	17.25	0.01%	0	0	0.03
17.26	17.50	0.01%	0	0	0.03
17.51	17.75	0.02%	0	0	0.04
17.76	18.00	0.03%	0	0	0.06

Table A-1. (cont.)

Starting Milepost	Ending Milepost	Expected Distribution	Observed Count	Expected Count	Chi-square Statistic
18.01	18.25	0.01%	0	0	0.02
18.26	18.50	0.02%	0	0	0.04
18.51	18.75	0.01%	0	0	0.03

Statistic	DF	Value	Probability
Chi-square	75	34.91	0.99998

Table A-2. Urban Chi-square Test Results

Starting Milepost	Ending Milepost	Expected Distribution	Observed Count	Expected Count	Chi-square Statistic
0	0	1.98%	5	9	1.68
0.01	0.25	44.13%	144	197	14.18
0.26	0.5	26.15%	124	117	0.47
0.51	0.75	15.22%	68	68	0.00
0.76	1	7.02%	61	31	28.14
1.01	1.25	2.48%	18	11	4.35
1.26	1.5	1.32%	13	6	8.66
1.51	1.75	0.85%	7	4	2.73
1.76	2	0.43%	4	2	2.29
2.01	2.25	0.22%	1	1	0.00
2.26	2.5	0.05%	0	0	0.23
2.51	2.75	0.02%	0	0	0.11
2.76	3	0.01%	0	0	0.06
3.01	3.25	0.01%	0	0	0.04
3.26	3.5	0.01%	0	0	0.04
3.51	3.75	0.03%	0	0	0.14
3.76	4	0.01%	0	0	0.05
4.01	4.25	0.01%	0	0	0.06
4.26	4.5	0.02%	1	0	12.58
4.51	4.75	0.03%	0	0	0.13

Statistic	DF	Value	Probability
Chi-square	19	75.92	9.278×10^{-9}