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Analyzing the Effectiveness of Safety Measures Using Bayesian Methods

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Analyzing the Effectiveness of Safety Measures
Using Bayesian Methods

Daniel J. Thurgood

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

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ABSTRACT

Analyzing the Effectiveness of Safety Measures

Using Bayesian Methods

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Master of Science

Recent research has shown that traditional safety evaluation methods have been inadequate in accurately determining the effectiveness of roadway safety measures. In recent years, advanced statistical methods have been utilized in traffic safety studies to more accurately determine the effectiveness of roadway safety measures. These methods, particularly hierarchical Bayesian statistical techniques, have the capabilities to account for the shortcomings of traditional methods. Hierarchical Bayesian modeling is a powerful tool for expressing rich statistical models that more fully reflect a given problem than a simpler model could.

This paper uses a hierarchical Bayesian model to analyze the effectiveness of two types of road safety measures: raised medians and cable barriers. Several sites where these safety measures have been implemented in the last 10 years were evaluated using available crash data. This study analyzes the effectiveness of raised medians and cable barriers of roadway safety by determining the effect each has on crash frequency and severity at selected locations. The results of this study show that the installation of a raised median is an effective technique to reduce the overall crash frequency and severity on Utah roadways. The analysis of cable barriers showed that cable barriers were effective in decreasing cross-median crashes and crash severity.

Keywords: Bayesian, cable barriers, raised medians, safety, transportation

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1 INTRODUCTION

The importance of transportation safety continues to be highly emphasized by the United States Department of Transportation (USDOT) as well as state agencies. The number of deaths on highways in the United States has remained steady over the past 15 years at approximately 40,000 fatalities per year. The Utah Department of Transportation (UDOT) has made transportation safety a high priority in recent years. UDOT has introduced several campaigns and programs in an attempt to increase awareness of traffic dangers and to reduce the number and severity of crashes on Utah roadways. While there have been great strides made in transportation and traffic safety, there are more improvements that can still be made.

1.1 Background

Transportation safety research continues to play a critical role in any state department of transportation (DOT) program. The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) are continually working to aid states in this analysis.

In recent years, advanced statistical methods have been utilized in traffic safety studies to more accurately determine the effectiveness of roadway safety measures. Traffic studies are not performed in a controlled environment such as a laboratory, but rather in the real world setting where a lot of accounted for and unaccounted for variables exist. Traditional methods lack to the capability to account for many of these variables. However, safety studies have had to continue

to rely on these flawed traditional methods due to the complexity of more effective models. Fortunately, the developments of advanced statistical software in recent years have overcome the complexity of advanced methods. These methods, particularly Bayesian statistical techniques, have the capabilities to account for the shortcomings of traditional methods.

One tool to aid in safety analysis is the Highway Safety Manual (HSM) that will be published in 2010 by AASHTO to aid in the analysis of transportation safety data (AASHTO 2010). The HSM is a huge step to beginning to implement some of these advanced techniques in traffic safety studies. The HSM was developed to incorporate the explicit role of highway safety in making decisions on roadway planning, design, maintenance, construction, and operations. Currently, there are no such widely accepted tools available for agencies responsible for managing the safety of roadways. As a result, safety considerations often carry little weight in the decision making processes.

1.2 Problem Statement

One element that can aid in the improvement of transportation safety is an increase in focused transportation safety data collection and analysis. The purpose of this research is to establish a procedure that can be used to analyze the effectiveness of safety treatments in improving roadway safety. Such a procedure will emphasize transportation safety data and the statistical analysis of that data in the development and/or implementation of new or existing analytical tools for safety analysis in the state.

1.3 Objectives

The objective of this research is to evaluate the traffic safety data collection and analysis procedures and to establish a set procedure for traffic safety data collection and analysis. To accomplish this task, this study analyzes the effectiveness of types of two roadway safety treatments: raised medians and cable barriers. An initial step for this task will include identification of necessary tools for use in crash data collection and analysis, such as standard before-after analysis, comparison group analyses, and Bayesian analyses, for both evaluating the effectiveness of safety features and in identifying high proportion areas for further analyses. It will be critical to coordinate these efforts with ongoing efforts at the FHWA level by identifying ways to use new safety analysis tools such as the soon to be released HSM.

1.4 Organization

This paper is organized into the following chapters: 1) Introduction; 2) Literature Review; 3) Site Selection; 4) Analysis Procedure; 5) Raised Median Results; 6) Cable Barrier Results; and 7) Conclusions. A References section and an Appendix follow the indicated chapters.

Chapter 2 is a literature review defining safety and how it is measured. Previous studies and methods for measuring safety are discussed such as the simple before and after approach, the empirical Bayesian method, and the hierarchical Bayesian method.

Chapter 3 provides details on the types of safety measures analyzed as well as background information on sites used in the analysis. The analysis will be performed on locations where raised medians and cable barriers have been installed on Utah roadways.

Chapter 4 documents the steps followed during the data collection and analysis for crash safety statistics. The steps are recorded in detail so that the procedure may be used for future analyses.

Chapter 5 presents the results of the raised median analyses. This includes the impacts of raised medians on overall and severe crash frequency where raised medians have been installed. Tables and figures are included to aid in the presentation of the results.

Chapter 6 presents the results of the cable barrier analyses. This includes the impacts the installation of cable barriers have had on cross-median and severe crashes frequencies on Utah roadways. Tables and figures are included to aid in the presentation of the results.

Chapter 7 provides the conclusions of the research as well as recommends future research possibilities.

Included in the Appendix section of the report is the modeling code used in the analysis.

2 LITERATURE REVIEW

A comprehensive literature review has been performed on current analysis methods used in safety evaluation. This process included researching recent safety analysis studies and determining the types of statistical tools utilized in their research. The literature review covers several different topics. First, safety is defined and methods used to measure safety are determined. Second, various characteristics of crash statistics are discussed to determine their implication on statistical methods of evaluation. Next, traditional methods of safety analysis and their benefits and deficiencies are included. Finally, modern approaches to more accurately determine the effectiveness of projects are discussed, including the use of the empirical Bayesian (EB) and hierarchical Bayesian methods.

2.1 Defining and Measuring Safety

To be able to determine the safety of a site during analysis, it is important to determine what safety is and how it is measured. This section discusses the use of crash history as a method to quantify safety, while two methods used for measuring crashes are also presented.

2.1.1 Characteristics of Crashes

Safety has both qualitative and quantitative characteristics. Qualitative characteristics can refer to how safe a driver feels on a system and are much more difficult to account for when

determining the safety of an entity. Quantitative characteristics, such as number of crashes, are easier to measure than qualitative characteristics.

The HSM defines safety as “the crash frequency and/or crash severity and collision type for a specific time period, a given location, and a given set of geometric and operational conditions” (AASHTO 2010). Roadway safety is usually defined and evaluated in terms of recorded number of crashes. Severity of crashes also plays an important role in understanding roadway safety. For example, one site may experience considerably more crashes than another, however, the second site may have a much larger proportion of severe, particularly fatal, crashes. Therefore, both frequency of crashes and severity of crashes are essential in determining the safety of a facility. In order to understand how to reduce frequency and severity, it becomes important to first understand the factors behind crashes.

2.1.2 Causes of Crashes

Crashes are a very small portion of events that occur on a transportation system. There have been numerous proposed theories that try to explain the causes of accidents or crashes. The Handbook of Road Safety Measures (Elvik and Vaa 2004) provides a more in depth look at the different proposed theories. In this research, it is sufficient to emphasize four conclusions that can be made from these various theories:

First, it is probable that all accident theories that have been proposed have an element of truth in them. However, while theories of the causes of crashes do include portions of the truth, none of the theories provide a complete understanding or explanation of why crashes occur. One of the key reasons why it is difficult to understand why crashes occur is because crashes are usually not the result of one factor, but the combination of several events, circumstances, and factors that are taken into account.

There are three categories of factors that contribute to crashes (AASHTO 2010):

1. Human - including age, judgment, driver skill, attention, fatigue, experience and sobriety, etc.
2. Vehicle - including design flaws, safety features, etc.
3. Roadway/Environment – including geometric alignment, cross-section, traffic control devices, surface friction, grade, signage, weather, visibility, etc.

The combination of multiple events can severely alter the amount of risk a driver may face. For example, imagine a deer runs in front of a driver on a rural highway. Driver A, driving during the daytime, is at considerably less risk than a Driver B, driving at night during a snowstorm. Driver A may have to deal with factors such as reaction time, stopping distance, and brake wear. Driver B would be affected by the same factors in addition to reduction in surface friction and visibility. Understanding this point helps to understand that crashes are the outcome of a vastly complex random process.

Second, there are certain trends of roadways, vehicles and drivers that make the occurrence of a crash more likely. Exactly the impact certain characteristics have on roadway safety has long been the focus of research. Difficulty arises due to the fact that some of these trends are known, while others are not.

Third, it is also important to understand that even though improvements are continually made to reduce crash frequency, no system is entirely perfect. Drivers are fallible and thus still subject to error in judgment, whether recklessly or not. This provides great difficulty in determining the effectiveness of an improvement.

Finally, even if it were possible to account for all possible factors that lead to a crash, the ability to predict a crash is not absolute. The reason is crashes are still to some extent a random event.

The key principle to understand is that understanding the nature of crashes is a vastly complex and random process when considering just the known factors. It is important to remember that there are factors that contribute to crashes that are unknown. The premature assumption might then be made that without understanding all the factors of crashes it would be extremely difficult, if not impossible, to determine the proper remedy for crashes. The Handbook of Road Safety Measures provides valuable insight in understanding the concept of the cause of accidents. The handbook states “the logic of the argument that you need to know the causes of a problem in order to solve it seems irresistible. Yet, as far as crashes are concerned, there is not necessarily a very close connection between the causes of the problem and its solution” (Elvik and Vaa 2004, p.85) The complexity of known and unknown contributing factors can be overcome through the development and use of proper statistical tools that can correctly model crash characteristics and behavior.

2.1.3 *Crash Rate*

To model crashes it first becomes necessary to define what exactly is being measured. Traditional practice has been to use crash rates as a measure of safety (Roess et al. 2004). The crash rate is the frequency of crashes adjusted to account for volume or exposure. The general relationship between crash frequency and crash rate is explained in Equation 2-1.

$$\text{Crash Rate} = \frac{\text{Average Crash Frequency in Period}}{\text{Exposure During Period}} \quad (2-1)$$

Crash rates for road segments are typically reported in crashes per million vehicle miles traveled (MVMT) or per hundred MVMT. Crash rates for intersections are typically reported in crashes per million entering vehicles (MEV). Equation 2-2 shows the crash rate equation for a section of roadway (Roess et al. 2004).

$$CR_{sec} = \frac{N}{V_{sec} \times 365 \times L} \times 10^6 \quad (2-2)$$

where: CR_{sec} = crash rate for section (in crashes per MVMT),
 N = number of crashes per year,
 V_{sec} = average annual daily traffic (AADT) of road section, and
 L = length of section (in miles)

Equation 2.3 shows the crash rate equation for intersections (Roess et al. 2004).

$$CR_{int} = \frac{N}{V_{int} \times 365} \times 10^6 \quad (2-3)$$

where: CR_{int} = crash rate for intersection (in crashes per MEV), and
 V_{int} = sum of average daily approach volumes of intersection.

When using crash rates the assumption is made that the relationship between frequency and exposure is linear. Recent studies have shown that this assumption is not always valid (Hauer et al. 2002). It has been determined that the use of crash frequency is a more accurate indicator of roadway safety than the use of crash rates. Research shows that the relationship

between traffic volume and crash count is more complex and relates to quantities such as the distribution of traffic through the day and the types of crashes experienced. Some studies have indicated that there is indeed a relationship between the number of crashes and the traffic volume (Miaou 1994). The exact form, however, is still unknown and likely depends on crash type. Models using aggregate data and exposure (not separated by crash type) as inputs ignore significant variation in highway crashes resulting from hourly volume changes and human behavioral changes throughout the day. A study performed using disaggregate data (crashes broken down by type) revealed how the relationship between crashes and traffic volumes varies from location to location and by crash type (Qin et al. 2004). New approaches are also being developed for incorporating traffic volumes in crash rate analysis and forecasting studies (Ivan 2004).

2.1.4 Crash Frequency

One solution to the problem with the lack of linearity in the relationship to frequency and exposure in crash studies is the use of crash frequency rather than crash rates as the fundamental basis for safety analysis and measurement of treatment effectiveness (AASHTO 2010). The use of crash frequency as a measure of safety eliminates the inclusion of exposure altogether. A crash frequency is obtained by counting the number of crashes at a certain site of interest, usually a roadway segment or intersection, over a certain period of time.

In summary, safety is measured by the frequency and severity of crashes on a roadway or at a facility. There are many known and unknown factors that contribute to the difficulty in understanding why crashes occur. This difficulty can be overcome through the use of the proper statistical tools. In order to properly perform analysis on crash statistics, it is essential to analyze the characteristics of crash statistics so as to determine the proper statistical tools to use.

2.2 Characteristics of Crash Statistics

This section provides an understanding of the characteristics of crash statistics that can later be used to determine the proper statistical tools that can be used for analysis. Misunderstanding of characteristics of crash statistics has long been the source of great difficulty in accurately predicting crash frequency. Proper understanding of the random nature of crashes, Regression-to-the-Mean (RTM) bias, and long and short-term trends, as discussed in this section, can be used more accurately model the crash behavior of a site.

2.2.1 Crashes as Random Events

In Section 2.1 various contributing factors of crashes were examined. One of the key discoveries from that examination was that crashes, while there are trends and factors that increase the likelihood of crashes, are still not completely predictable. One of the reasons crashes are not completely predictable is that crashes, by nature, are still random events. As such the frequencies of crashes will naturally fluctuate from year to year. The random nature of crashes must be considered during analysis because it presents a problem when performing studies using a short-term period. It would be nearly impossible to determine if the short-term values are representative of the long-term behavior of the site (AASHTO 2010).

Fluctuations in crash frequency make it difficult to determine whether a reduction in number of crashes is a result of a specific treatment, changes in site conditions over time, or a result of the natural fluctuations due to the random nature of crashes. This phenomenon is referred to as RTM bias.

2.2.2 Regression-to-the-Mean Bias

The RTM phenomenon expects that a value that is determined to be extreme will tend to regress to the long term average over time as illustrated in Figure 2-1. This means that a period of high crash frequencies at a site is statistically probable to be followed by a period of low crash frequencies (Hauer 1997). RTM bias refers to selection of a site as a result of the short term trend it exhibits, thus not taking into account the RTM. One of the many problems with many current practices in safety analysis is that they do not account for the RTM bias.

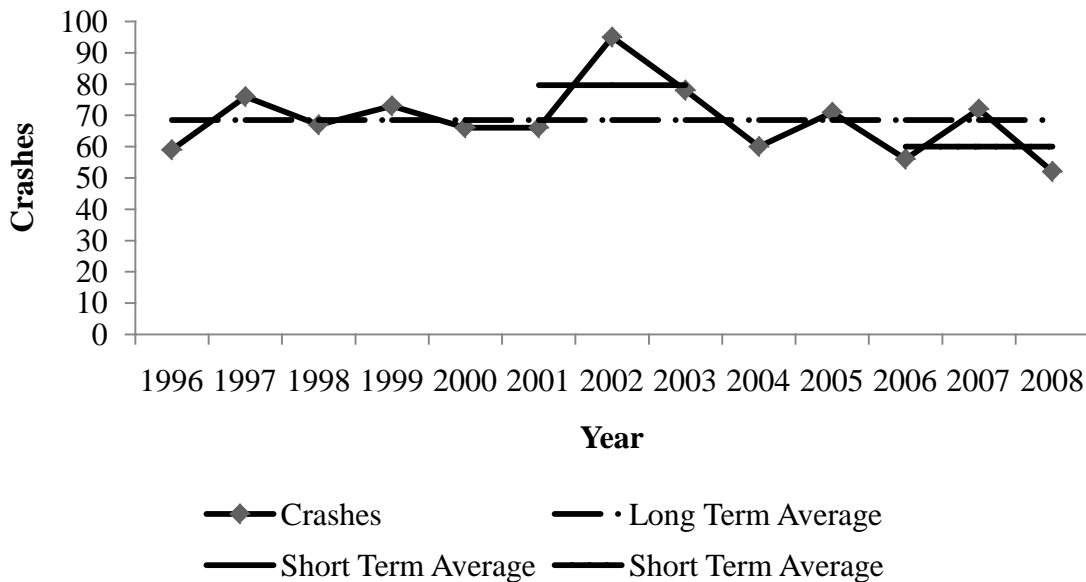


Figure 2-1. Variation in Short-Term and Long-Term Crash Frequency.

In Figure 2-1 the observed crash frequency of a specific site is plotted over the course of a long term, in this case 19 year, period. The expected average crash frequency line represents the actual crash behavior of the site. The short term average crash lines represent the value of the crash frequency if only those respective short term windows were used in the estimation. As

is evident from the figure, the average crash frequency estimation could be considerably higher or lower than the expected average crash frequency if only short term periods are used in the estimation (Hauer 1997).

If RTM bias is not accounted for, it could lead to inaccurate reporting of the effectiveness of a specific treatment. Discovered findings of a treatment at a site may lead to an overestimation of underestimation of the effectiveness of a specific treatment due to the natural fluctuation in the long term statistical characteristics of a site. Figure 2-2 shows the difference between the perceived reduction in crashes when RTM bias is not accounted for and the actual reduction in crashes when RTM is accounted for.

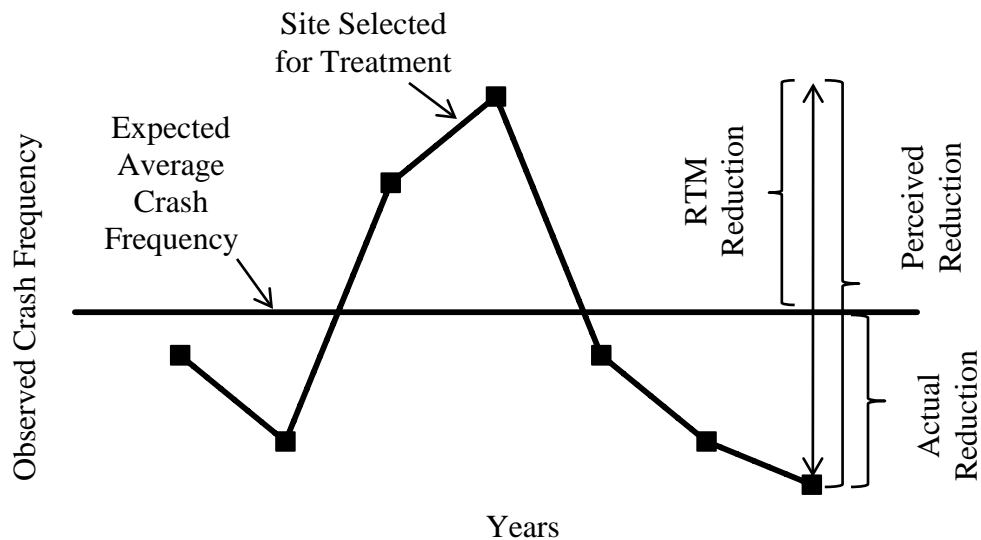


Figure 2-2. Perceived vs. Actual Reduction (adapted from AASHTO 2010).

2.2.3 Conflict between the Use of Short-Term and Long-Term Periods in Analysis

The RTM bias provides evidence of dangers when using short-term data for analysis. This would lead to the assumption that using data for longer periods provides a better

representation of crash behavior at a site. However, there are problems associated with this method as well. The characteristics of a site, such as traffic volume, weather, and pavement condition change over time. Some of these characteristics, such as weather, continually fluctuate with time. Other factors, such as pavement condition, roadway markings, etc. deteriorate gradually over years of use. These latter factors create a legitimate danger when using long-term crash statistics for site analysis. If longer periods of time are studied to account for RTM bias and site variation characteristics, it is probable that site characteristics have changed during that time period (AASHTO 2010).

Difficulties exist in the use of both short-term and long-term periods to predict the average crash frequency of a site. Long-term crash statistics operate on the false assumption that all contributing factors to crashes remain constant over time, while the use of short-term crash statistics fails to account for the RTM bias. If not properly accounted for these characteristics can lead to misleading results of the effectiveness of a specific treatment. Fortunately, these issues have been addressed by improvements statistical methods of analysis (Hauer 1997).

2.3 Distribution of Crash Statistics

Factors contributing to crashes can never be completely controlled or maintained, providing a large amount of difficulty in accurately predicting crashes. Traditional methods have used simple before and after approaches to analyze crash statistics. This requires simply comparing the crash frequency at an entity immediately before an improvement was made to the crash frequency directly after the improvement to determine the effectiveness of the treatment (Hauer 1997).

2.3.1 *Crashes as Counts*

A common mistake when performing a statistical analysis on crash data is to model crash data as continuous by using traditional methods such as standard least squares regression. This is incorrect because these types of models can produce results that are non-integers or negative which is inconsistent with count data (Washington et al. 2003). Crash data are statistically classified as count data and by nature are non-negative integers. Therefore generalized linear models are insufficient because the assumption that the dependent variable is continuous is not true for crash studies (Liu et al. 2008). It then becomes essential to use a different type of analysis when analyzing count data.

2.3.2 *Poisson and Negative-Binomial Distribution*

Previous studies have suggested the use of Poisson models or Negative-binomial models are more appropriate for count statistics. However, one of the basic assumptions to the Poisson distribution is that both the mean and the variance are equal. Recent research has shown that in crash studies the variance often exceeds the mean (Liu et al. 2008). In this case, the data are said to be overdispersed, which is a major complication when using the Poisson assumption. One of the ways to address this complication is to use a variation of the Poisson distribution called the Negative-binomial distribution which accounts for the overdispersion parameter (Bonneson and McCoy 1993). The larger the overdispersion parameter, the more the crash data vary as compared to the Poisson distribution. The various methods discussed further in this research are based on the assumption that crash statistics follow the Negative-binomial distribution.

2.4 Predicting Crash Frequency

When performing any type of analysis of the effectiveness of a treatment on the safety of an entity it is not only important to determine what the result was, but also what the result would have been had the treatment not been implemented (AASHTO 2010). Determining what result actually occurred is a relatively simple task that can usually be done by observational analysis. However, it is difficult predicting what would have happened had the treatment not been implemented at a site. It is even more difficult to predict what would have happened to a site if the treatment had been implemented, but was not. Since it is impossible to determine the effect of something that didn't happen by observation, statistical models have been used to estimate the result. This section describes types of statistical tools useful in creating the aforementioned estimation including the development of Safety Performance Functions (SPFs), Crash Modification Factors (CMFs), and local calibration factors.

2.4.1 *Safety Performance Functions*

One method of predicting the average crash frequency of an entity requires the development of SPFs. SPFs are developed through statistical regression modeling using historic crash data collected over a number of years at sites with similar roadway characteristics (AASHTO 2010). SPFs use characteristics particular to each site, such as Average Annual Daily Traffic (AADT) and segment length to create an estimate the average crash frequency for a specified facility type.

The regression coefficients used in the SPFs are determined based the assumption that the data follows a Negative-binomial distribution. As stated previously, the Negative-binomial distribution is an extension of the Poisson distribution that accounts for differences between the

mean and variance. When the variance exceeds the mean, the data are said to be overdispersed. Studies have shown that this is often the case when dealing with crash data (Hauer et al. 2002). The degree of overdispersion is represented by an overdispersion parameter. This is estimated along with the regression coefficients in the Negative-binomial model. The larger the value of the overdispersion parameter, the more the data varies compared to the Poisson distribution.

Until recently one of the major deficiencies of SPFs is that they need to be derived for each site. Recent research has helped derive some of these for different facility types, some of which are covered in the HSM. In the first edition of the HSM SPFs have been developed for three facility types (AASHTO 2010):

1. Rural Two-Lane Two-Way Roads
2. Rural Multilane Highways
3. Urban and Suburban Arterials.

And for three site types:

1. Signalized Intersections
2. Unsignalized Intersections
3. Divided and Undivided Roadway Segments

Methods for additional facility types will be added to later editions of the HSM as future research is performed. As these become more widely available, the methods outlined in the HSM will become much simpler to use. Agencies with sufficient expertise may develop SPFs

unique to their jurisdiction but it is not a requirement for the method outlined in the HSM. Alternatively, the model can be calibrated to imitate local conditions using calibrations factors which will be discussed further in later sections of the literature review.

2.4.2 *Crash Modification Factors*

The CMF is the ratio of the expected crash frequencies under two different conditions. The expected average crash frequency with base conditions represents the value based on the conditions the CMF was based on. The expected average crash frequency with condition 'x' represents the expected crash frequency when a specific characteristic of interest differs from the base condition while all other characteristics remain constant. Therefore, the CMF represents the relative change in crash frequency due to a change in one specific characteristic, while all others are being held constant (AASHTO 2010). Equation 2-4 illustrates the calculation of a CMF.

$$CMF = \frac{\text{Expected Average Crash Frequency with Condition 'x'}}{\text{Expected Average Crash Frequency with Base Conditions}} \quad (2-4)$$

To help illustrate how a CMF is calculated, consider the following example: The CMF value is sought for the effect in increase in lane width. For the purposes of this example, assume that the expected crash frequency before the change was 100 crashes per year and the expected crash frequency after the change was 90 crashes per year. Using equation 2-4, the value of the $CMF = 90/100$ or 0.90.

CMFs may serve as an estimate to the effectiveness of a specific type of design, control feature, or treatment. If a particular site has a specific design feature or treatment that results in an CMF greater than 1, by definition the crash frequency of the site is greater than it would have

been had the site not had that feature or treatment. Conversely, if the CMF is less than 1, then the site experiences a reduction in crash frequency as a result of the treatment. Finally, a CMF value equal to 1 implies that the treatment of feature had no effect.

The CMF can also be used to determine the expected percentage reduction (or increase) in crash frequency using Equation 2-5 (AASHTO 2010):

$$\text{Percent Reduction in Crashes} = 100 \times (1.0 - CMF) \quad (2-5)$$

Consider the previous example of a proposed change in lane width. Previously, the CMF was calculated to be 0.90 using equation 2-4. Inputting this value into equation 2-5 yields an expected percent change of $100 \times (1.0 - 0.90) = 10$ or a 10 percent reduction in the average crash frequency.

SPFs are multiplied by the CMFs to account for the unique characteristics of a specific site. The HSM assumes that CMFs can be multiplied together to estimate the effect of multiple treatments or characteristics. This is based upon the assumption that the effects of treatments or characteristics are independent from one another. The HSM acknowledges that this assumption may or may not be valid. Due to limited research done regarding independence of treatments, the HSM follows this assumption until more research is performed. Various uses of CMFs are discussed in Chapter 3 of the HSM (AASHTO 2010).

2.4.3 *Local Calibration Factor*

One of the critical steps in the HSM method is to include locally calibrated factors to adjust the base model for each site type to local crash tendencies. Jurisdictions can vary widely

in climate, driver demographics, crash reporting methods, etc. As a result, crash frequencies on similar facility types can vary from one jurisdiction to another. Calibration factors function similarly to CMFs. Multiplying local calibration factors with the crash frequency calculated by the SPF account for differences between jurisdiction and time period for the site of interest from the facility type the models are based on (Bauer et al. 2004).

While the use of SPFs and the EB method correct for previously mentioned shortcoming of traditional methods such as correcting for the RTM bias, effects related to changes in demographics, weather, and other characteristics unique to each geographic jurisdiction (such as states) still need to be addressed (AASHTO 2010). This is accomplished by calibrating the model for the jurisdiction of interest using a ratio, calculated according to Equation 2-6, comparing the actual observed crash frequency of facility type with the frequency predicted using SPFs and CMFs.

$$C_i = \frac{\sum \text{observed crashes}}{\sum \text{predicted crashes}} \quad (2-6)$$

where, C_i = local calibration factor for site type i .

Crash frequencies, even with relatively similar characteristics, can vary widely between jurisdictions. This result was emphasized in research done on two-way left-turn lanes using the EB method (Lyon et al. 2008). The results of this study displayed a wide range of effects outlining a need to disaggregate analysis to determine if significant effects can be detected for specific conditions.

For roadways that experience higher crash frequencies than those SPFs are based on, calibration factor values will be greater than one, and less than one for sites that experience a

lower crash frequency. Methods for developing calibration factors to adjust SPFs to local conditions are included in the HSM. Equation 2-7 displays how local calibration factors and CMFs are combined with SPFs to more accurately predict crash frequency (AASHTO 2010).

$$N_{predicted} = N_{spf} \times (CMF_1 \times CMF_2 \times \dots \times CMF_n) \times C_i \quad (2-7)$$

where, C_i = local calibration factor.

$N_{predicted}$ = predicted crash frequency for a specific site type.

N_{spf} = predicted crash frequency under base conditions.

CMF_i = Crash Modification factor.

Combining SPFs with adjustment factors such as CMFs to adjust for differences in site characteristics, and local calibration factors to adjust for differences within jurisdictions, creates more accurate estimation of the crash frequency of a given site or facility. This approach helps to correct the uncertainty of both known and unknown factors contributing to crashes thereby reducing the amount of error.

2.5 Methods of Analysis

Several methods have been developed that more accurately determine the effectiveness of a safety measure by combining observed crash statistics with predicted values obtained by the use of SPFs, CMFs and local calibration factors. Some of those approaches include the EB approach and the HSM predictive method. In recent years, interest in the use of various Bayesian approaches in traffic safety studies have increased significantly. This section provides an overview of these different approaches.

2.5.1 Empirical Bayesian Approach

Several methods are available to model count data such as crash statistics. One of the more common methods being used in safety studies is the use of EB method of analysis. The EB approach has been demonstrably better suited to estimate safety than naive statistical methods (Hauer 1997).

The EB method combines an estimation of the crash frequency of the study site with characteristics of similar sites using SPFs to estimate the predicted number of crashes. This is combined, in Equation 2-8, with crash records at the site to create an estimate of the site-specific expected number of crashes.

$$N_{expected} = w \times N_{predicted} + (1 - w) \times N_{observed} \quad (2-8)$$

where, w = weighting factor.

$N_{expected}$ = estimate of expected average crash frequency

$N_{predicted}$ = predicted value determined by Equation 2-5.

$N_{observed}$ = observed crash frequency at the site.

The weighting factor is used to determine how much “weight” is given to the two estimate methods: the estimate derived using SPFs based on roadways with similar characteristics and the estimate of the expected number of crashes on the site of interest. The overdispersion parameter that coincides with each SPF is used in the determination of the value of the weighting factor. Therefore, the reliability of the estimation of safety depends greatly on the strength of the crash record and on the reliability of the SPF used. The weighting factor is

also used to reflect the statistical reliability of the model. The strength of the EB method is in the use of a weight that is based on sound logic and on real data (Hauer 1997). Equation 2-9 shows how the weighting factor is calculated.

$$w = \frac{1}{1+k \times (\sum_{all\ years} N_{predicted})} \quad (2-9)$$

where, k = overdispersion parameter of the associated SPF used to determine $N_{predicted}$

$N_{predicted}$ = predictive model estimate determined using Equation 2-5.

The EB method addresses two problems encountered when performing safety estimation analysis: First, it corrects for the previously mentioned RTM bias by determining the expected crash frequency of an entity. The elimination of the RTM bias is important whenever the safety of a site is estimated partially or completely by crash history at the site. Second, it also can use crash data older than the traditionally used three year period (Hauer 1997).

The EB method does suffer from several deficiencies. Perhaps most unfortunate among those is the need to spend time, resources, and effort on the estimation of SPFs required for implementation of the EB method. Another major disadvantage of the EB approach is that the SPF is estimated using an aggregate crash data for more than a year. Therefore, to accurately apply this model, the units of crash frequencies per three years needs to be maintained, (i.e., annual crash data cannot be used in place of three year aggregated data) (Powers and Carson 2004). The EB method is also only applicable when both predicted and observed crash frequencies are available for a roadway network.

2.5.2 *HSM Predictive Method*

The HSM produces a step-by-step guide to estimating crash frequencies at a site using the EB method. The functions used in the predictive methods discussed in the HSM are based on Negative-binomial distribution. The HSM predictive method combines the SPFs, CMFs, and local calibration factors to predict the expected crash frequency of an entity. These can then be used independently or as part of the EB method. Various additional studies have been done to aid in developing methods for evaluating safety impacts of highway projects using the EB approach (Al Masaeid et al. 1993).

2.5.3 *Hierarchical Bayesian Approach*

In recent years, a full or hierarchical Bayesian approach has been suggested as a useful alternative to the EB approach. Though more complex, the hierarchical Bayesian approach has several advantages over the EB approach in that it is believed to require less data for untreated reference sites, it better accounts for uncertainty in data used, and it provides more detailed causal inferences and more flexibility in selecting crash count distributions (Persaud et al. 2010). Additionally, the EB approach has been criticized for its inability to incorporate uncertainties in the model parameters. The EB approach assumes the parameters are error free and can be replaced simply by their estimates for the posterior analysis. These limitations can be overcome with the use of the flexible modeling associated with the hierarchical Bayesian method (Sloboda 2009).

The hierarchical Bayesian approach has many advantages over the EB approach. In a hierarchical Bayesian analysis, prior information and all available data are integrated into posterior distributions from which inferences can be made from. Therefore, all uncertainties are

accounted for in the analyses. Hierarchical Bayesian methods may well be less costly to implement and may result in safety estimates with more realistic standard errors (Carriquiry and Pawlovich 2004). A study performed by Iowa State University argues that by using a hierarchical Bayesian approach it is possible to improve on the prediction of the expected number of crashes at a site while at the same time avoiding the need to obtain estimates of SPFs or CMFs (Carriquiry and Pawlovich 2004).

One important difference between hierarchical Bayesian and the EB approach is the manner which the model parameters are determined. In the EB approach, model parameters are dependent on the data only. Model parameters are estimated using techniques involving the use of crash data such as the maximum likelihood technique. In the hierarchical Bayesian approach, the parameters of the prior distributions are fixed by modelers. The hierarchical Bayesian approach is normally implemented using hierarchical Poisson Bayesian models. There has been increased interest in this approach over the past few years due to the modeling flexibility associated with this approach (Sloboda 2009).

The hierarchical Bayesian method was applied to evaluate the safety effect of conversion from stop to signalized control at rural intersections in California. The results were then compared with those from the EB method and it was found that the hierarchical Bayesian method can provide similar if not better results as EB approach (Lan et al. 2009).

2.6 Chapter Summary

Effectiveness evaluation is an important component of determining the overall impact of a treatment on a project as well as assessing how well funds have been invested in safety improvements. Evaluating the change in crashes from implemented safety treatments leads to an

assessment of the effectiveness of a specific treatment on reducing crash frequency or severity. Simple before and after analysis of crash data are usually insufficient in determining the actual effect of a treatment. These types of studies are based on the incorrect assumption that all factors other than the treatment remain unchanged over the course of the evaluation. Simple before and after studies fail to take into consideration factors such as the RTM bias, changes in climate and land use that occur over time and other factors that can impact results. Improved methods in estimating the effects of a specific treatment using Bayesian analysis methods greatly improve the ability to accurately determine the effectiveness of the treatment.

3 SITE SELECTION

In this report, the safety data collection and analysis techniques developed are applied to two types of safety mitigation devices: raised medians and cable barriers. Before conducting a detailed crash analysis, the study area must be defined. The locations that have been selected for analysis where raised medians and cable barriers have been installed are discussed in this section. For crash analysis purposes, the study area will be roadway segments where raised medians or cable barriers have been installed during the past 10 years. This section describes the background steps taken for the selection of sites to be used in the analysis as well as a summary of sites selected for raised median and cable barrier analysis.

3.1 Site Selection Background

The process for site selection included identifying locations where raised medians have been installed on Utah roadways. The locations where raised medians and cable barriers have been installed were identified using previous safety studies (Schultz and Lewis 2006), UDOT project records, as well as online resources such as Google Maps (Google 2010). Possible sites were limited to locations where before and after crash data were available at the time of this study.

One of the difficulties in site selection was the accuracy of mile posts on Utah roadways. Mile posts on Utah roadways have been altered several times over the past 10 years to account for various roadway improvement and changes in alignment. UDOT is currently working to

establish and maintain a continually updated database of mile postings on Utah roadways. Sites where uncertainty of reporting accuracy existed have been excluded from selection. For example, US-89 is a major north-south corridor through Utah that has raised medians installed on multiple segments. However, mile postings along the route have changed repeatedly over the past 10 years and reliability is insufficient. Mile posts of sites that have been selected for analysis have been verified by UDOT to ensure any and all changes have been accounted for.

In order to perform an analysis on the impact of raised medians, the year in which the medians were installed needed to be determined. Installation dates at selected sites were determined by previous raised medians studies in the state, UDOT records, or by utilizing UDOT's Roadview Explorer tool (UDOT 2010). This tool is located in the Systems Planning and Programming Division at the UDOT Complex in West Valley City, UT.

3.2 Raised Medians

A raised median is a physical barrier, such as a concrete or landscaped island, in the center portion of the roadway that separates opposing lanes of traffic and is not easily traversed. Raised medians are appropriate in some, though not all locations. Raised medians are most useful on high volume, high speed roads (CTRE 2005).

The use of raised medians is an access management technique used in an effort to improve roadway safety in two ways: First, raised medians reduce the number of conflict points by allowing turning movements to be made only at designed openings or at signalized intersections. Second, raised medians provide a physical barrier separating opposing traffic aimed at eliminating the possibility of head-on collisions (TRB 2003).

Raised medians provide a pedestrian benefit, because they can serve as a place of refuge for pedestrians who cross a street midblock or at intersections. Raised medians can also be used for beautification or a traffic calming measure by providing space for landscaping changing the character of the street which, in turn, may help reduce speeds by changing the character of a street.

Raised medians are not always used to mitigate one specific type of crash or factor (CTRE 2005). Raised medians have been installed for beautification purposes, as an access management technique, and various other purposes. Regardless of the purpose, the installations of raised medians have had an impact on crash trends and patterns (TRB 2003).

The locations of the selected sites where raised medians have been installed were selected from research done previously (Schultz and Lewis 2006). An overview of each location is provided in the following subsections. Images were obtained utilizing Google Images (Google 2010).

3.2.1 University Parkway (SR 265)

University Parkway (SR 265) is a major east-west arterial through Orem and Provo illustrated in Figure 3-1. SR 265 begins on the west side of Interstate 15 at Geneva Road and terminates at 900 East in Provo on the east side. SR 265 provides access to two of Utah's Universities, Utah Valley University (UVU) and Brigham Young University (BYU), as well as a regional shopping mall and several other large businesses. In 2002 a raised median was installed in a portion of the Orem section between 400 West and 200 East.



Figure 3-1. Raised median on University Parkway (SR 265) (Google 2010).

3.2.2 Alpine Highway (SR 74)

The Alpine Highway (SR 74), illustrated in Figure 3-2, is the major north-south highway providing access to the cities of Highland and Alpine. SR 74 is a two-lane highway mostly through residential areas. In 2002, a raised median was installed on the section from 9840 North to 11300 North.



Figure 3-2. Raised median on Alpine Highway (SR 74) (Google 2010).

3.2.3 400/500 South (SR 186)

The 400/500 South segment of SR 186 is a six-lane east-west arterial through downtown Salt Lake City. SR 186 curves from 400 South to 500 South between 900 East and 1100 East. A light rail line is located in the raised median of SR 186. Construction of the raised median and light rail line was completed in 2001. The segment of raised median used in analysis, illustrated in Figure 3-3, extends from Main Street to 1300 East.



Figure 3-3. Raised median on 400/500 South (SR 186) (Google 2010).

3.2.4 12300 South (SR 71)

12300 South (SR 71) is a major east-west arterial in Draper illustrated in Figure 3-4. Due to a substantial growth of the surrounding area 12300 South received major improvements in 2004 including widening to six lanes and the installation of a raised median. The raised median segment used for analysis extends from 300 East to 265 West. A short extension west from the south end to the new SR-154 was made in 2001. The extension caused a shift in the mile posts, which was taken into consideration during analysis.



Figure 3-4. Raised median on 12300 South (SR 71) (Google 2010).

3.2.5 St. George Boulevard. (SR 34)

St. George Boulevard (SR 34) is major road through the center of St. George in southern Utah illustrated in Figure 3-5. Improvements to the road, including the installation of a raised median, were completed in 2006. The raised median extends over the entire length of the project from Bluff Street to 1000 East.



Figure 3-5. Raised median on St. George Boulevard (SR 34) (Google 2010).

3.2.6 SR 36

SR 36 is a major north-south arterial through Tooele County illustrated in Figure 3-6. SR 36 serves as the major connector for communities within Tooele County as well as surrounding cities, including Salt Lake City. A project completed in 2005 widened the roadway to two lanes in each direction and installed a raised median for a short segment in the city of Erda in north Tooele County.



Figure 3-6. Raised median on SR 36 (Google 2010).

3.3 Cable Barriers

A cable barrier is a type of roadside or median barrier. Although cable barriers have been used since the 1960s it wasn't until the mid 1990s that many DOTs began to deploy them with any regularity.

Cable barriers consist of steel wire ropes mounted on weak posts. By far, the most popular use of the cable barrier system occurs in the medians of divided highways. Given the opposing directions of traffic on divided highways, cross median crashes are particularly severe.

While median width plays a large role in the occurrence of these crashes, increased width alone does not eliminate them and quite often, the median must be shielded with a barrier. Cable barriers provide a cost-effective solution to cross median crashes. The primary purpose of cable barriers is to prevent a vehicle from leaving the traveled way, by capturing and/or redirecting the errant vehicle, and striking a fixed object particularly vehicles traveling in the opposite direction of travel. A cable barrier is typically more forgiving than traditional concrete barrier or steel barriers. The flexibility of the system absorbs impact energy and dissipates it laterally, which reduces the forces transmitted to the vehicle occupants (AASHTO 2006).

Due to the fact that cable barriers are relatively inexpensive to install and very effective at capturing vehicles, they are being used more frequently by state DOTs. In Utah, cable barriers have been installed primarily on the freeway system. The locations of the selected sites where cable barriers have been installed as outlined in the following subsections. Images were obtained utilizing Google Images (Google 2010).

3.3.1 I-15 Provo S-curves to University Parkway

The majority of the sites where raised medians have been installed in the last few years occur along Interstate 15 (I-15). I-15 is the one of the longest north–south transcontinental Interstate Highways in the United States, traveling through the states of California, Nevada, Arizona, Idaho, and Montana, and just over 400 miles through Utah. I-15 serves as the main north–south connection for the state.

This specific site is a 2 mile segment along I-15 located between the Provo S-curve and University Parkway in Utah County between mile points 267 and 269. A cable barrier was installed along this segment in 2004. Originally 5 miles of cable barrier were installed, but 3 miles of the cable barrier were replaced with a concrete barrier as part of a widening project in

2005. The remaining 2 mile segment, illustrated in Figure 3-7, retained the cable barrier and was used for analysis.



Figure 3-7. Provo S-curves to University Parkway (Google 2010).

3.3.2 I-15 between Pintura and Kolob Canyons

This site is a 2 mile segment of I-15 located in the Southern part of Utah from Cedar City and St. George. The cable barrier was installed between mile points 36 and 38, as illustrated in Figure 3-8. A cable barrier was installed along this segment in 2005. The population of cities in this portion of the State is relatively low. The majority of the traffic this segment of I-15 experiences is from long distance travelers between St. George and the Wasatch Front.



Figure 3-8. I-15 between Pintura and Kolob Canyons (Google 2010).

3.3.3 I-15 Spanish Fork to SR 75

The Wasatch Front is an urban area in the north-central part of the Utah. It consists of a chain of cities and towns stretched along the Wasatch Range from approximately Santaquin in the south to Brigham City in the north. Roughly 80 percent of Utah's population resides in this region, as it contains the major cities of Salt Lake City, Provo and Ogden.

In 2005 a cable barrier was installed in the south end of Utah County in the Southern portion of the Wasatch Front as illustrated in Figure 3-9. This section is a 4 mile segment of I-15 located this section of I-15 between Spanish Fork and SR 75 between mile points 257 and 261. This section of I-15 serves as the main connection between the communities south of Provo to the Provo-Orem area as well as various other destinations.



Figure 3-9. I-15 between Spanish Fork and SR 75 (Google 2010).

3.3.4 I-15 South Layton to Syracuse

This segment of I-15 is located in Davis County north of Salt Lake. Congestion is a significant problem in the county, as east-west transportation is restricted by the narrow urban corridor and many of its citizens commute south to Salt Lake County. In 2006 a cable barrier was installed along a 4 mile segment between mile points 330 and 334 from South Layton and Syracuse as illustrated in Figure 3-10.



Figure 3-10. I-15 between Layton and Syracuse (Google 2010).

3.3.5 *I-15 600 North to 2300 North in Salt Lake*

In 2007, a cable barrier was installed along a 3 mile segment of I-15 in the northern portion of Salt Lake between 600 North and 2300 North (mile points 309 and 312) as illustrated in Figure 3-11. This section has frequently been one of the most congested in the State as it provides primary service for commuting traffic from Salt Lake to Davis County to the north.



Figure 3-11. I-15 between 600 North and 2300 North in Salt Lake (Google 2010).

3.3.6 *I-215E 3100 South to 3800 South in Salt Lake*

Interstate 215 (I-215), also known as the Belt Route, is an auxiliary interstate in the that forms a 270-degree loop around Salt Lake City and many of its suburbs. In 2007 a cable barrier was installed along the east portion of I-215 in Salt Lake. This section is a 1 mile segment located between 3100 South and 3800 South between. The cable barrier was installed between mile points 1.5 and 2.5 as illustrated in Figure 3-12.



Figure 3-12. I-215 East between 3100 South and 3800 South in Salt Lake (Google 2010).

3.3.7 I-215W 2100 South to 4500 South Salt Lake

In 2007 a cable barrier was also installed along the west side of I-215 in Salt Lake. This section is a 2.5 mile segment located between 2100 South and 4500 South between mile points 17 and 19.5 as illustrated in Figure 3-13.



Figure 3-13. I-215 West between 2100 South and 4500 South in Salt Lake (Google 2010).

3.3.8 I-80 Lamb's Canyon Interchange

Interstate 80 (I-80) is one of the major east-west corridors through the state. It is also one of the longest east-west corridors in the country. The Utah portion of I-80 begins west of the Great Salt Lake at Wendover, passes through Salt Lake and continues through Parley's Canyon towards Wyoming. In 2007, a cable barrier was installed along a short segment of I-80 at the Lamb's Canyon interchange in Parley's Canyon east of Salt Lake. This section where the cable barrier was installed, illustrated in Figure 3-14, begins at current mile point 135.8 and ends at 136.1.



Figure 3-14. I-80 near Lamb's Canyon Interchange.

3.4 Chapter Summary

This chapter provides a summary of sites selected for analysis where raised medians and cable barriers have been installed on Utah roadways. The exact beginning and ending mileage points of the segments used in the analysis were determined to match the crashes that occurred at each selected site for each year of analysis. The year that a raised median or cable barrier was installed at each site was also determined to separate the before and after periods used in

analysis. Table 3-1 provides a summary of raised median sites used in for analysis. Table 3-2 provides a summary where cable barriers have been installed on Utah roadways.

Table 3-1. Raised Median Locations

Street	Route	Length (Mi)	Location	Year Installed
University Parkway	265	0.76	400 West to 200 East	2002
Alpine Highway	74	1.89	9840 North to 11300 North	2002
400/500 South	186	2.05	Main Street to 1300 East	2001
12300 South	71	0.90	265 West to 300 East	2004
St. George Blvd	34	1.74	Bluff Street to 1000 East	2006
SR 36	36	1.53	Erda Way to Bates Canyon Rd	2005

Table 3-2. Cable Barrier Locations

Site	Route	Length (Miles)	Location	Year Installed
1	I-15	2.0	Provo S-curves to University Parkway	2004
2	I-15	2.0	Between Pintura and Kolob Canyons	2005
3	I-15	4.0	Spanish Fork to SR 75	2005
4	I-15	4.0	South Layton to Syracuse	2006
5	I-15	3.0	600 N to 2300 N - Salt Lake	2007
6	I-215 E	1.0	3100 S to 3800 S - Salt Lake	2007
7	I-215 W	2.5	2100 S to 4500 S - Salt Lake	2007
8	I-80	0.3	Lamb's Canyon Interchange	2007

4 ANALYSIS PROCEDURE

A set procedure was followed in the analysis of data for the selected sites. The analysis provides an opportunity to estimate the safety impacts of the installation of raised medians and cable barriers in the state of Utah. Chapter 3 provides the necessary background information on the selected sites used in the analysis.

As part of the analysis, a statistical model was developed to calculate crash frequency before and after the installation of raised medians or cable barriers. The model uses Bayesian techniques to account for RTM bias and thereby more accurately determining the impacts of raised medians or cable barriers than traditional before-after studies.

This section describes the steps taken during the analysis. This includes data collection, types of analysis performed, and an outline of the development of the model. This chapter also includes a description of the analysis steps taken to determine if the installation of a raised median or cable barrier had an impact on the overall crash frequency as well as the severity of crashes at the selected critical sites.

4.1 Data Collection

The analysis for this study was performed based upon data obtained from UDOT. This section describes the steps taken in the selection and collection of data used in the development of the model including crash data, AADT data, and mile point data.

4.1.1 Crash Data

Raw crash statistics were provided by the UDOT Traffic and Safety Division from the UDOT crash database. The UDOT crash database is comprised of records and statistics obtained from police reports for crashes that occurred on all Utah roadways. At the time of this study, consistent data were available from 1996 to 2008.

The raw statistics needed to be refined to be able to extract data necessary for use in the analysis. The full data set was reduced to locations where raised medians had been installed with boundaries set by the mileage points shown previously in Table 3-1. Duplicate records as well as crashes that occurred during the installation years were removed from the dataset.

4.1.2 AADT Data

AADT data are used to measure total volume of vehicle traffic of a highway or road. Previous research has determined that a relationship exists between crashes and AADT. Although the exact relationship is still not entirely known, it is known that the relationship is generally non-linear (Hauer 1997). However, AADT is still an important parameter in predicting crash frequency and was used as a covariant in the development of the model.

AADT is collected for individual road segments on Utah roadways. AADT values were obtained using the annual Traffic on Utah Highways reports available on the UDOT website (UDOT 2008). Each annual report provides AADT on Utah roadways for the corresponding year as well as AADT values for the two previous years. Each route is broken down to section usually defined by physical barriers (county or state boundaries) or where changes in roadway characteristics occur (such as intersections or interchanges). Annual reports are available on-line

back to the year 2000. An example taken from the 2008 report (UDOT 2008) is shown in Figure 4-1.

ROUTE NAME	BEG. ACCUM. MILEAGE	END ACCUM. MILEAGE	LOCATION DESCRIPTION	2008 AADT	2007 AADT	2006 AADT
0013	24.956	31.057	SR 30 Riverside	835	860	2,470
0013	31.057	31.641	20000 North Plymouth	665	670	665
0013	31.641	32.224	20400 North Plymouth	650	670	665
0013	32.224	32.841	Road to Nucor Steel Plant - I 15	820	840	1,920
0014	0.000	0.546	SR 130 Main Street Cedar City	3,010	3,165	2,745
0014	0.546	4.961	580 East Cedar City	2,170	2,455	2,390
0014	4.961	18.172	Scenic Backway to Kolob Reservoir	1,575	1,780	860
0014	18.172	25.711	SR 148 Road to Cedar Breaks National Monument	840	890	850
0014	25.711	40.995	Navajo Lake Rd - SR 89 Long Valley	855	905	850
0015	0.000	4.660	Arizona State Line	20,415	22,505	21,930
0015	4.660	6.310	Bloomington	32,235	35,540	34,640
0015	6.310	8.660	SR 18 Bluff Street St George	24,615	27,140	40,750
0015	8.660	10.930	SR 34 St. George Boulevard	43,260	44,230	42,145
0015	10.930	13.378	SR 212 Washington	38,295	40,995	39,955
0015	13.378	15.910	Washington Parkway Interchange	36,645	40,405	39,380
0015	15.910	22.580	SR 9 Hurricane Zion National Park	19,820	21,075	20,495
0015	22.580	23.720	SR 228 South Leeds Silver Reef	19,365	20,600	20,040
0015	23.720	27.480	SR 228 North Leeds Silver Reef	20,655	21,975	21,375
0015	27.480	30.680	SR 17 Anderson Jct. Toquerville	21,170	22,520	20,725
0015	30.680	31.870	Browse Interchange	21,125	22,490	21,310
0015	31.870	33.440	Pintura	20,940	22,275	21,670
0015	33.440	36.770	Ranch Exit (Snowfield)	20,950	22,285	21,675
0015	36.770	40.270	Ranch Exit (Black Ridge)	20,835	21,105	20,530
0015	40.270	42.170	Kolob Canyons Interchange	20,415	21,580	20,990
0015	42.170	51.160	New Harmony/Kanarrville Interchange	20,610	21,795	21,190
0015	51.160	56.800	Hamilton Fort (North Kanarrville)	20,970	22,310	21,700
0015	56.800	58.850	SR 130 Main Street Cedar City	23,980	25,510	23,595
0015	58.850	62.500	SR 56 200 North Cedar City	25,140	26,745	24,185
0015	62.500	70.260	SR 130 Enoch/Minersville	18,255	19,560	19,025
0015	70.260	75.210	Summit	17,495	18,875	18,760

Figure 4-1. Example of UDOT 2008 *Traffic on Utah Highways Annual Report (UDOT 2008)*.

4.1.3 Mile Point Data

Locations of crashes are reported as the mile point where the crash occurred on the corresponding route. However, mile points on Utah highways have undergone several changes over the past 10 years. Shifts in mile posts are usually the result of either a realignment of the route, or an extension added onto the either end of the route. Although the segments of each route of interest were held constant through each analysis year, corresponding mile points have changed over the course of the study period. To ensure that data for the correct segment was

used for each analysis year, correct mile posts were verified through UDOT. A summary of changes in mile points for each analysis segment are displayed in Table 4-1.

Table 4-1. Summary of Raised Median Mile Point Changes

Route	Years	Beg MP	End MP
265	1995-2001	1.21	1.97
	2002-2009	1.20	1.96
74	1995-2009	2.40	4.29
186	1995-2001	5.50	7.55
	2002-2005	5.54	7.59
	2006-2007	5.48	7.53
	2008-2009	-	-
71	1995-2001	2.17	3.07
	2002-2005	4.56	5.46
	2006-2009	4.55	5.45
34	1995-2009	0.00	1.74
36	1995-2001	59.31	60.84
	2002-2005	59.43	60.96
	2006-2008	59.29	60.82

For the cable barrier sites, a mile point change occurred only at one of the study sites. At the I-80 Lamb's Canyon Interchange the mile points 135.8 to 136.1 reflect 2006 to current. The 2002-2005 mile points for the same section were 132.16 to 132.46. The mile points for all other sites remained unchanged during the study period. The mile points for each site were summarized previously in Table 3-2.

4.2 Type of Analysis

This section describes the types of analysis performed on location where raised medians and cable barriers have been installed in the state of Utah. An overall analysis on all crashes and a severe crash analysis on only severe crashes were performed for both raised median and cable

barrier locations. Additional analysis was performed on cross-median crashes for cable barrier sites.

4.2.1 Overall Crash Analysis

An overall crash analysis was conducted on all crashes that occurred at sites before and after the installation of cable barriers and raised medians were installed. The roadway safety assessment of a segment should consider the roadway elements (roadway type, weather), the driver (age, fatigue) and the vehicle (type, volume, speed). These safety characteristics need to be reviewed whenever a roadway analysis is performed. The crash data should be analyzed to determine the current crash trends and related traffic issues should be identified. Changes in types of crashes or contributing factors that can be attributed to the specific mitigation technique used need to be identified.

4.2.2 Severe Crash Analysis

An analysis was also performed on severe crashes that occurred where raised medians and cable barriers have been installed. Crash severity refers to the severity corresponding to the most severe of injuries sustained as a result of a crash.

One of the main goals in the installation of both raised median and cable barriers is to reduce severe crashes. As described in Chapter 3, the primary purpose of a cable barrier is to eliminate median crossover crashes. Similarly, raised medians reduce sideswipe and head-on collisions by limiting turning movements and providing a physical barrier from opposing traffic as discussed in Chapter 3. Median crossover crashes often result in fatalities or severe injuries to occupants of the errant vehicle and the motorists in the opposing traffic lanes.

According to the National Safety Council (NSC), “there are five mutually exclusive categories of injury severity for classification of road vehicle (crashes)” (NSC 1996). The five categories are fatal, incapacitating injury, non-incapacitating evident injury, possible injury, and non-injury. A common abbreviation for these severity levels is referred to as the KABCO scale, with each letter, “K” through “O”, representing fatal through non-injury levels of severity, respectively. The five severity classifications are mutually exclusive because a crash is classified based on the most severe injury (e.g., a crash with a fatality and a minor injury is classified as a fatal crash, not a fatal crash and a minor injury crash).

Severity of each crash is available from police reports that data are based on. The reporting officer codes the crash as one of the five categories mentioned above. Initially fatal crashes were an area of interest in the analysis. However, due to the limited availability of data, fatal crashes were expanded to severe crashes. Severe crashes were determined to be crashes indicated on the report as “fatal” or “incapacitating injury.”

4.2.3 Cross-Median Crash Analysis

An analysis was also performed on cross-median crashes. The cross-median analysis was performed only on locations where cable barriers have been installed. As described in Chapter 3, the primary purpose of a cable barrier is to eliminate median crossover crashes. Median crossover crashes often result in fatalities or severe injuries to occupants of the errant vehicle and the motorists in the opposing traffic lanes.

4.3 Development of Model

A set procedure was followed in the analysis of crash data for the selected sites. A hierarchical Bayesian model was constructed to perform the analysis. The development of the model was necessary to more accurately determine the impact of raised medians on crashes. The analysis procedure presents an opportunity to estimate the safety impacts of various types of treatments, particularly raised medians and cable barriers. This section outlines the development of the model by first outlining the background of the hierarchical Bayesian model, and then identifying model specification and estimation.

4.3.1 Background of Hierarchical Bayesian Modeling

In order to understand how the model utilized in this study operates, a few foundational statistical principles must be discussed. With respect to notation, denote $p(\cdot)$ as a marginal distribution and $p(\cdot | \cdot)$ as a conditional distribution. The foundation of Bayesian statistics is Bayes' rule outlined in Equation 4-1 (Gelman 2004):

$$p(\theta, y) = p(y)p(\theta|y) \quad (4-1)$$

where, y = crashes per mile

θ = mean number of crashes per mile

This equation can be rearranged and written as outlined in Equation 4-2:

$$p(\theta|y) = \frac{p(\theta, y)}{p(y)} = \frac{p(y|\theta)p(\theta)}{p(y)} \quad (4-2)$$

The distribution $p(\theta)$ denotes the prior distribution for θ . The prior, also referred to as a prior probability distribution, of an uncertain quantity p is the probability distribution that would express the uncertainty about p before the data are taken into account. It is meant to attribute uncertainty associated with that data rather than randomness to the uncertain quantity. The prior is useful in that it allows the incorporation of information available into the model before the collection of data and reflects the belief of what will happen. The distribution $p(y|\theta)$ is the likelihood of the data given the parameter θ . The conditional distribution $p(\theta|y)$ is the posterior distribution of θ given the data. The posterior distribution is used to draw conclusions in this study.

4.3.2 *Model Specification and Estimation*

A hierarchical Bayesian model was constructed for the analysis as follows. The model uses crash data and AADT data for selected analysis sites as inputs. Other covariates may also be included. It was assumed that y_i is Poisson distributed as outlined in Equation 4-3:

$$y_i \sim \text{Poisson}(\theta_i) \tag{4-3}$$

The Poisson distribution is utilized due to the nature of crash data classified as count data as discussed in Chapter 2, and are easily able to include the exposure parameter (AADT) associated with the number of miles in a given segment. The estimation of the mean number of crashes per mile is then calculated using Equation 4-4.

$$\log(\theta_i) = \beta_A I(A_i) + \beta_B (1 - I(A_i)) + \beta_1 AADT_i, \quad (4-4)$$

where, θ_i = the mean number of crashes per mile
 $AADT_i$ = AADT for the i^{th} observation
 $I(A_i)$ = an indicator variable stating whether or not the i^{th} observation was in the after period of data collection (equal to 0 for before period and 1 for after period).

This result is the consideration of two intercepts: one for the before data and one for the after data. AADT is constrained to be the same for either time period. The log transform was chosen as part of the standard Poisson regression procedures.

The prior for each β_j where $j \in \{A, B, 1\}$ is normally distributed as defined in Equation 4-5 where A represents the after period and B represents the before period.

$$\beta_j \sim Normal(0,1) \quad (4-5)$$

These priors are quite uninformative, which reflects the lack of convincing evidence to suggest more specific priors.

The posterior distribution for the β parameters is expressed in Equation 4-6.

$$\pi(\beta|y) \propto P(y|\beta)\pi(\beta_A)\pi(\beta_B)\pi(\beta_1) = \frac{\exp\left[-\sum_{i=1}^n \exp\{X_i\beta\}\right]}{\prod_{i=1}^n y_i!} \times \frac{1}{(\sqrt{2\pi})^3} \exp\left[-\frac{1}{2}(\beta_A^2 + \beta_B^2 + \beta_1^2)\right] \quad (4-6)$$

where, X_i = matrix containing the appropriate covariates to satisfy the model.
 n = total number of observations.

Due to the complexity of the posterior distribution, rather than deriving the distribution theoretically, it was determined to sample from the posterior using Metropolis Hastings under the Markov Chain Monte Carlo (MCMC) methodology. This involves beginning with initial values and sampling each of the β_k parameters one at a time from the complete conditional distributions, using the newly sampled value in ensuing complete conditional calculation. The results of the algorithm are a number of random draws from the posterior distribution for each of the β_k parameters. In this study, each site is modeled with its own set of β parameters for both overall and severe crashes. The modeling code developed for the analysis is included in Appendix A.

4.4 Chapter Summary

This chapter outlines the process used in the analysis including collection of needed data, development of model, and types of analysis performed. Data collected for the study include crash histories of Utah roadways, AADT data, and milepost data used to identify locations where raised medians and cable barriers have been installed. A hierarchical Bayesian model was constructed for the analysis. Using the model, an analysis was also performed on overall and severe crashes that occurred where raised medians and cable barriers have been installed. The overall crash analysis included all crashes that occurred at each site before and after the

installation of the specific treatment. Severe crashes were determined to be crashes indicated on the report as “fatal” or “incapacitating injury.” Severity of each crash is available from police reports that data are based on.

5 RAISED MEDIAN RESULTS

A hierarchical Bayesian analysis was performed at selected sites where raised medians have been installed following the procedure outlined in Chapter 4. An analysis was performed on both overall crash frequency and severe crash frequency where raised medians were installed.

Two types of plots are produced for each analysis performed: The first plot is a plot of the actual data. The data plots display the actual data points and the mean of the posterior predictive distribution. Essentially it represents the mean regression line through the points from a Bayesian perspective. The reduction is calculated by taking the mean of the posterior distribution of differences between the two intercepts. This is a percent reduction because $\log(\text{after/before}) = \log(\text{after}) - \log(\text{before})$, and the intercepts are on the log scale. This is equivalent essentially to taking the after curve and dividing it by the before curve and getting the percent reduction.

The second plot produced is the plot of the distribution of the differences between the before and after periods. The differences plots display the posterior distributions of differences between the before and after intercepts of the model. Negative values indicate that the after time period saw a reduction in crashes. As the exact form of those posterior distributions is unknown, the model uses simulated draws from the posterior with MCMC; since those draws represent the actual posterior distribution, the proportion of the draws less than zero represents the probability that there was a decrease in crashes from the before time period to the after time period.

5.1 Raised Median Individual Site Results

The safety impacts of the locations that have been chosen for analysis where raised medians have been installed are discussed in this section. Details about each location are provided in Chapter 3. The analysis procedure is described in Chapter 4. The following sections summarize the results of the analysis performed at each individual site where raised medians were installed based on crash data provided by UDOT as well as an overall analysis performed on all sites. Sites selected for analysis are shown in Table 5-1.

Table 5-1. Raised Median Locations

Street	Route	Length (Mi)	Location	Year Installed
University Parkway	265	0.76	400 West to 200 East	2002
Alpine Highway	74	1.89	9840 North to 11300 North	2002
400/500 South	186	2.05	Main Street to 1300 East	2001
12300 South	71	0.90	265 West to 300 East	2004
St. George Blvd	34	1.74	Bluff Street to 1000 East	2006
SR 36	36	1.53	Erda Way to Bates Canyon Rd	2005

5.1.1 University Parkway (SR 265)

In 2002 a raised median was installed in a portion of the Orem section between 400 West and 200 East. This section summarizes the results of the analysis performed before and after the raised median was installed. The before period used in the analysis is from 1998 to 2001 and the after period is from 2003 to 2008.

The results of the analysis showed Figure 5-1 shows the results of the model on overall crash frequency for SR 265. The plot displays the crash frequency of all crashes for the before and after periods as a function of AADT. The results of the analysis indicated the expected percent change after the raised median was installed was only 0.34 percent decrease as can be seen in Figure 5-1.

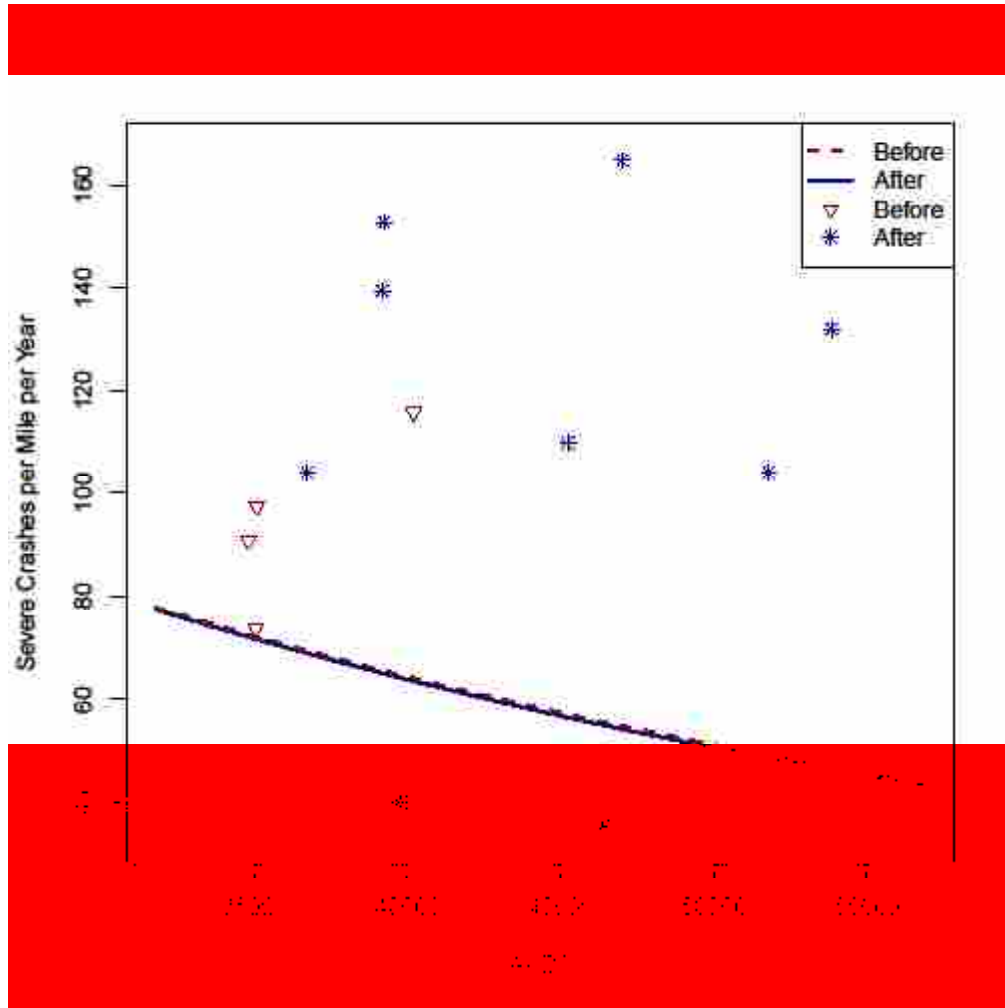


Figure 5-1. Overall Crashes on SR 265.

Figure 5-2 shows the corresponding probability distribution of the differences between the before and after periods for overall crashes for SR 265. The gray portion of the distribution

represents the probability that a decrease in overall crashes occurred. The probability a decrease in overall crash frequency occurred was 0.53 as is represented by the gray portion of Figure 5-2. Therefore it is possible this segment of University Parkway experienced no difference in overall crash frequency after the installation of the raised median.

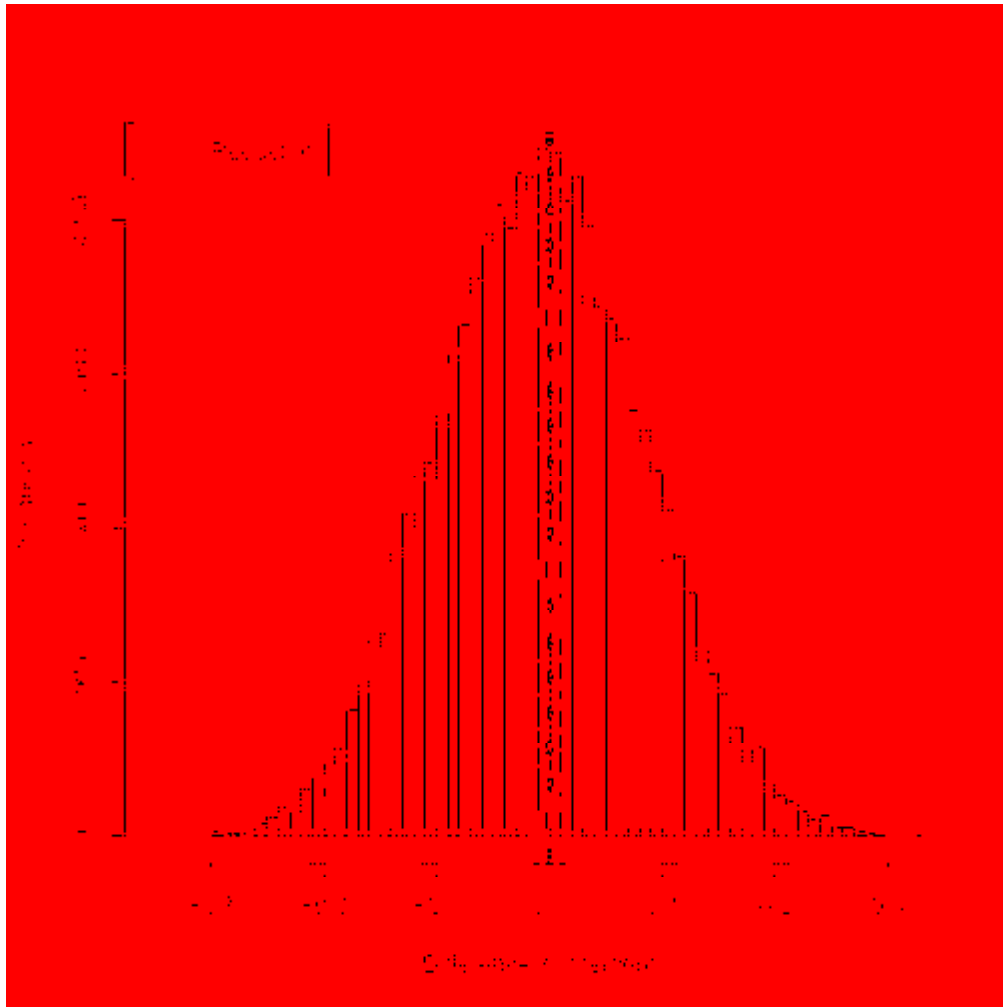


Figure 5-2. Distribution of difference in overall crashes on SR 265.

The severe crash frequency analysis provided different results. Figure 5-3 displays the results of the severe crash analysis on SR 265. The figure shows the crash frequency of severe crashes for the before and after periods as a function of AADT. The expected difference was a

66.68 percent average reduction in severe crash frequency after a raised median was installed, as can be seen in Figure 5-3.

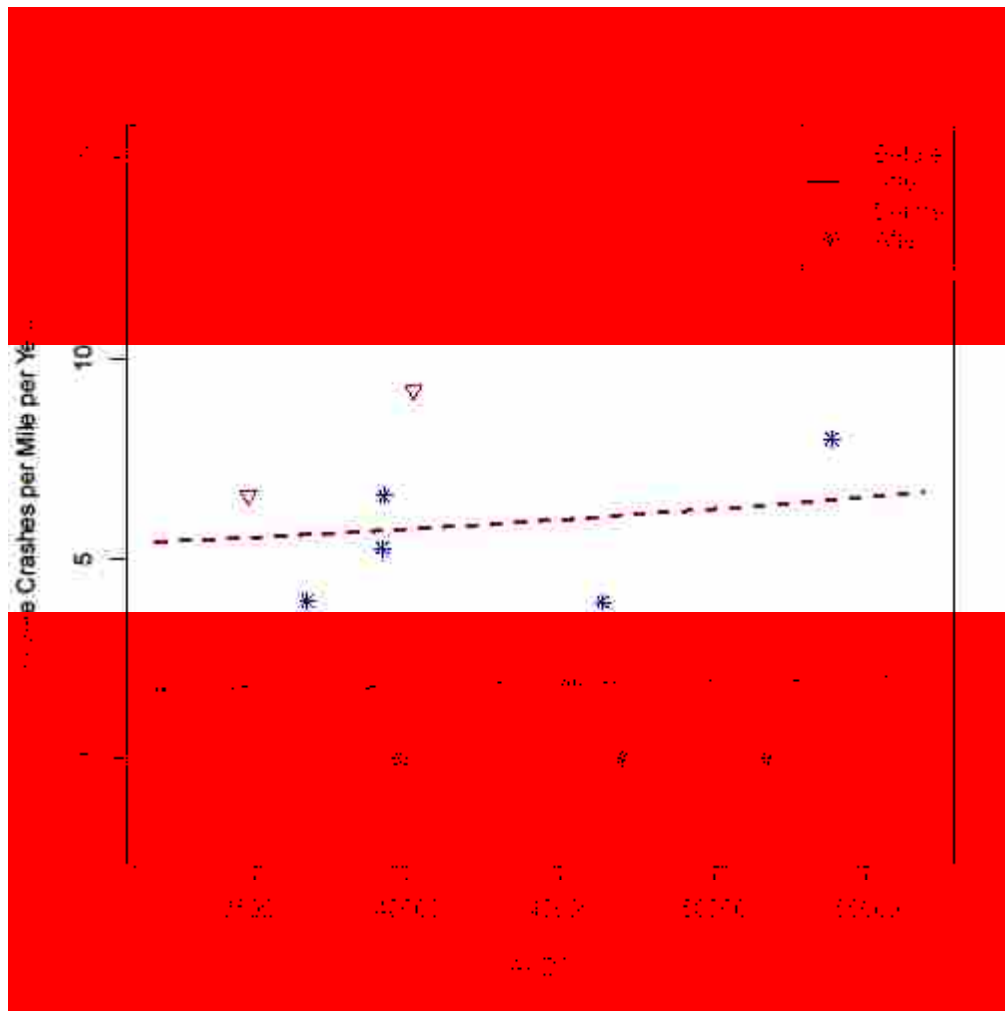


Figure 5-3. Severe Crashes on SR 265.

Figure 5-4 shows the corresponding probability distribution of the difference between the before and after periods for severe crashes for SR 265. In Figure 5-4, the entire distribution of differences was less than zero, indicating a 100 percent probability a reduction in severe crash frequency occurred after the raised median was installed.

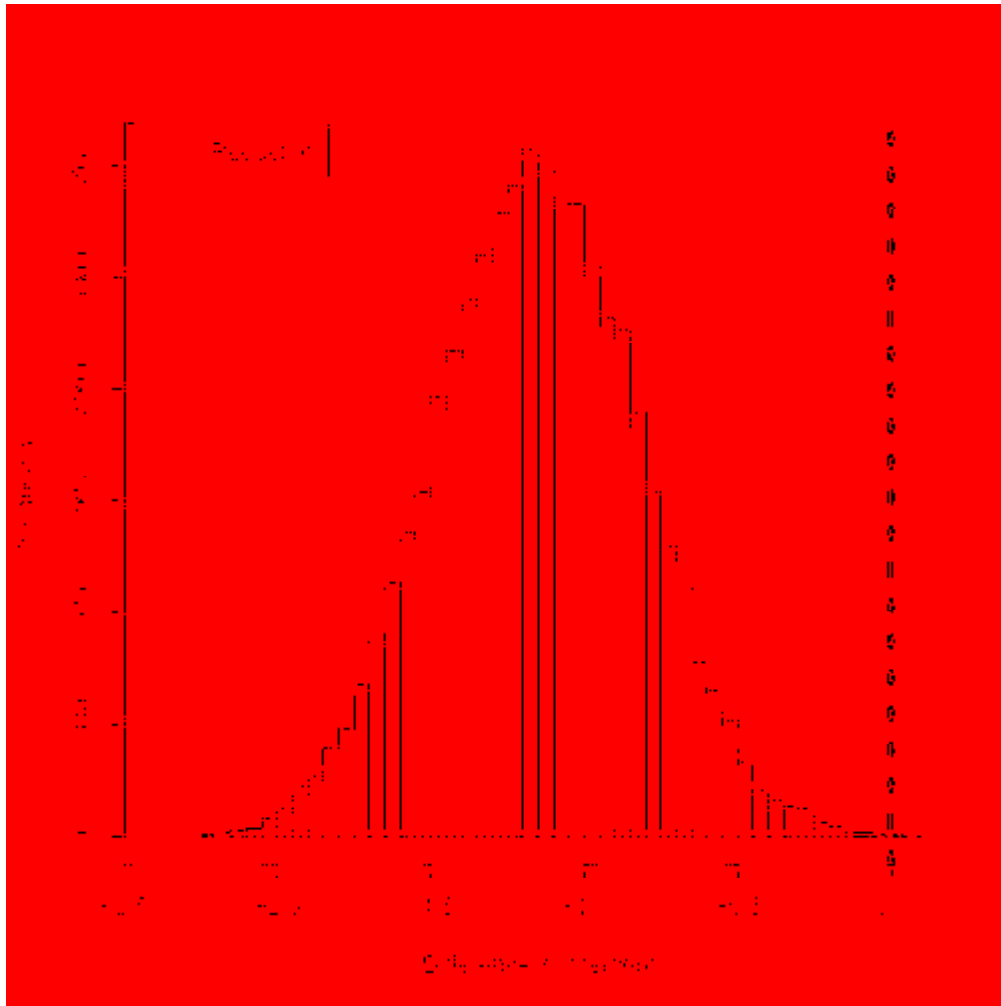


Figure 5-4. Distribution of differences in severe crashes on SR 265.

5.1.2 Alpine Highway (SR 74)

In 2002, a raised median was installed on the section of SR 74 from 9840 North to 11300 North in Highland. This section summarizes the results of the analysis performed before and after the raised median was installed. The before period used in the analysis is from 1998 to 2001 and the after period is from 2003 to 2008.

Figure 5-5 displays the crash frequency of all crashes for the before and after periods as a function of AADT for this segment of SR 74. The overall analysis for this segment of SR 74

showed promising results. The results indicated the overall crash frequency decreased by 21.49 percent after the installation of the raised median.

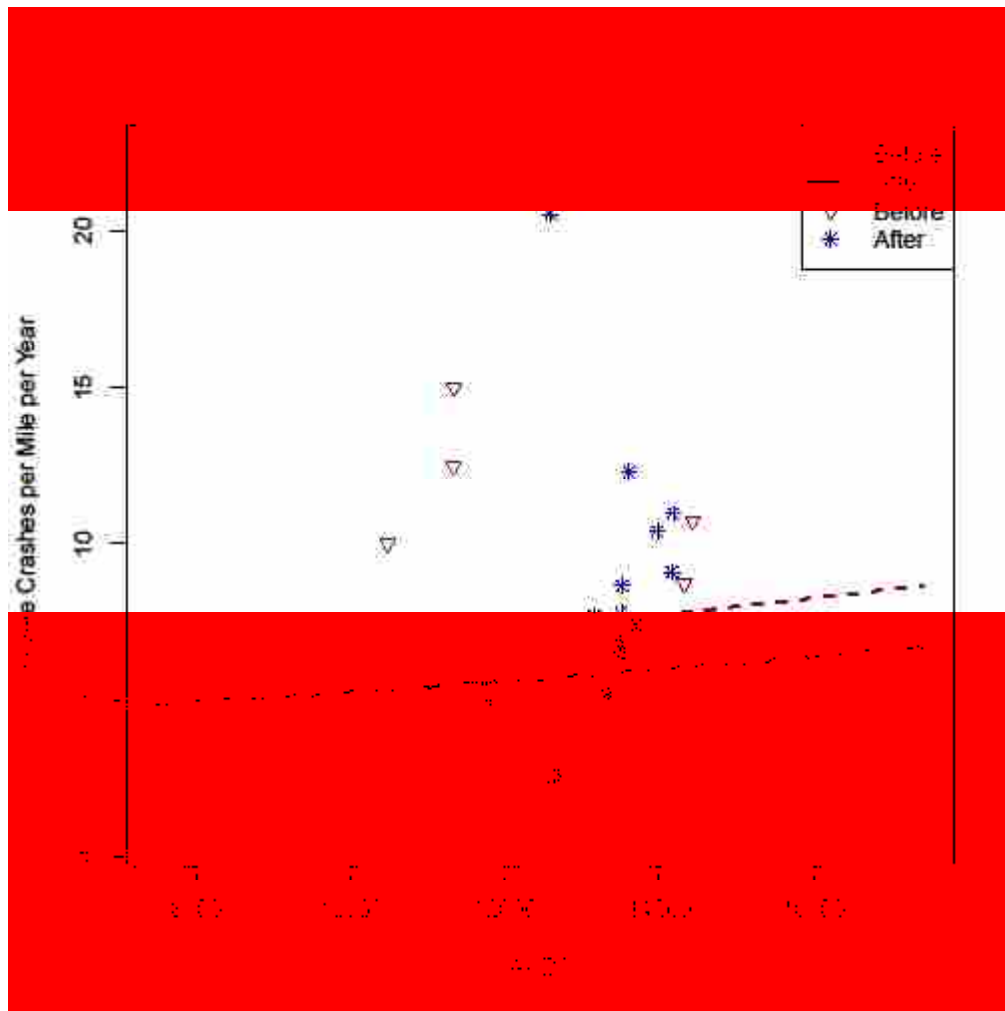


Figure 5-5. Overall crashes on SR 74.

Figure 5-6 shows the corresponding probability distribution of the differences between the before and after periods for all crashes for SR 74. The results of the analysis indicated there was a 94 percent probability a decrease in the overall crash frequency occurred along this segment of SR 74 after the installation of the raised median. This is represented as the gray portion of the distribution shown in Figure 5-6.

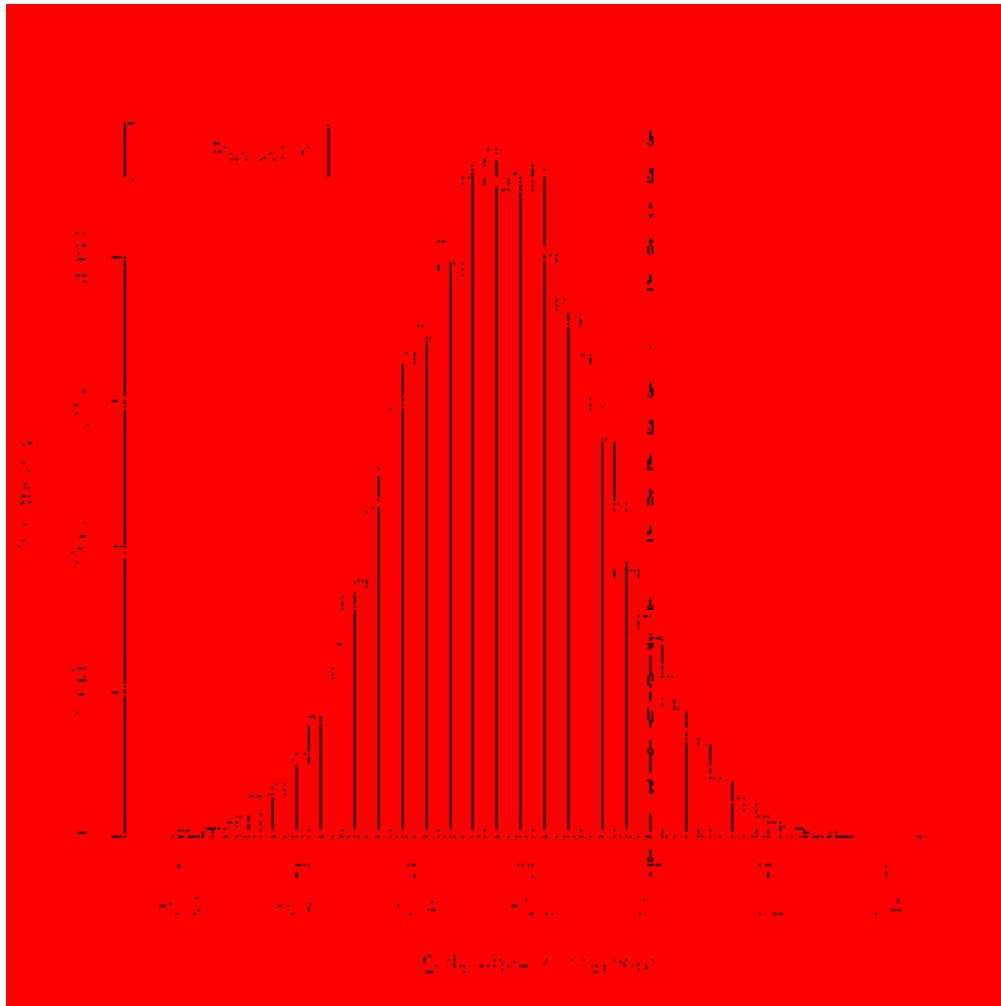


Figure 5-6. Distribution of differences in overall crashes on SR 74.

The severe crash analysis results showed differing results. Figure 5-7 displays the crash frequency of severe crashes on SR 74 for the before and after periods as a function of AADT. The severe crash frequency for this segment of SR 74 actually increased after the installation of the raised median by over 38.2 percent.

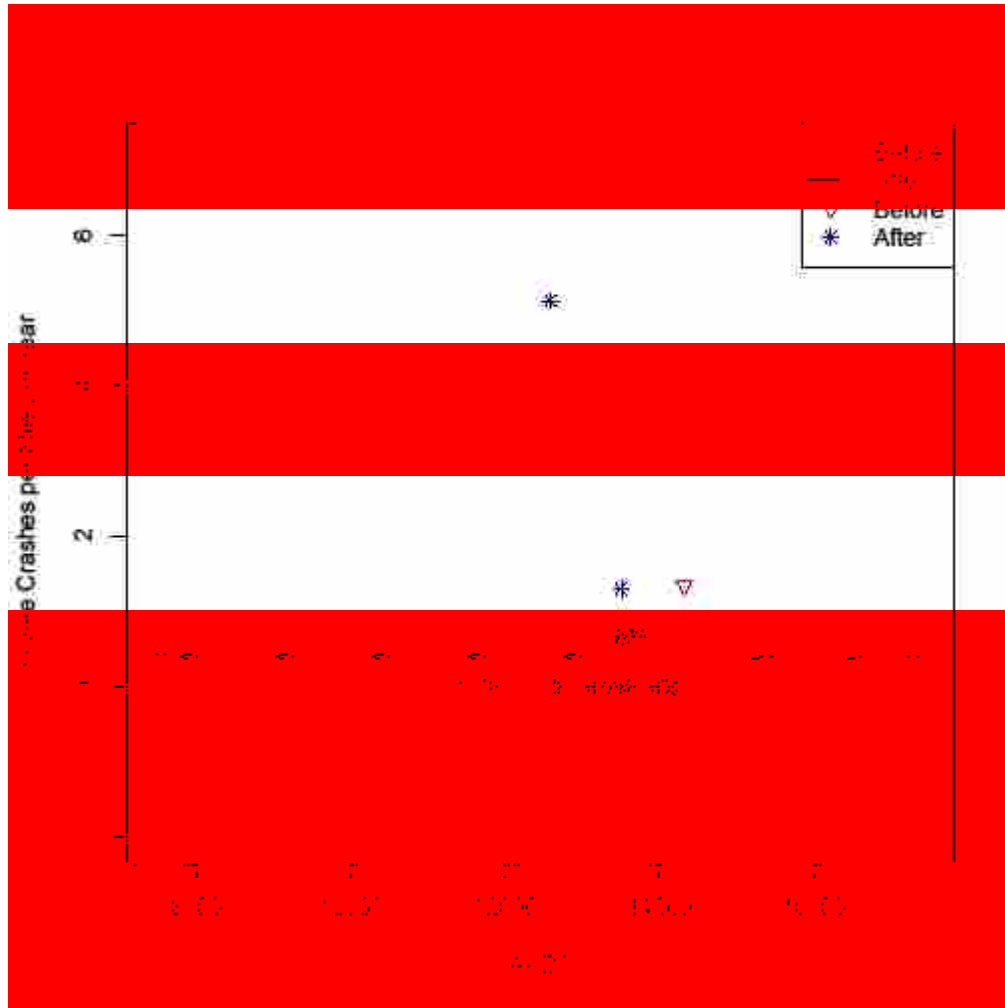


Figure 5-7. Severe crashes on SR 74.

This increase in severe crashes is unexpected. However, the distribution of the difference for the severe crash analysis shown in Figure 5-8, indicates only a 57 percent chance an increase occurred, as represented by the gray portion of the distribution in Figure 5-8. The low probability represents uncertainty that a difference was even detected before and after the raised median was installed. Figure 5-7 also revealed an outlier that occurred after the installation of the raised median. Further research should be done to identify reasons why this unusually high frequency occurred.

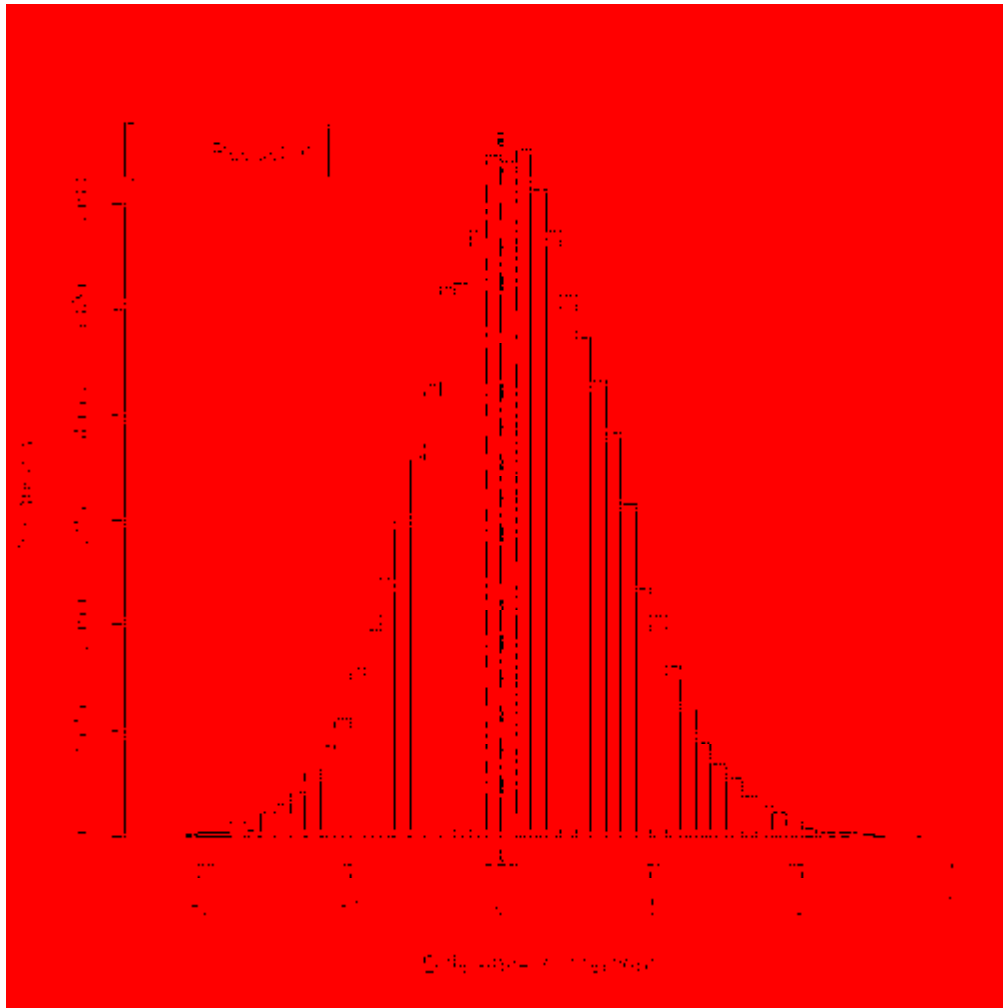


Figure 5-8. Distribution of differences in severe crashes on SR 74.

Even if an increase in severe crashes did occur at this site, there are a few possible explanations that could contribute to the significant increase in severe crashes. First, it appears the raised median was installed more for beautification purposes rather than as a safety technique. Second, this area has experienced continual increases in residential growth over the past 10 years which may contribute to the increase in severe crash frequency.

5.1.3 400/500 South (SR 186)

Construction of the light rail/raised median project on SR 186 between Main Street and 1300 East was completed in 2001. This section summarizes the results of the analysis performed before and after the raised median was installed. The before period used in the analysis is from 1998 to 2000 and the after period is from 2002 to 2007. In 2007, SR-186 was realigned to cover all of former SR-184; therefore data for 2008 was not used in the analysis.

Figure 5-9 displays the results of the overall crash analysis. The overall crash frequency for this segment of SR 74 decreased 43.4 percent after the installation of the raised median.

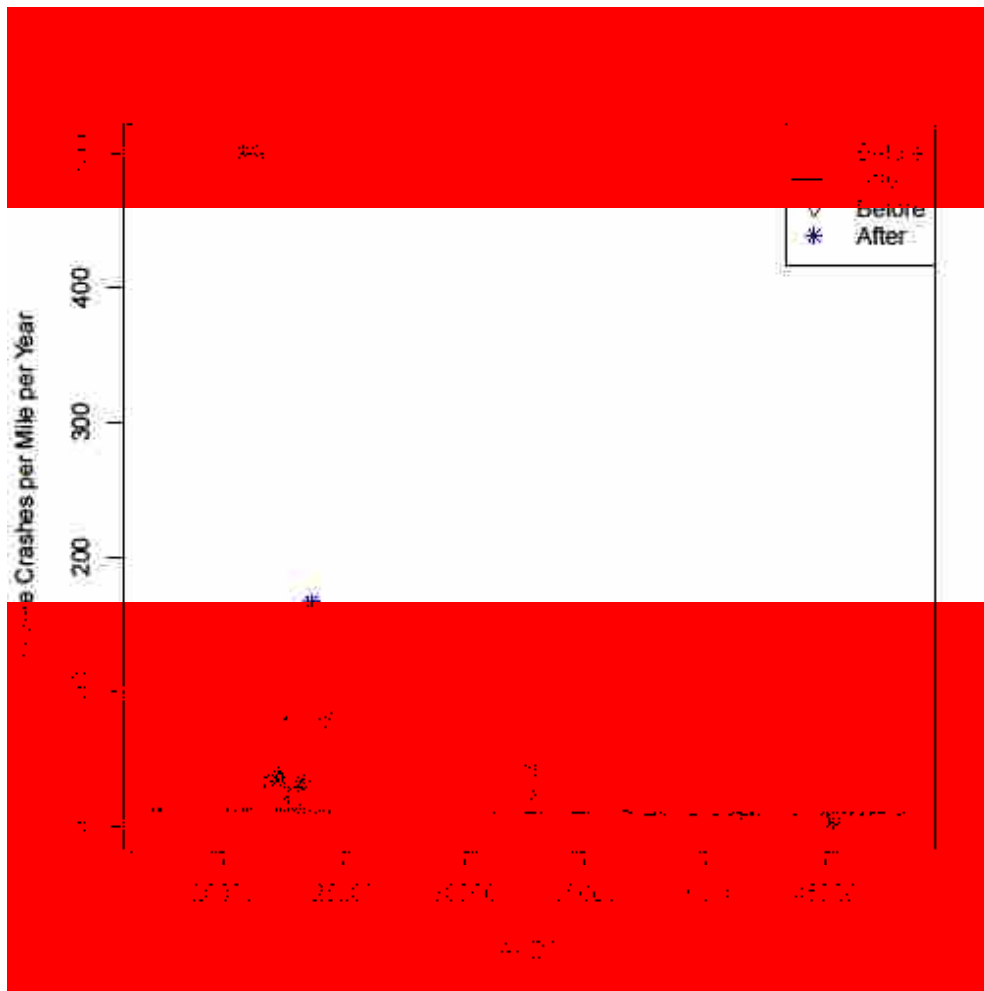


Figure 5-9. Overall crashes on SR 186.

Figure 5-10 shows the corresponding probability distribution of the difference between the before and after periods for all crashes. The probability of a decrease in crash frequency occurring is represented by the gray portion of the distribution. The entire distribution of the differences, shown in Figure 5-10, is less than zero indicating a 100 percent probability that a decrease occurred. The analysis also revealed a few outliers that experienced an unusually high crash frequency after the raised median was installed. Further research should be performed to identify contributing factors that could be mitigated.

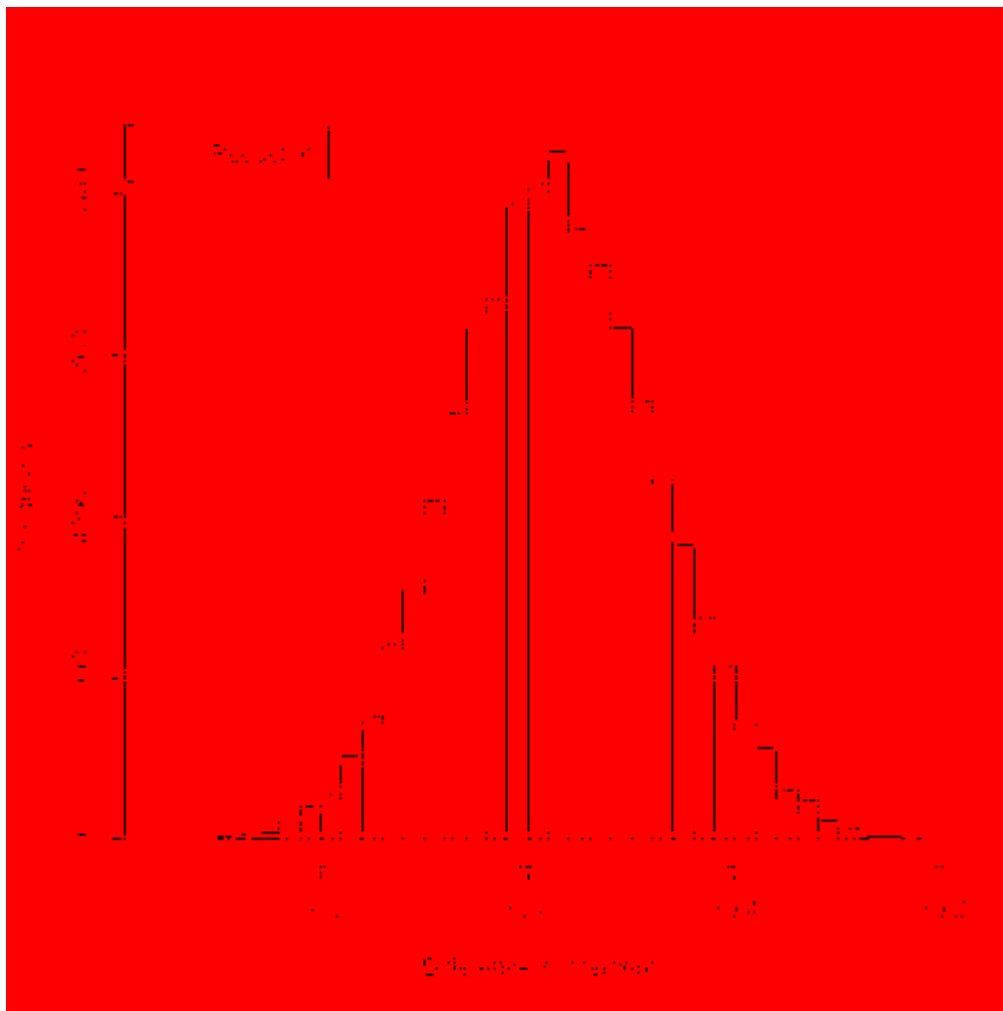


Figure 5-10. Distribution of differences in overall crashes on SR 186.

The severe crash analysis for this segment provided similar results. The severe crash frequency for this segment of SR 74 decreased after the installation of the raised median by over 80 percent. Figure 5-11 displays the crash frequency of severe crashes on SR 186 for the before and after periods as a function of AADT.

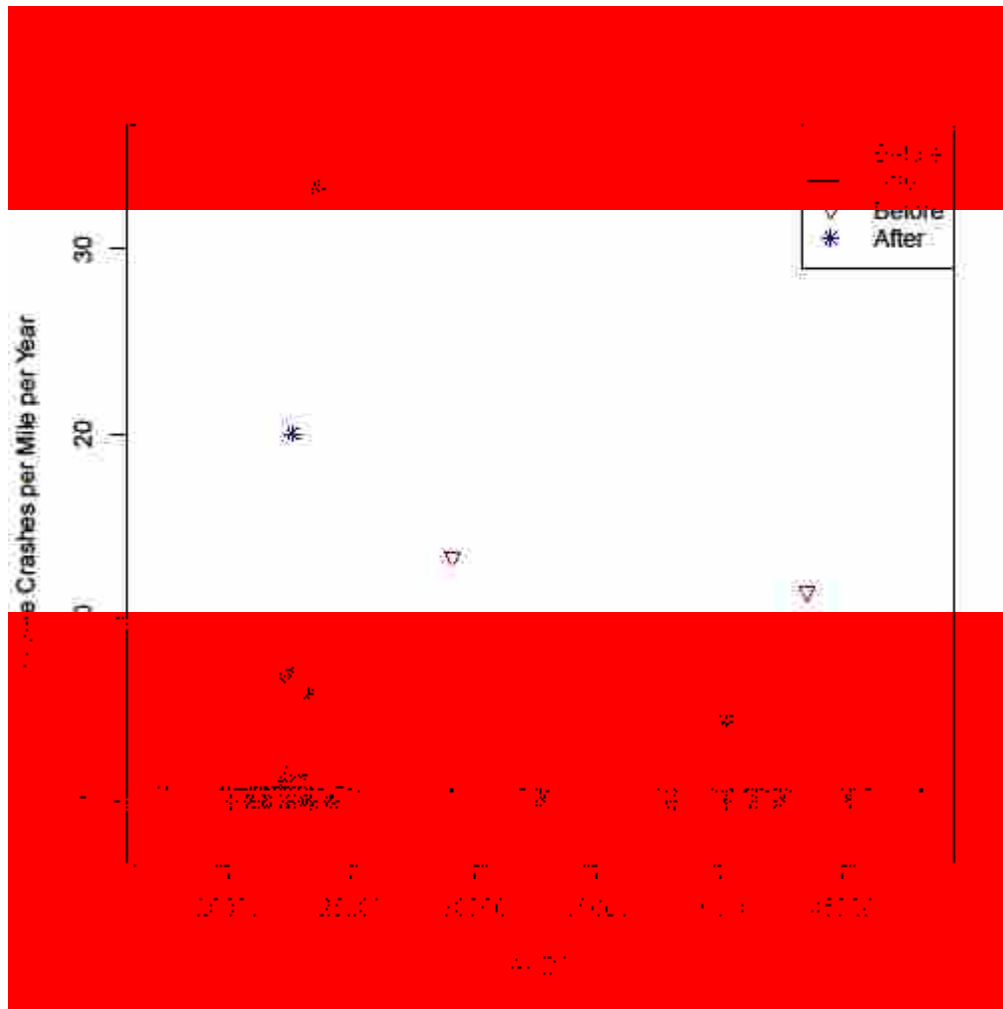


Figure 5-11. Severe crashes on SR 186.

Figure 5-12 shows the probability distribution of the difference between the before and after periods for severe crashes. The entire distribution of the differences, shown in Figure 5-12,

is less than zero indicating a 100 percent probability that a decrease occurred. SR 186 showed the largest reduction in both overall and severe crashes among all the study sites.

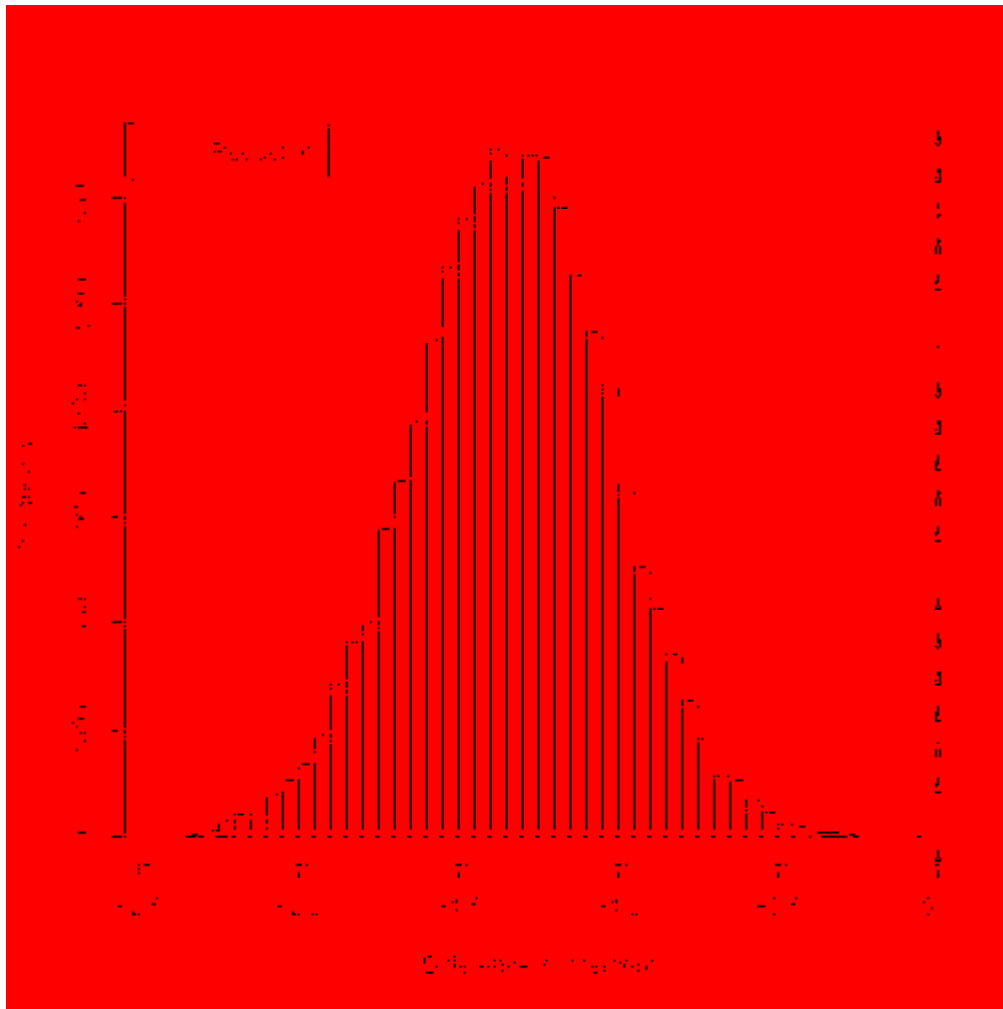


Figure 5-12. Distribution of differences in severe crashes on SR 186.

5.1.4 12300 South (SR 71)

In 2004, SR 71 received some major improvements including widening to six lanes and the installation of a raised median. The raised median segment used in the analysis extends from 300 East to 265 West. This section summarizes the results of the analysis performed before and

after the raised median was installed. The before period used in the analysis is from 1998 to 2003 and the after period is from 2005 to 2008.

Figure 5-13 displays the results of the overall crash analysis. The overall crash results of this site differed from other sites. The analysis showed this segment of SR 71 experienced an increase of 26.2 percent in overall crash frequency after the installation of the raised median.

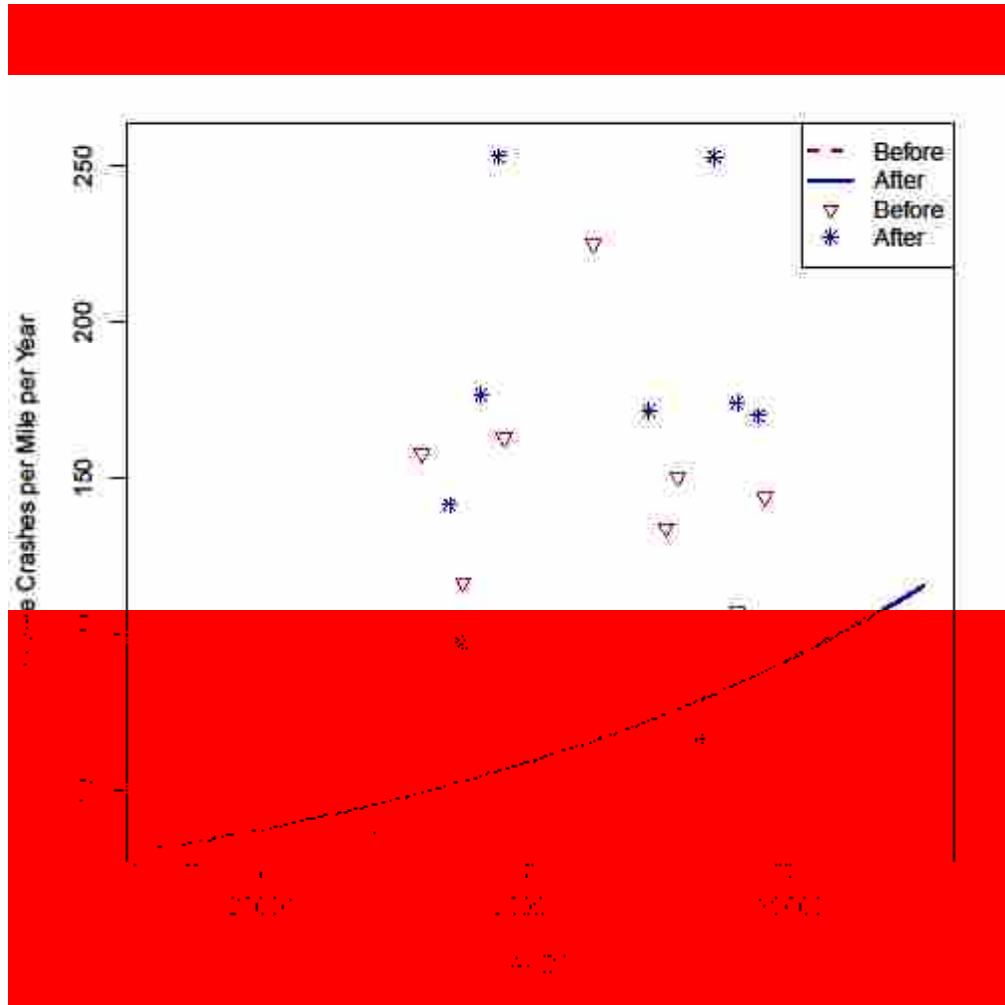


Figure 5-13. Overall crashes on SR 71.

Figure 5-14 shows the corresponding probability distribution of the differences between the before and after periods for all crashes. The entire corresponding distribution of differences is

greater than zero, indicating a 100 percent probability that an increase in overall crashes occurred at this site after the raised median was installed.

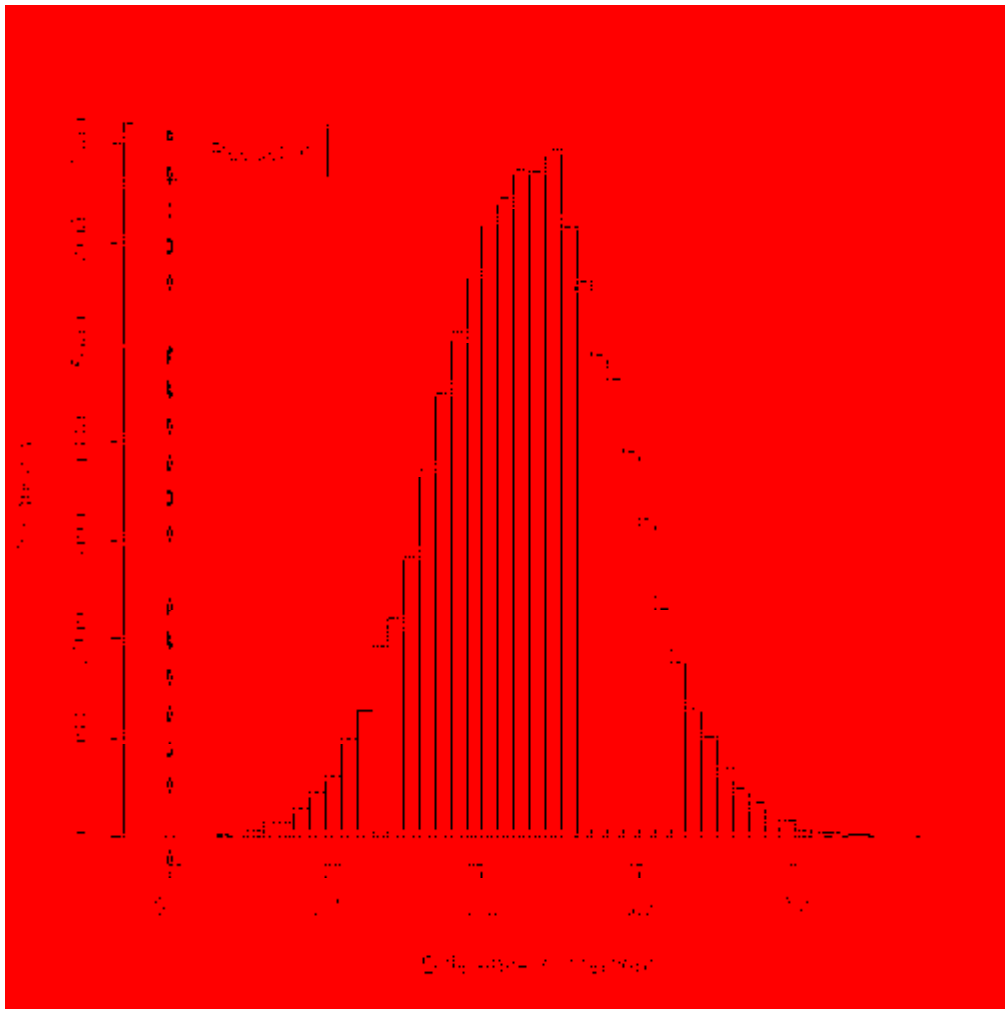


Figure 5-14. Distribution of differences in overall crashes on SR 71.

This increase in overall crash frequency is somewhat unexpected. The most likely contributing factor to this result has to do with the widening of this segment of SR 71 to six lanes that occurred as part of the raised median installation project. As noted in Chapter 3, rapid growth in the surrounding area warranted the need for widening. However, the increase in

number of lanes increases weaving complexity and conflict points which could have had a significant impact on the overall crash results.

The severe crash analysis of SR 71 showed similar results. Figure 5-15 displays the crash frequency of severe crashes for the before and after periods of SR 71 as a function of AADT. The analysis showed that the severe crash frequency of SR 71 also increased by 20.1 percent.

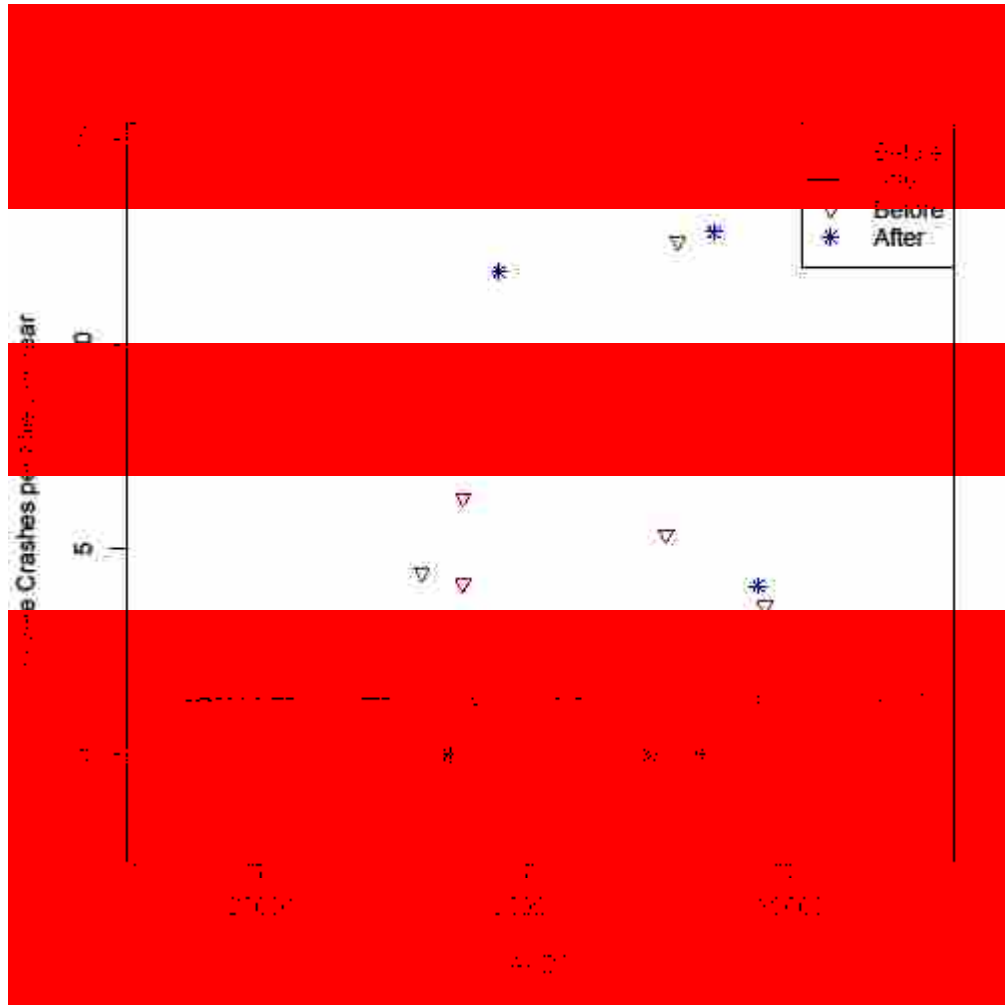


Figure 5-15. Severe crashes on SR 71.

Figure 5-16 shows the corresponding distribution of differences for the severe crash analysis. The portion of the difference that in less than zero was only 37 percent, as represented

by the gray portion of the distribution in shown in Figure 5-16, meaning a 37 percent probability that a decrease occurred. Therefore, it cannot be definitively concluded that SR 71 experienced any change in severe crash frequency after the raised median was installed.

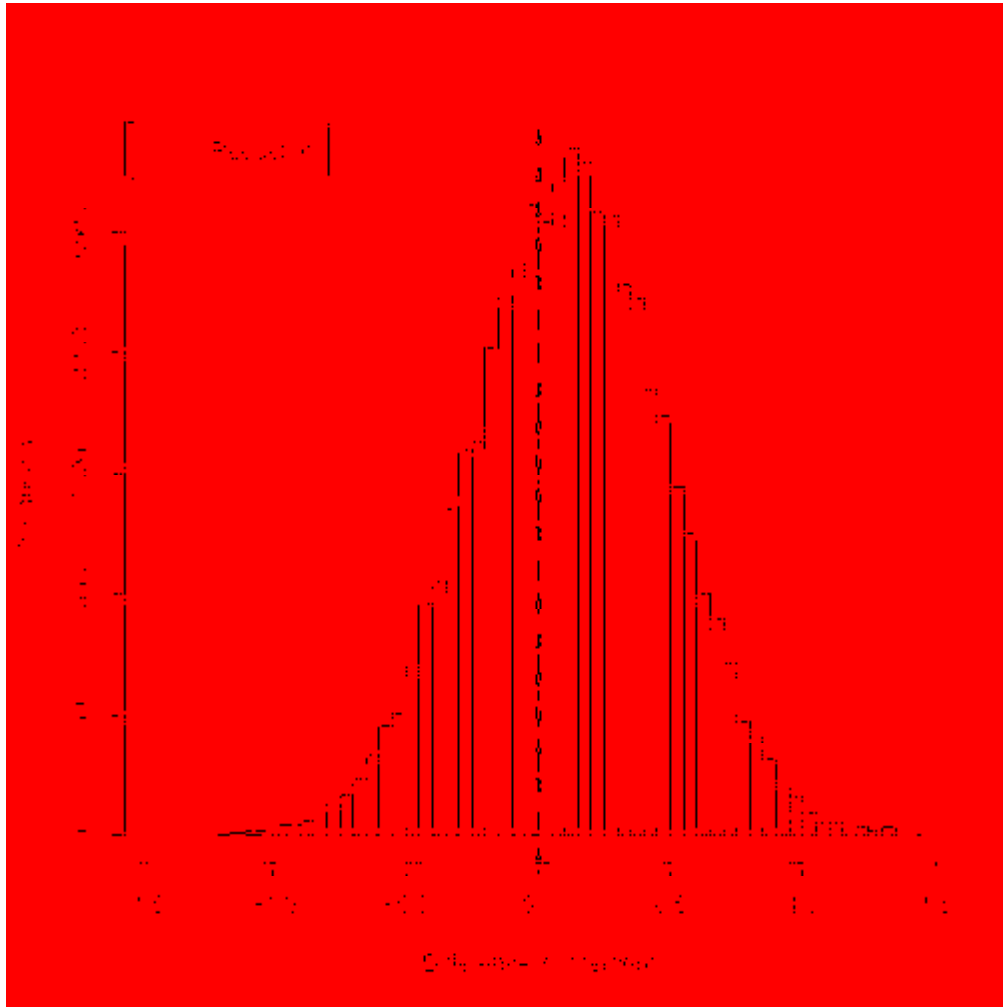


Figure 5-16. Distribution of differences in severe crashes on SR 71.

5.1.5 St. George Boulevard (SR 34)

A raised median was installed over the entire length of the St. George Boulevard from Bluff Street to 1000 East. The project was completed in 2006. This section summarizes the

results of the analysis performed before and after the raised median was installed. The before period used in the analysis is from 1998 to 2005 and the after period is from 2007 to 2008.

Figure 5-17 displays the crash frequency for the before and after periods as a function of AADT for this segment of SR 34. The overall crash frequency for this segment of SR 71 decreased after the installation of the raised median by 28.7 percent.

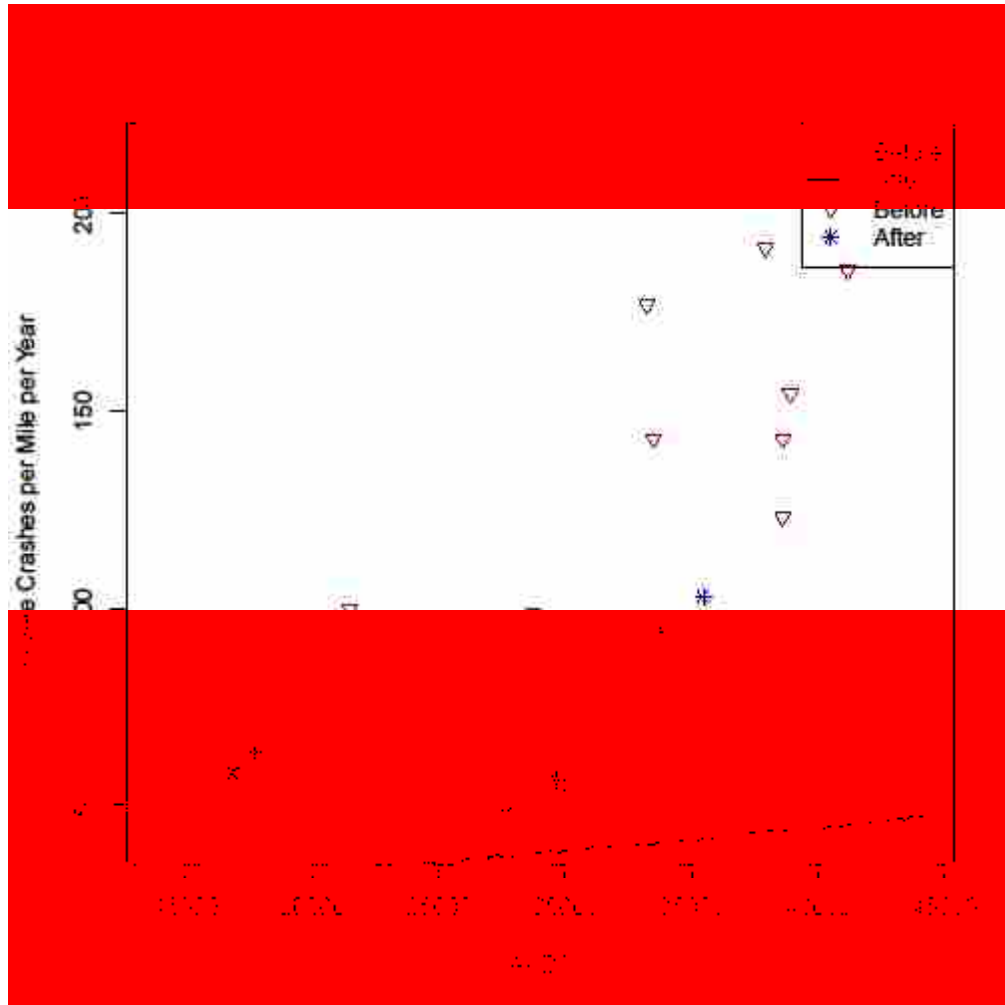


Figure 5-17. Overall crashes on SR 34.

Figure 5-18 shows the corresponding probability distribution of the differences between the before and after periods for all crashes. The entire distribution of differences, shown in Figure 5-18, is greater than zero indicating a 100 percent probability that a decrease occurred.

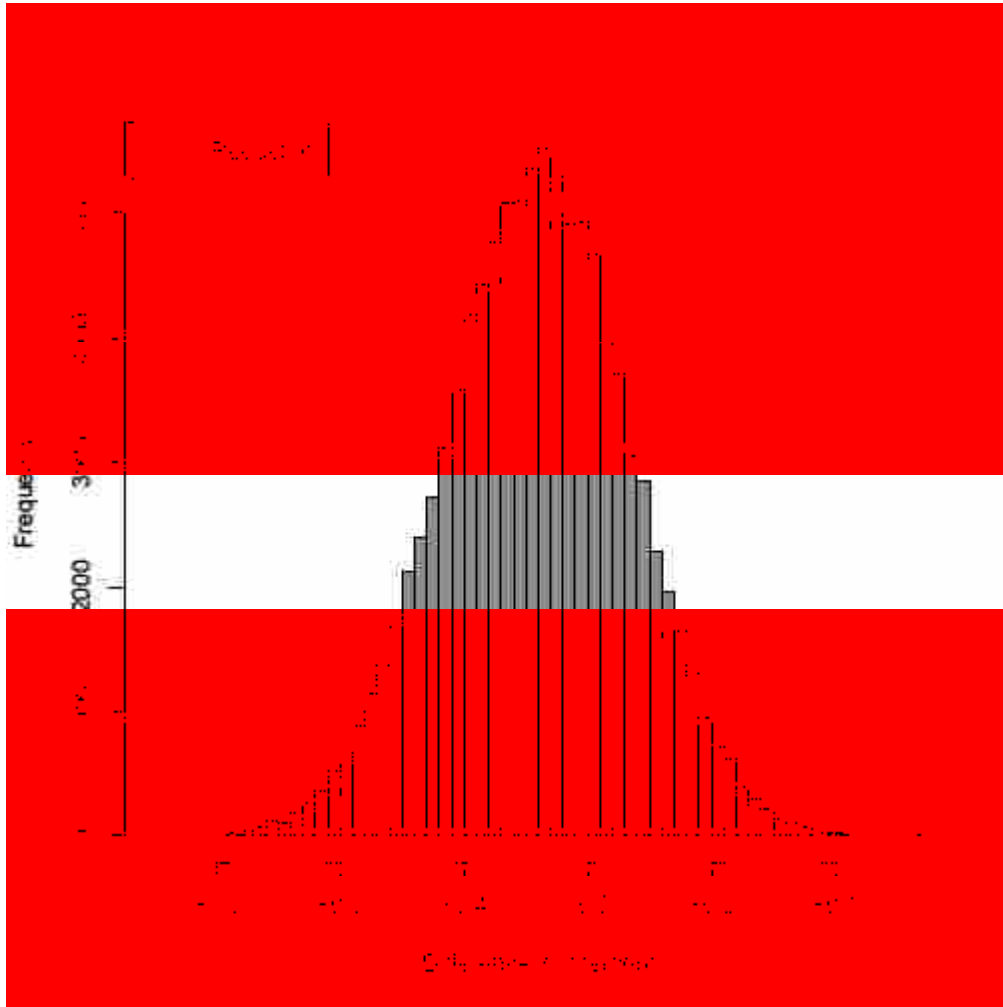


Figure 5-18. Distribution of differences in overall crashes on SR 34.

The results of the severe crash analysis showed similar results. The results showed the severe crash frequency for SR 34 also decreased an estimated 47.9 percent after the raised median was installed. Figure 5-19 displays the crash frequency of severe crashes on SR 34 for the before and after periods as a function of AADT.

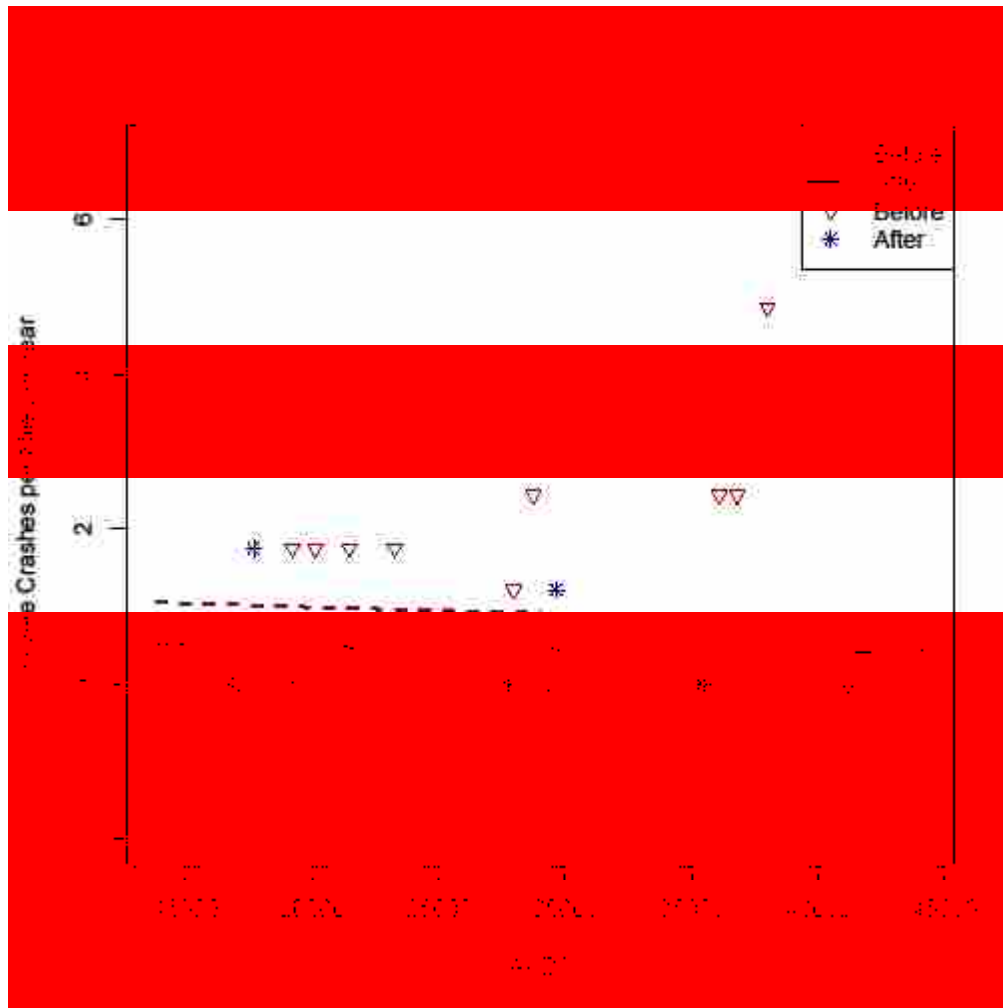


Figure 5-19. Severe crashes on SR 34.

Figure 5-20 shows the probability distribution of the differences between the before and after periods for severe crashes. Approximately 93 percent of the distribution of differences shown in Figure 5-20 is less than zero, indicating a 93 percent probability that SR 34 also experienced a decrease in the frequency of severe crashes after the installation of a raised median.

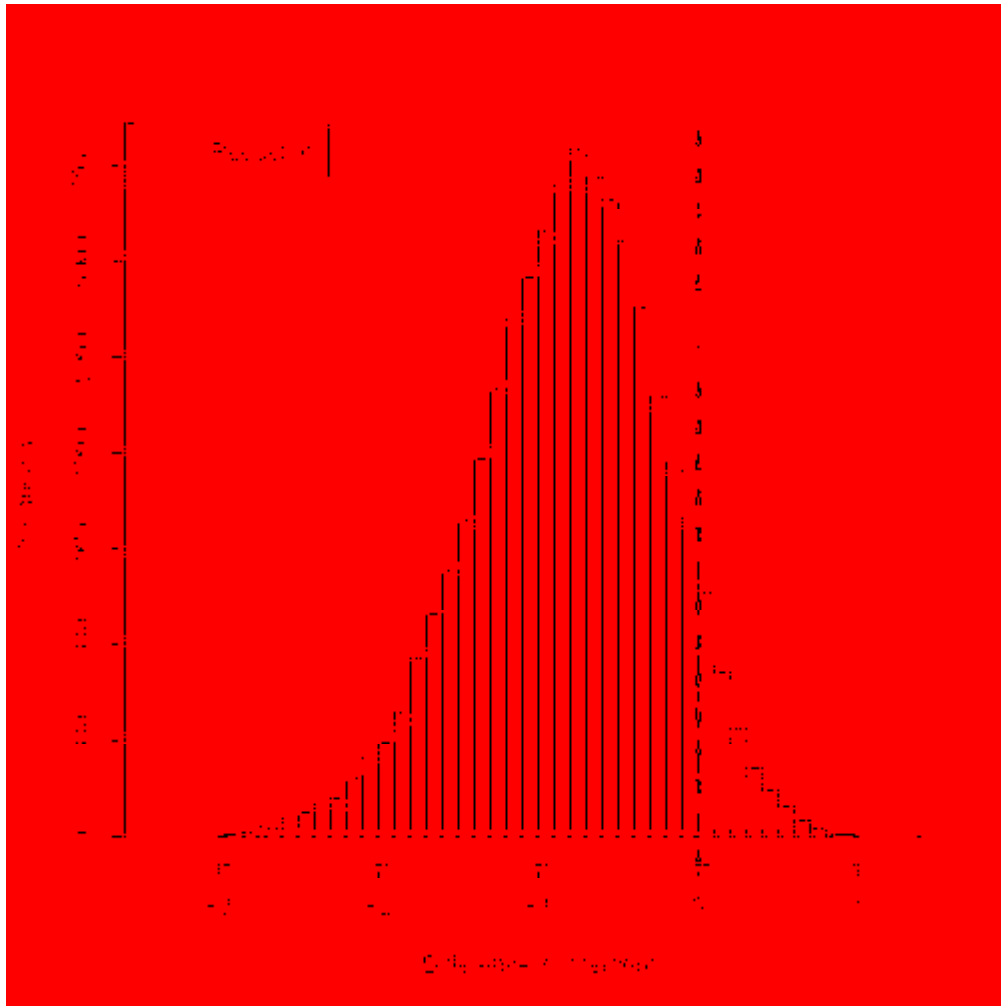


Figure 5-20. Distribution of differences in severe crashes on SR 34.

5.1.6 SR 36

A project completed in 2005 widened SR 36 to two lanes in each direction and installed a raised median for a short segment of SR 36 in the city of Erda in north Tooele County. This section summarizes the results of the analysis performed before and after the raised median was installed. The before period used in the analysis is from 1998 to 2004 and the after period is from 2006 to 2008.

Figure 5-21 displays the crash frequency of all crashes for the before and after periods as a function of AADT. The overall crash frequency for this segment of SR 36 decreased by an estimated 44.4 percent after the installation of the raised median.

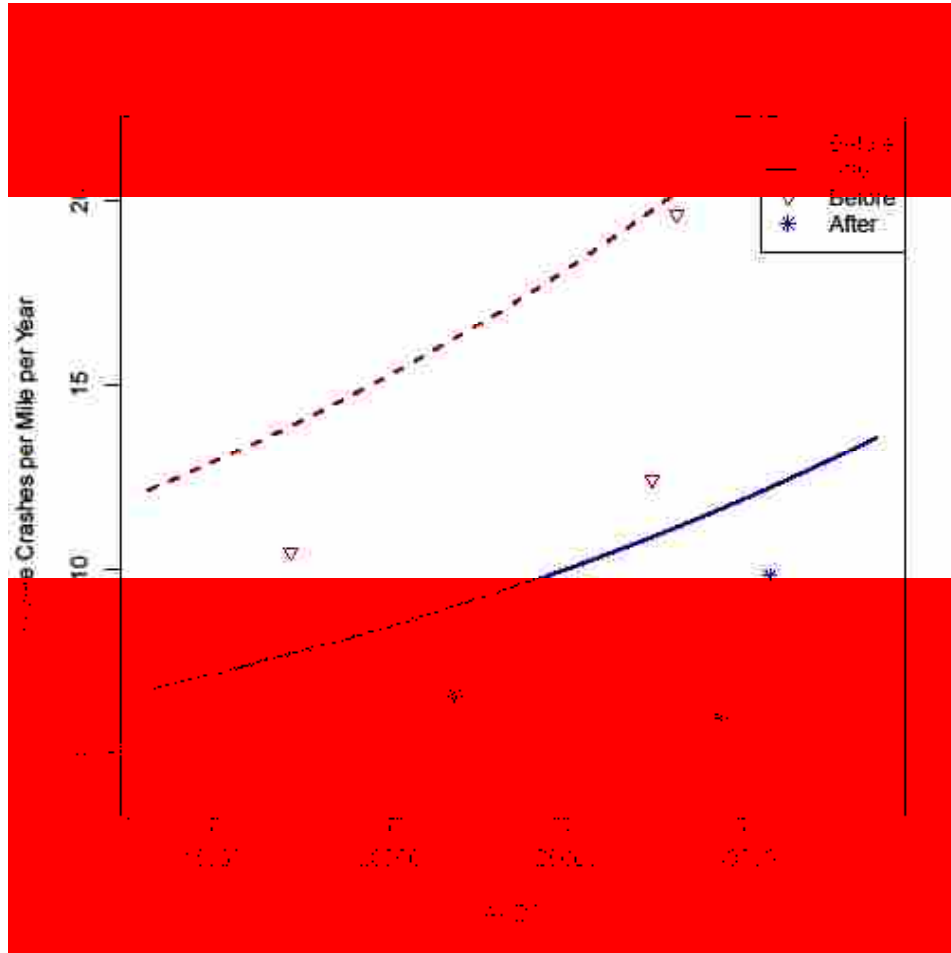


Figure 5-21. Overall crashes on SR 36.

Figure 5-22 shows the corresponding probability distribution of the differences between the before and after periods for all crashes. The entire distribution of the differences for this site was less than zero indicating this segment experienced a 100 percent probability that a decrease occurred after the raised median was installed.

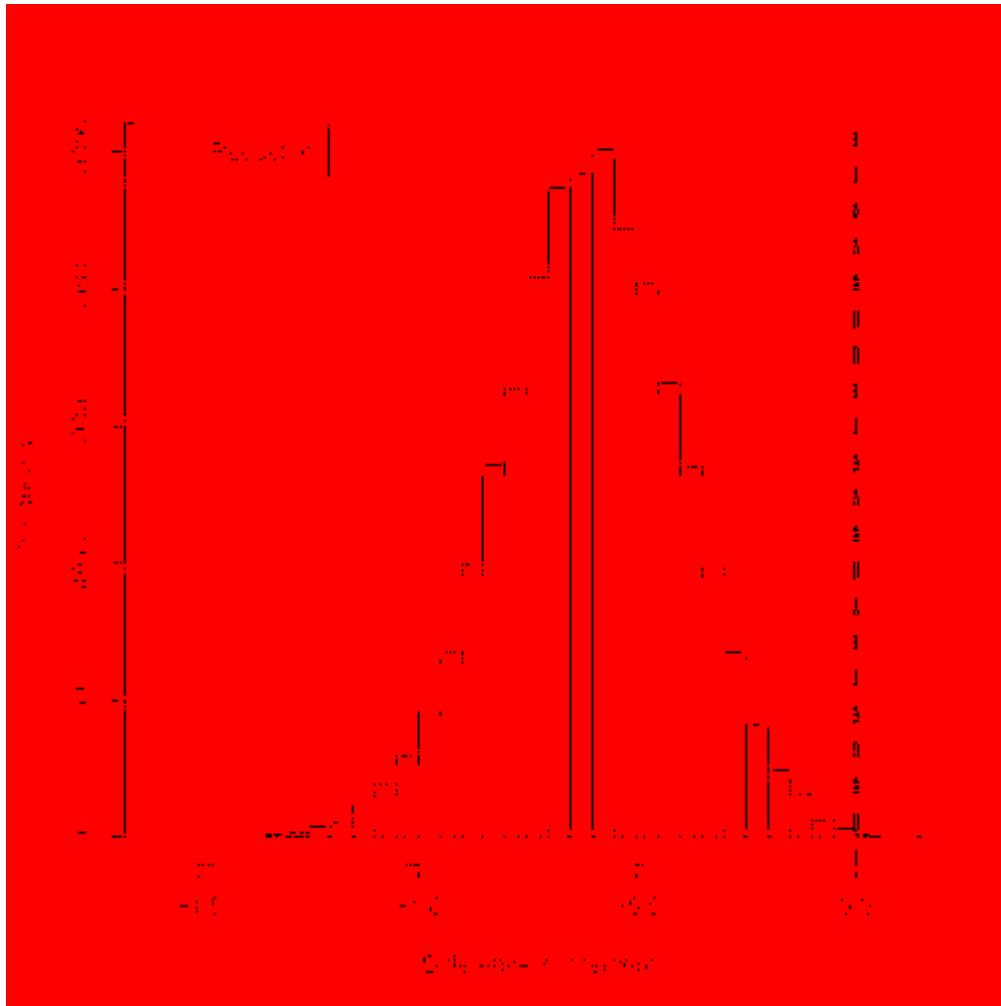


Figure 5-22. Distribution of differences in overall crashes on SR 36.

The severe crash analysis provided similar results. Figure 5-23 displays the crash frequency of severe crashes for the before and after periods as a function of AADT. The analysis showed SR 36 experienced a significant decrease in severe crash frequency. The results indicate the segment experienced a 61.9 percent decrease in severe crash frequency after the raised median was installed.

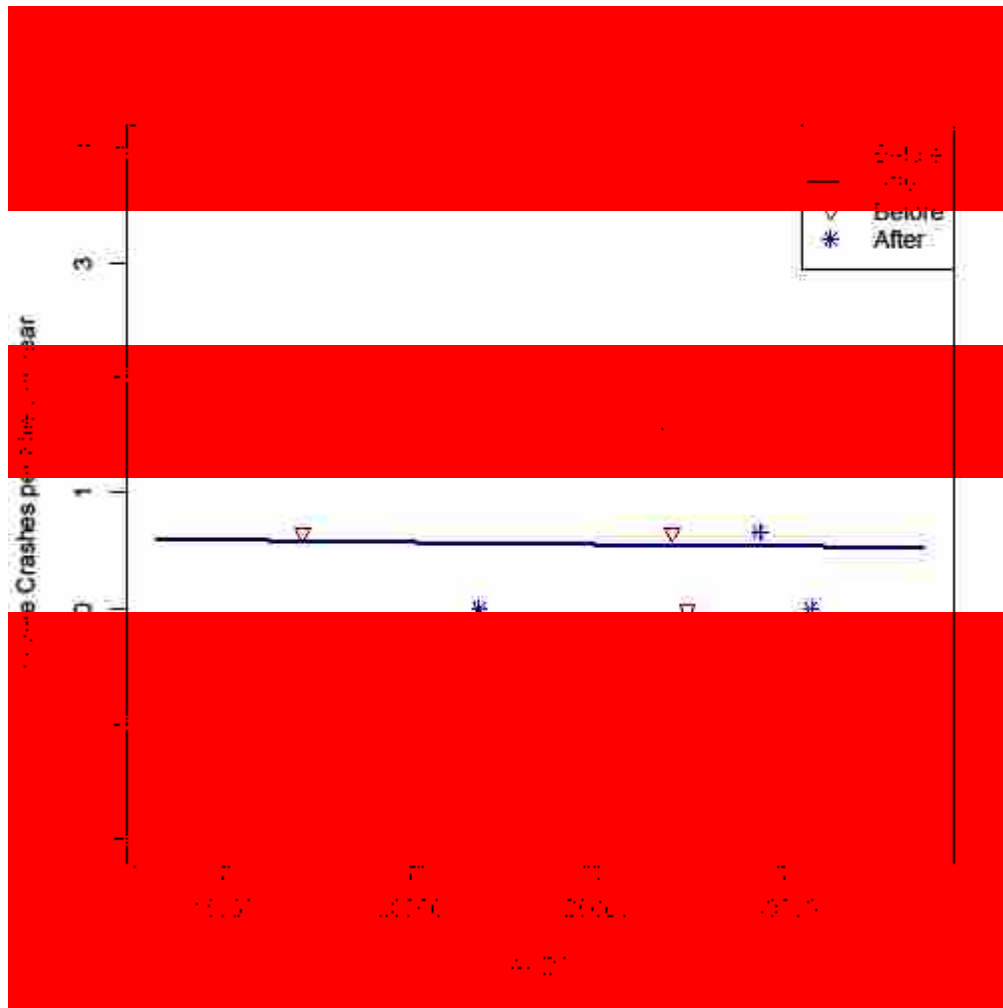


Figure 5-23. Severe crashes on SR 36.

Figure 5-24 shows the probability distribution of the differences between the before and after periods for severe crashes. Approximately 97 percent of the distribution of differences shown in Figure 5-24 is less than zero, indicating a 97 percent probability that a decrease in severe crash frequency occurred on SR 36 after the raised median was installed.

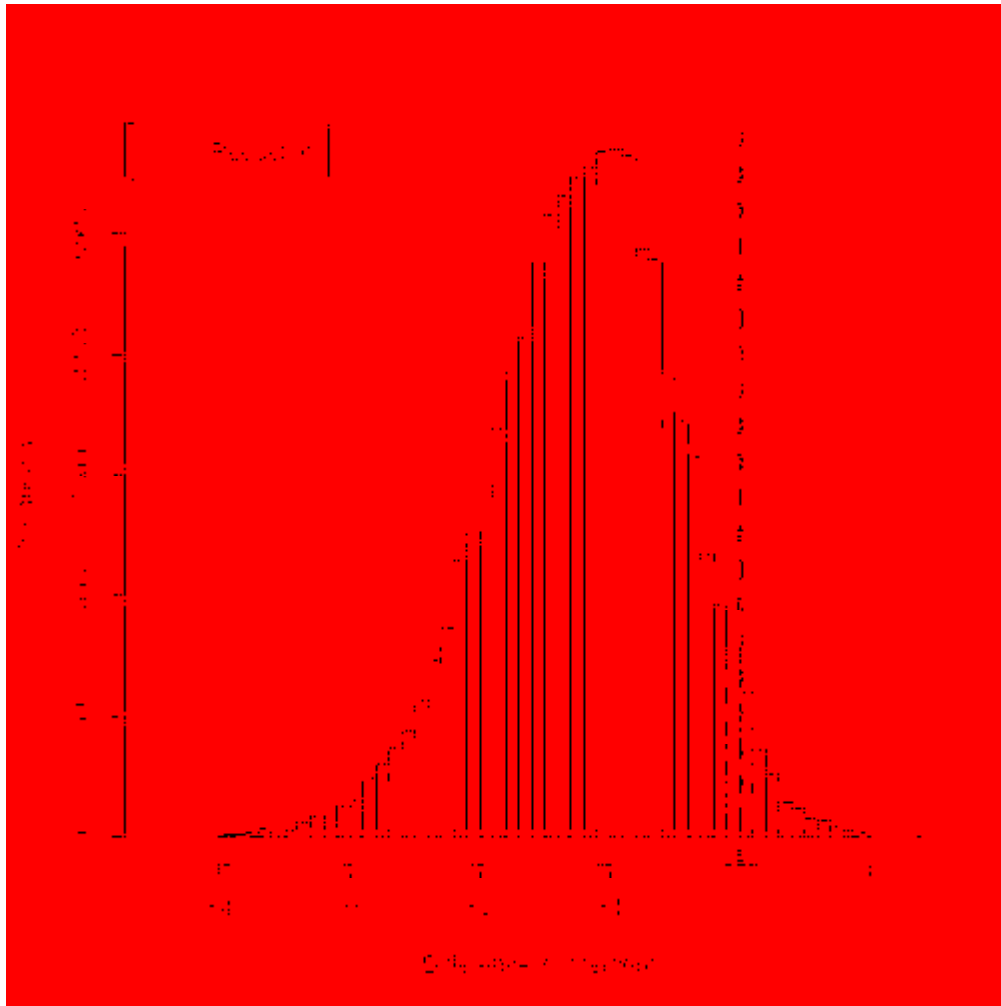


Figure 5-24. Distribution of differences for severe crashes on SR 36.

5.2 Overall Raised Median Results

The overall safety impacts of all locations that have been chosen for analysis where raised medians have been installed are discussed in this section. Data from all analysis sites were grouped together for analysis.

Figure 5-25 displays the overall crash frequency for the before and after periods as a function of AADT. The overall analysis results indicate 34.8 percent decrease in overall crash frequency after the raised medians were installed.

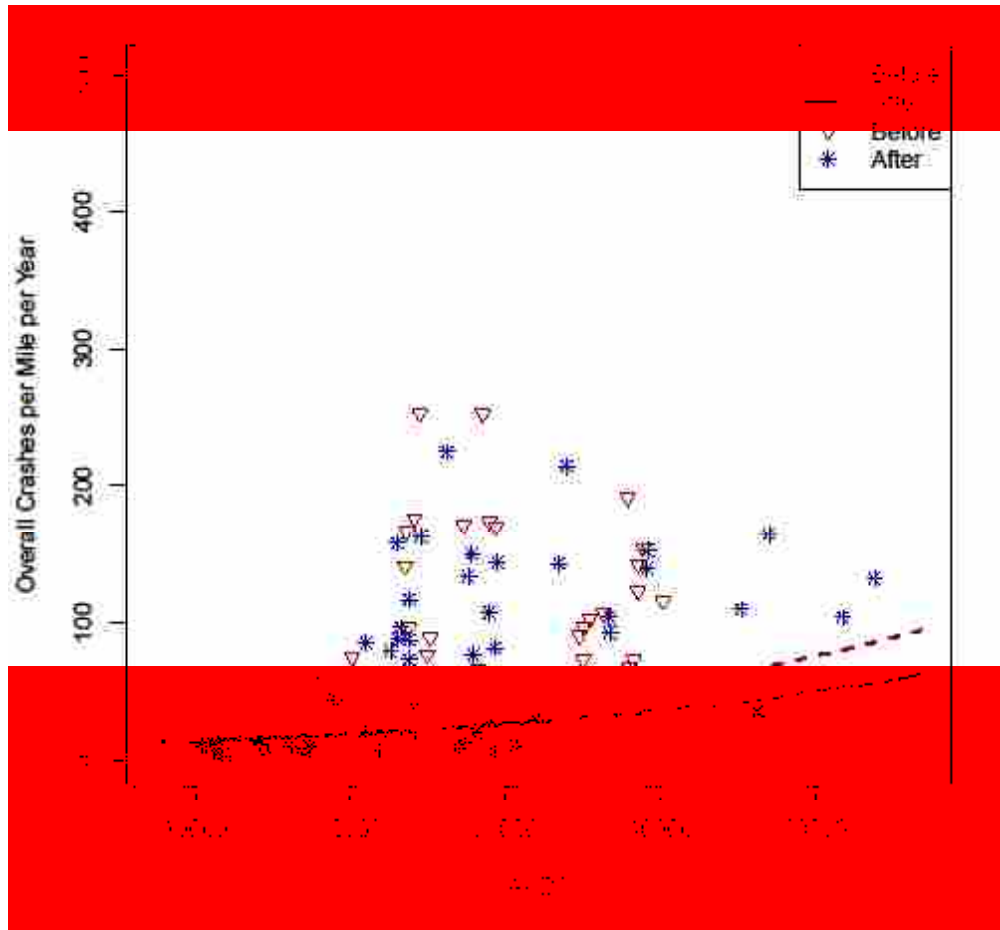


Figure 5-25. Overall crashes on all study sites.

Figure 5-26 shows the corresponding probability distribution of the differences between the before and after periods for overall crashes. The gray portion of the distribution represents the probability that a decrease was detected from the before to the after period. The entire distribution of differences shown in Figure 5-26 is less than zero, indicating a 100 percent probability that a decrease in overall crash frequency occurred after raised medians were installed.

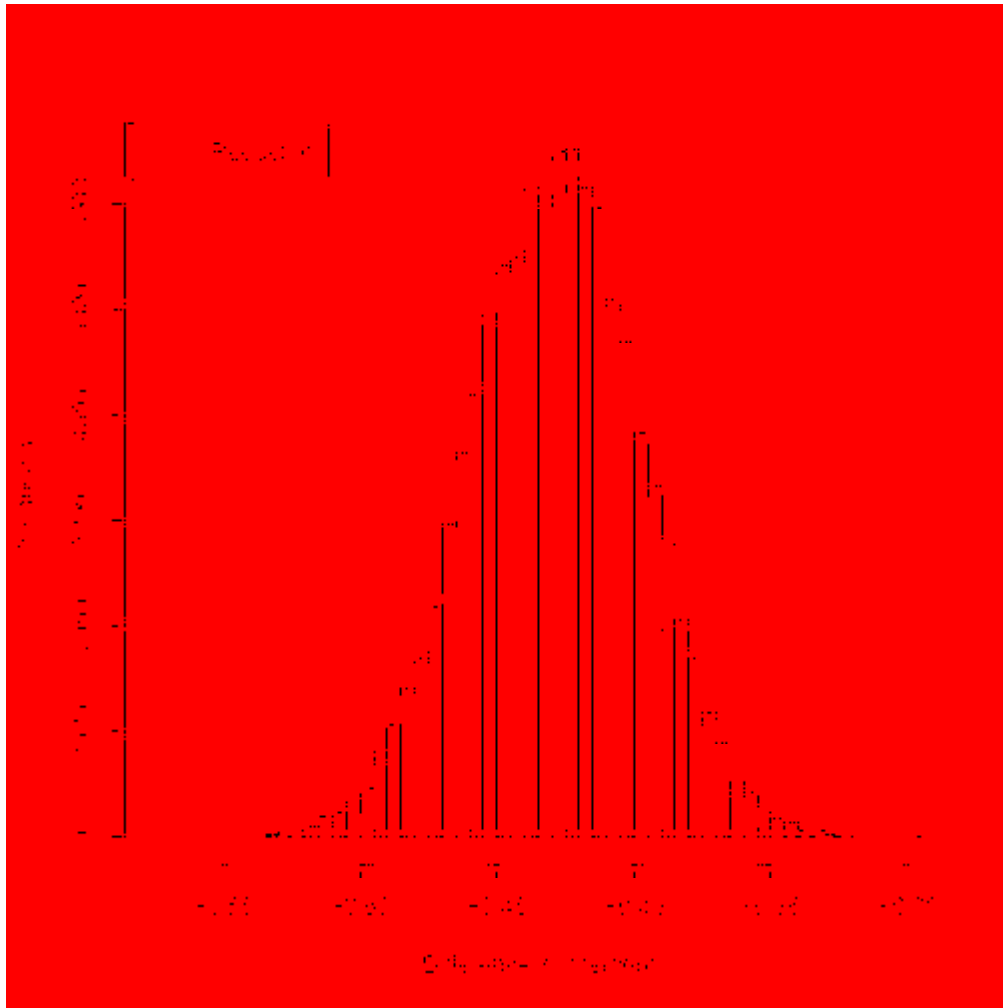


Figure 5-26. Distribution of differences for overall crashes on all sites.

The severe analysis results display an even greater reduction. Figure 5-27 displays the results of the severe crash analysis for all locations where raised medians were installed in Utah. The severe crash analysis results on all sites show a 46.8 percent reduction in severe crash frequency after raised median installation.

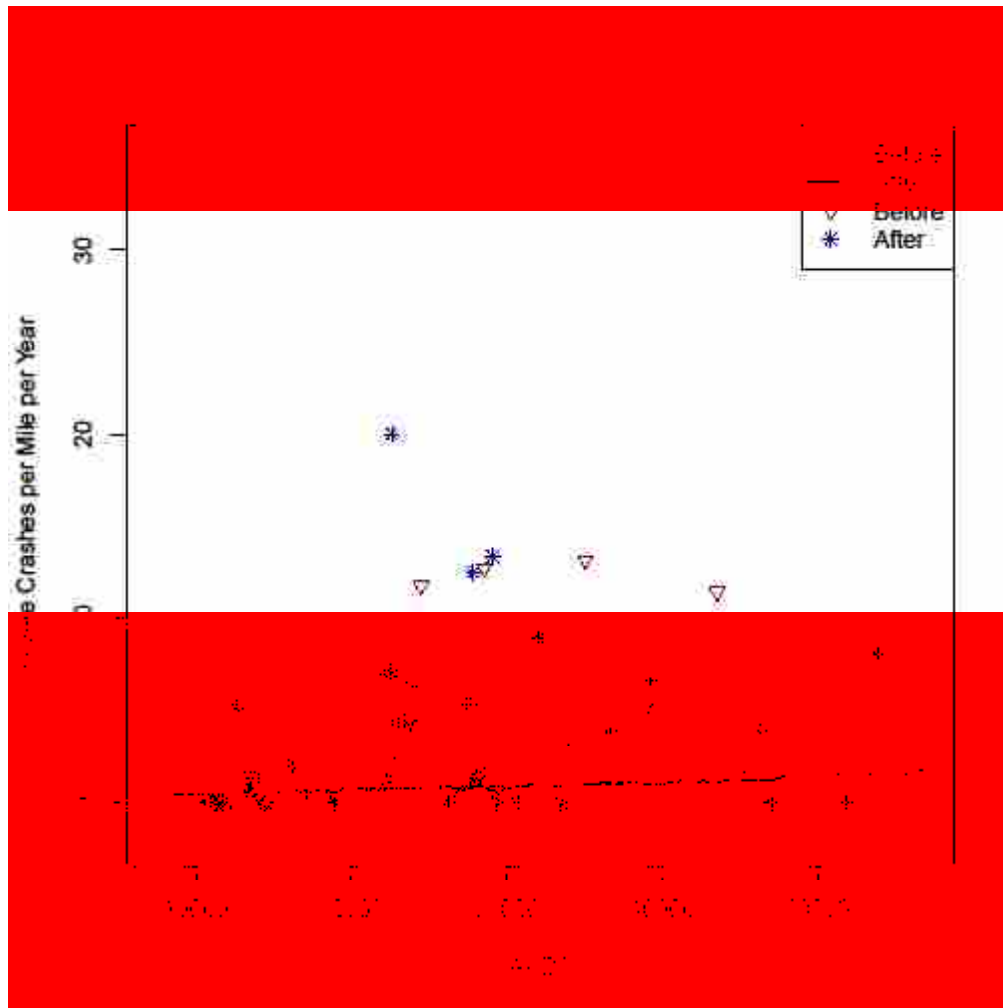


Figure 5-27. Severe crashes for all sites.

Figure 5-28 shows the corresponding probability distribution of the differences between the before and after periods for severe crashes. The gray portion of the distribution represents the probability that a decrease was detected from the before to the after period. As with the overall analysis, the entire distribution of differences shown in Figure 5-28 is less than zero, indicating a 100 percent probability that a decrease in severe crash frequency occurred after raised medians were installed.

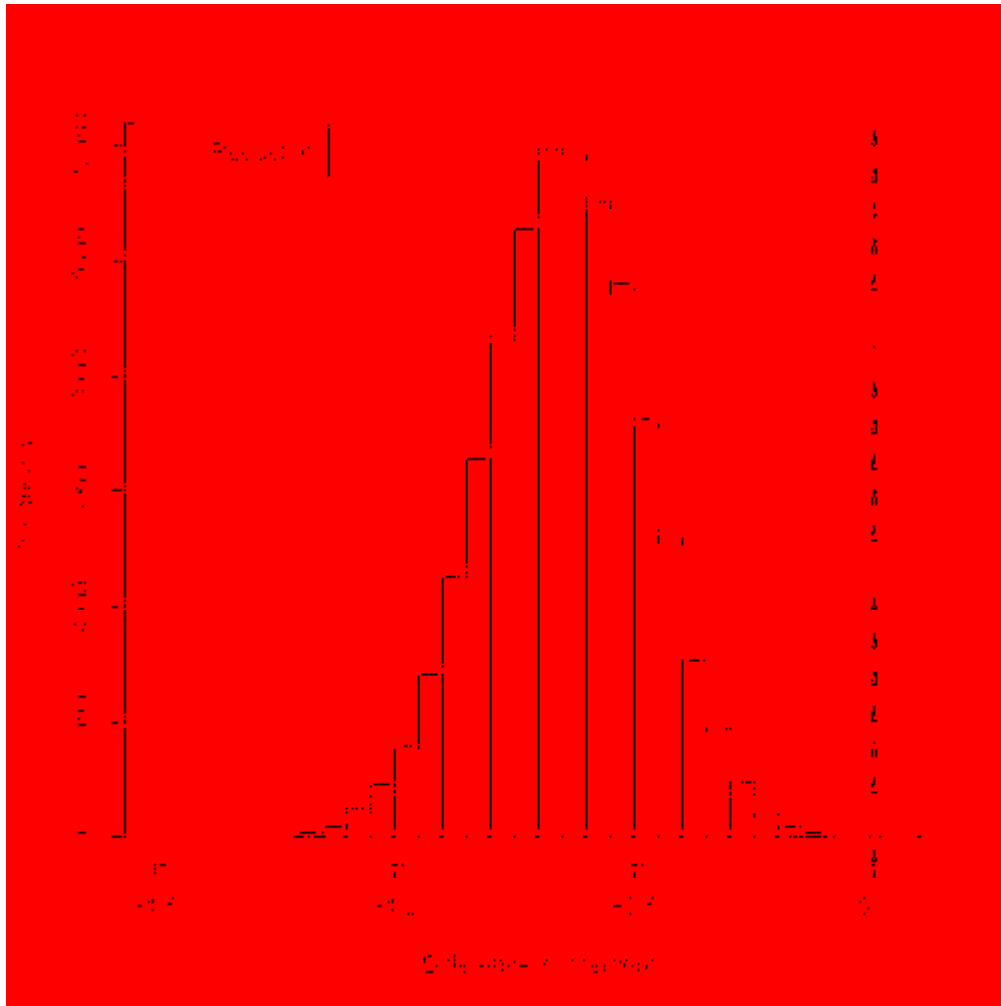


Figure 5-28. Distribution of differences of severe crashes for all raised median sites.

5.3 Chapter Summary

A summary of the results of the analysis performed on sites where raised medians have been installed are presented in this chapter. An analysis was performed on individual locations as well as an analysis of data for all locations grouped together. In each case decrease or increase in overall and severe crash frequency was presented. Additionally, the corresponding distribution of differences was presented.

The analysis of the individual locations where raised medians have been installed show interesting results. Based on the large percent chance of decrease, the analysis showed four of the six study sites experienced a significant decrease in the overall crash frequency while the remaining site (SR 71) experienced an increase in the overall crash frequency. The probability of difference for the remaining site (SR 265) was too low to confidently determine if a reduction or increase occurred. Table 5-2 provides a summary of the impact of raised medians on all crashes.

Table 5-2. Summary of Overall Raised Median Crashes

Location	State Route	Year Installed	Probability of Decrease	Percent Change
University Parkway	265	2002	53%	-0.3%
Alpine Highway	74	2002	94%	-21.5%
400/500 South	186	2001	100%	-43.4%
12300 South	71	2004	0%	26.2%
St. George Blvd	34	2006	100%	-28.7%
SR 36	36	2005	100%	-44.3%

Similarly, many of the sites also showed a decrease in the severity of crashes. Table 5-3 provides a summary of the impact of raised medians on severe crashes. The results indicate that four of the six study sites experienced a significant decrease in the frequency of severe crashes after raised medians were installed. The analysis indicated an increase may have occurred at the two remaining sites (SR 74 and SR 71). However, the probability of a difference at both of the sites was far too low to make any definite conclusions.

Table 5-3. Summary of Severe Raised Median Crashes

Location	State Route	Year Installed	Probability of Decrease	Percent Change
University Parkway	265	2002	100%	-66.7%
Alpine Highway	74	2002	43%	38.2%
400/500 South	186	2001	100%	-72.2%
12300 South	71	2004	37%	20.1%
St. George Blvd	34	2006	93%	-47.9%
SR 36	36	2005	97%	-61.9%

Data from all analysis sites grouped together also provided interesting results. The combined analysis showed 100 percent probability of a reduction of 34.8 percent in overall crash frequency. The severe crash analysis results on all sites showed an even better increase in safety as the analysis showed a 100 percent probability that severe crashes reduced by 46.8 percent. These results are summarized in Table 5-4.

Table 5-4. Results of All Raised Median Sites

Type	Probability of Decrease	Percent Change
Overall	100%	-34.8%
Severe	100%	-46.8%

Additionally, the analysis revealed several outliers that experienced an unusually high frequency of either overall or severe crashes. Further research should be performed to identify factors that may contribute to the high frequency.

6 CABLE BARRIER RESULTS

A hierarchical Bayesian analysis was performed at selected sites where cable barriers have been installed following the procedure outlined in Chapter 4. An analysis was performed on overall crash frequency, severe crash frequency, and cross-median crash frequency at locations where cable barriers have been installed. It is predicted that cable barriers will have no impact on overall crash frequency since cable barriers are designed to decrease severity and are not a preventative measure. The overall crash frequency analysis was included to provide background information for each location.

Two types of plots are produced for each analysis performed: The first plot is a plot of the actual data. The data plots display the actual data points and the mean of the posterior predictive distribution. Essentially it represents the mean regression line through the points from a Bayesian perspective. The reduction is calculated by taking the mean of the posterior distribution of differences between the two intercepts. This is a percent reduction because $\log(\text{after/before}) = \log(\text{after}) - \log(\text{before})$, and the intercepts are on the log scale. This is equivalent essentially to taking the after curve and dividing it by the before curve and getting the percent reduction.

The second plot produced is the plot of the distribution of the differences between the before and after periods. The differences plots display the posterior distributions of differences between the before and after intercepts of the model. Negative values indicate that the after time period saw a reduction in crashes. As the exact form of those posterior distributions is unknown,

the model uses simulated draws from the posterior with MCMC; since those draws represent the actual posterior distribution, the proportion of the draws less than zero represents the probability that there was a decrease in crashes from the before time period to the after time period.

6.1 Cable Barrier Individual Site Results

The safety impacts of the locations that have been chosen for analysis where cable barriers have been installed are discussed in this section. Details about each location are provided in Chapter 3. The analysis procedure is described in Chapter 4. Sites selected for analysis are shown in Table 6-1.

Table 6-1. Cable Barrier Locations

Site	Route	Begin MP	End MP	Length (Miles)	Location	Year Installed
1	I-15	267	269	2.0	Provo S-curves to University Parkway	2004
2	I-15	36	38	2.0	Between Pintura and Kolob Canyons	2005
3	I-15	257	261	4.0	Spanish Fork to SR 75	2005
4	I-15	330	334	4.0	South Layton to Syracuse	2006
5	I-15	309	312	3.0	600 N to 2300 N - Salt Lake	2007
6	I-215 E	1.5	2.5	1.0	3100 S to 3800 S - Salt Lake	2007
7	I-215 W	17	19.5	2.5	2100 S to 4500 S - Salt Lake	2007
8	I-80	135.8	136.1	0.3	Lamb's Canyon Interchange	2007

Analyses were performed on overall crashes, severe crashes, and cross-median crashes that occurred at each site, along with an overall analysis for all sites grouped together. The following sections summarize the results of the analysis performed at each individual site based

on crash data provided by UDOT as well as an overall analysis performed on all sites where cable barriers were installed.

6.1.1 I-15 Provo S-curves to University Parkway

A cable barrier was installed along a 2 mile segment of I-15 between Provo Center Street and University Parkway 2004. This section summarizes the results of the analysis performed before and after the cable barrier was installed. The before period used in the analysis is from 2002 to 2003 and the after period is from 2005 to 2008.

Figure 6-1 displays the crash frequency of overall crashes for the before and after periods as a function of AADT. The analysis indicates that the overall crash frequency increased by 39.1 percent after the installation of the cable barrier.

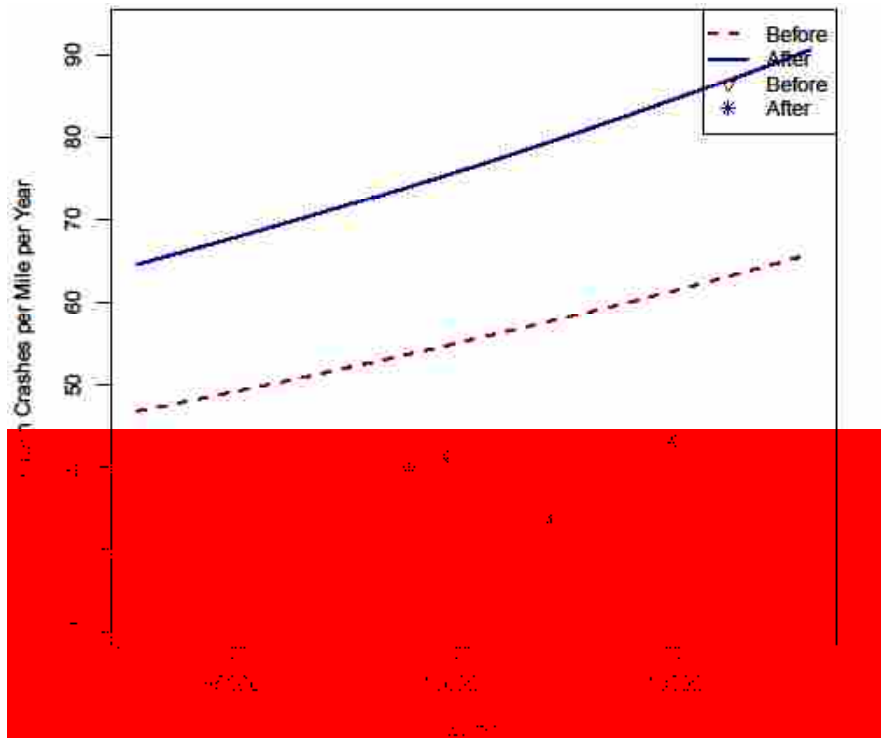


Figure 6-1. Overall crashes on I-15 between Provo S-curves to University Parkway.

Figure 6-2 shows the corresponding probability distribution of the difference between the before and after periods for all crashes. Approximately 98 percent of the distribution of the differences is greater than zero, indicating a 98 percent probability an increase in overall crashes occurred after the cable barrier was installed. However, it is anticipated the increase is likely the result of an increase in traffic volumes or other factors other than the cable barrier. As noted previously, cable barriers are not generally designed as a preventative measure for crashes.

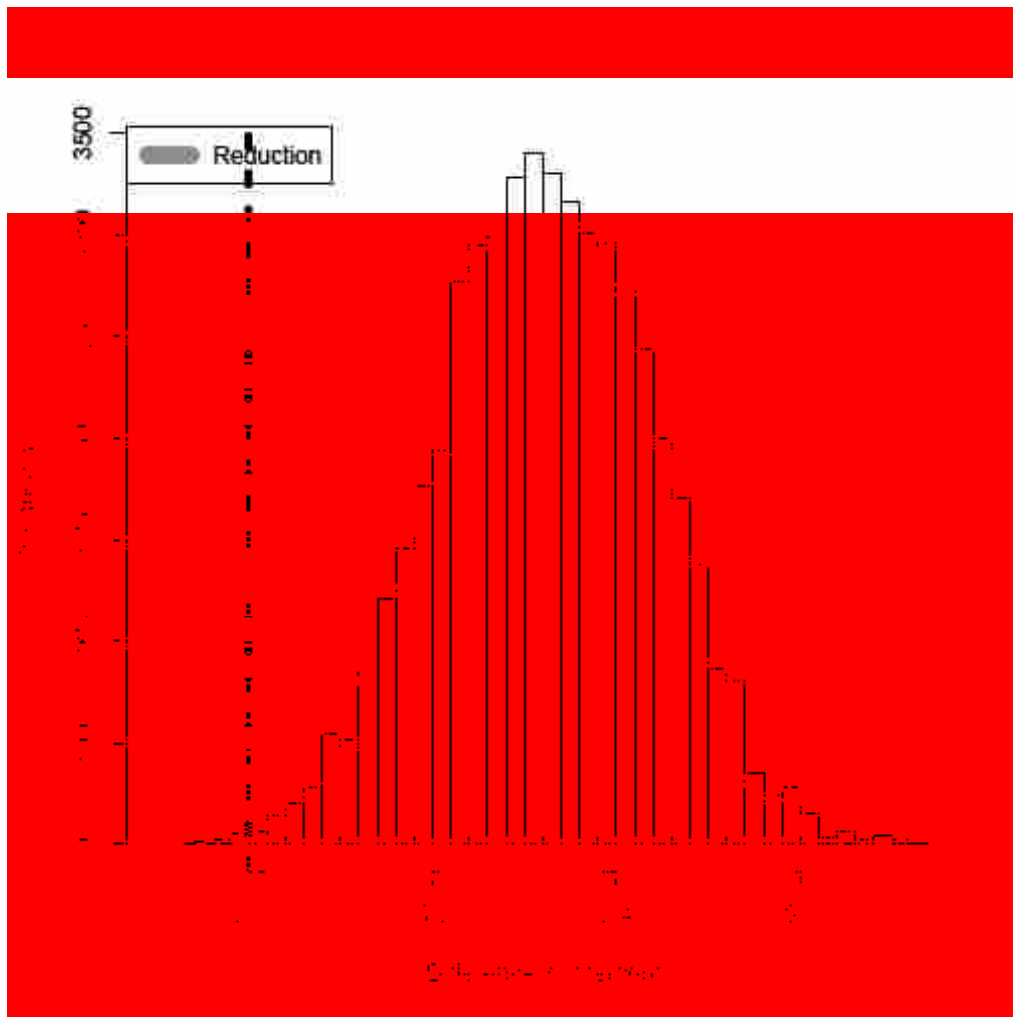


Figure 6-2. Distribution of differences for overall crashes on I-15 between Provo S-curves and University Parkway.

Figure 6-3 displays the crash frequency of severe crashes for the before and after periods. The severe crash analysis for this segment of I-15 suggest the possibility that severe crashes decreased by 16.4 percent after the installation of the cable barrier. However, the probability of a decrease, approximately 74.3 percent as illustrated by the percent of the distribution shown in Figure 6-4 greater than zero, was determined to be too low to confidently conclude a decrease occurred.

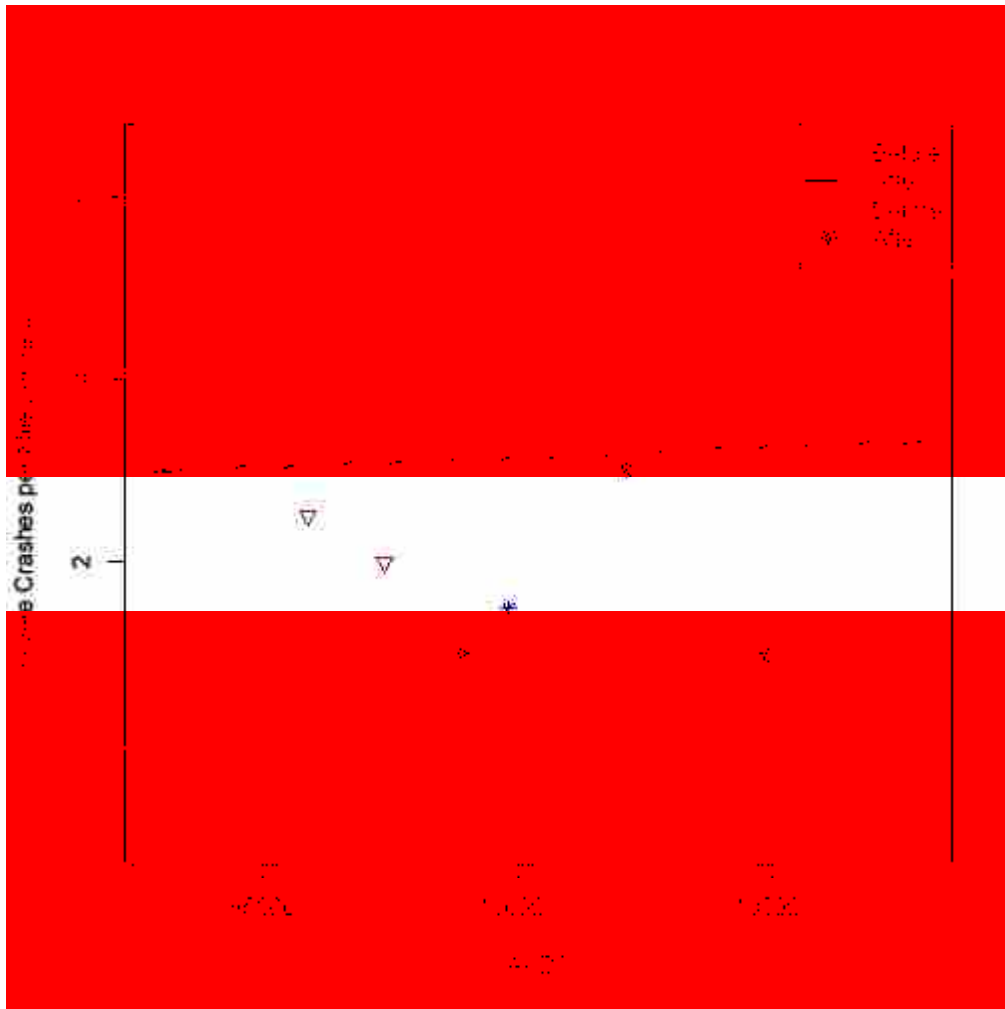


Figure 6-3. Severe crashes on I-15 between Provo S-curves and University Parkway.

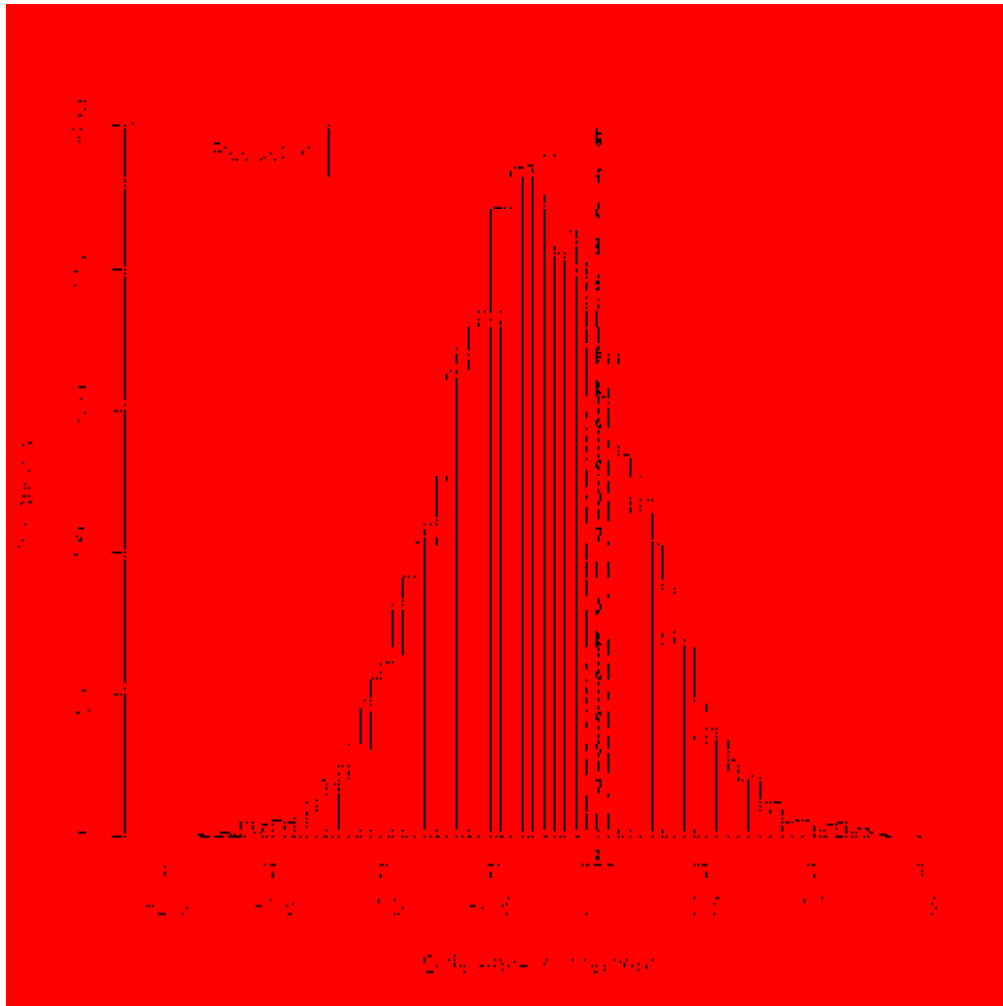


Figure 6-4. Distribution of differences for severe crashes on I-15 between Provo S-curves and University Parkway.

The results of the cross-median analysis for this segment of I-15 were similar to the severe crash analysis results. The cross-median crash analysis for this segment of I-15 suggest the possibility that severe crashes decreased by 31.0 percent after the installation of the cable barrier. The results of the analysis are represented graphically in Figure 6-5.

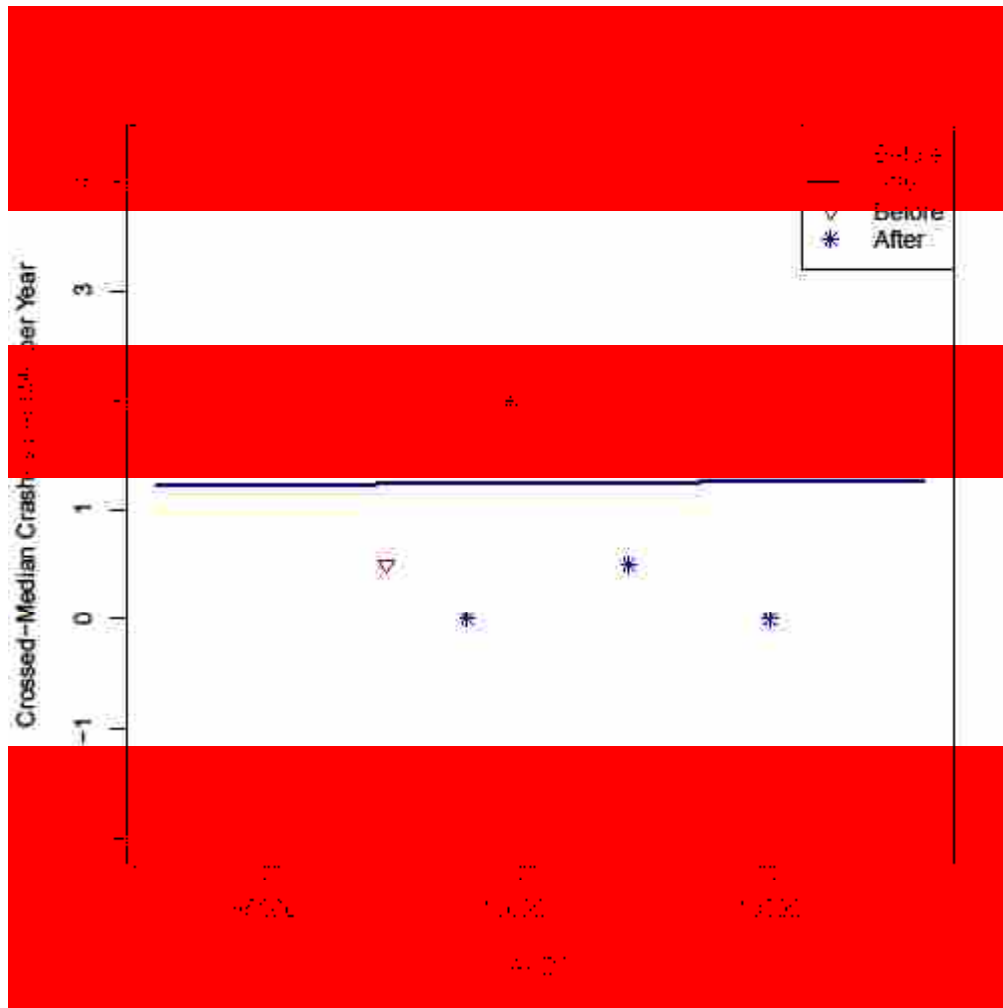


Figure 6-5. Cross-median crashes on I-15 between Provo S-curves and University Parkway.

Figure 6-6 shows the probability distribution of the difference between the before and after periods for cross-median crashes. The grayed portion of the plot shows the portion of the distribution that was less than zero. Approximately 82.2 percent of the distribution of cross-median crashes for this segment of I-15 was less than zero. This can be interpreted to mean an 82.2 percent probability a decrease occurred. While the probability is suggestive a decrease occurred, the probability was determined to be too low to confidently conclude a decrease occurred.

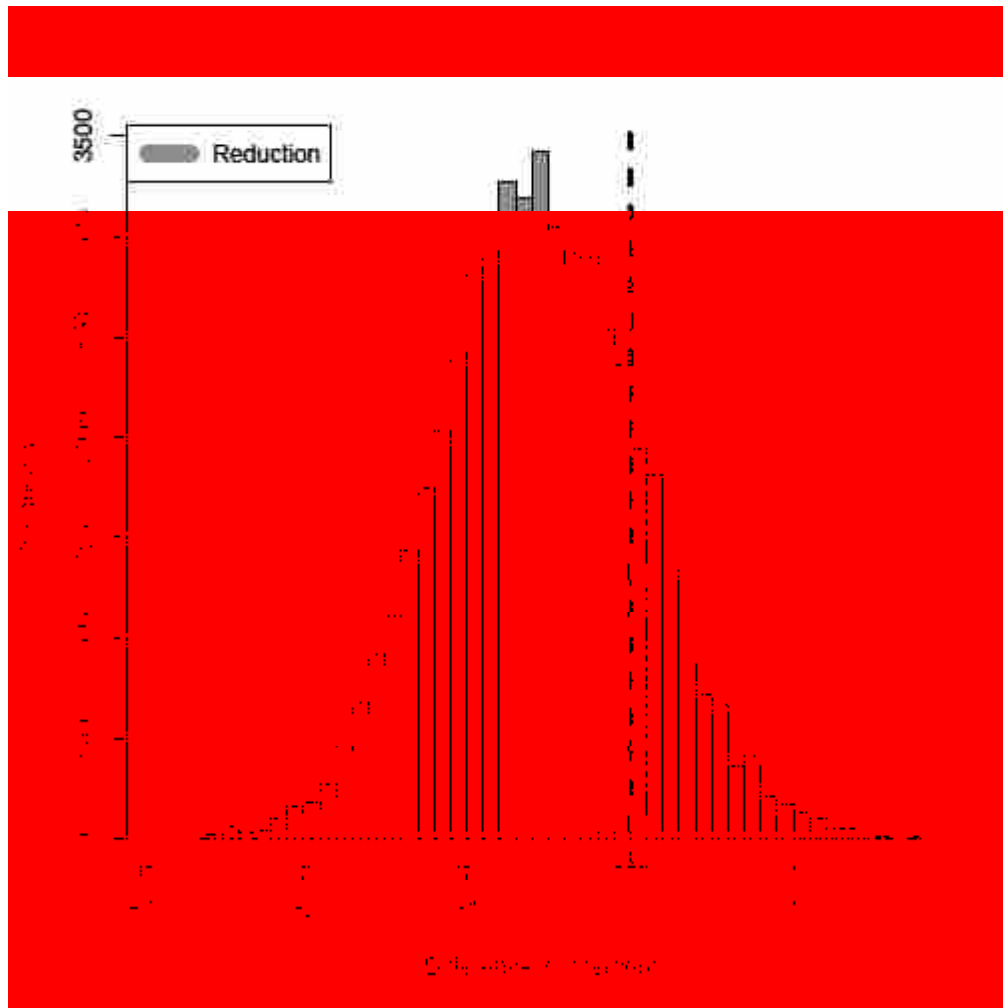


Figure 6-6. Distribution of differences for cross-median crashes on I-15 between Provo S-curves and University Parkway.

6.1.2 I-15 between Pintura and Kolob Canyons

This analysis site is a 2 mile segment of I-15 located in the Southern part of Utah between Cedar City and St. George. A cable barrier was installed along this segment in 2005. This section summarizes the results of the analysis performed before and after the cable barrier was installed. The before period used in the analysis is from 2002 to 2004 and the after period is from 2006 to 2008.

The results of the overall crash analysis for the segment of I-15 are displayed graphically in Figure 6-7. Figure 6-8 shows the probability distribution of the difference between the before and after periods for the overall crash analysis. The results of the analysis indicated that there was 23.4 percent chance a decrease occurred after the installation of the cable barrier. This result can be interpreted to mean that there was a greater probability an increase in overall crash frequency occurred at this site. However, the results are too low to confidently claim any change occurred. Several outlier sites were also revealed that need to be explored further in future research.

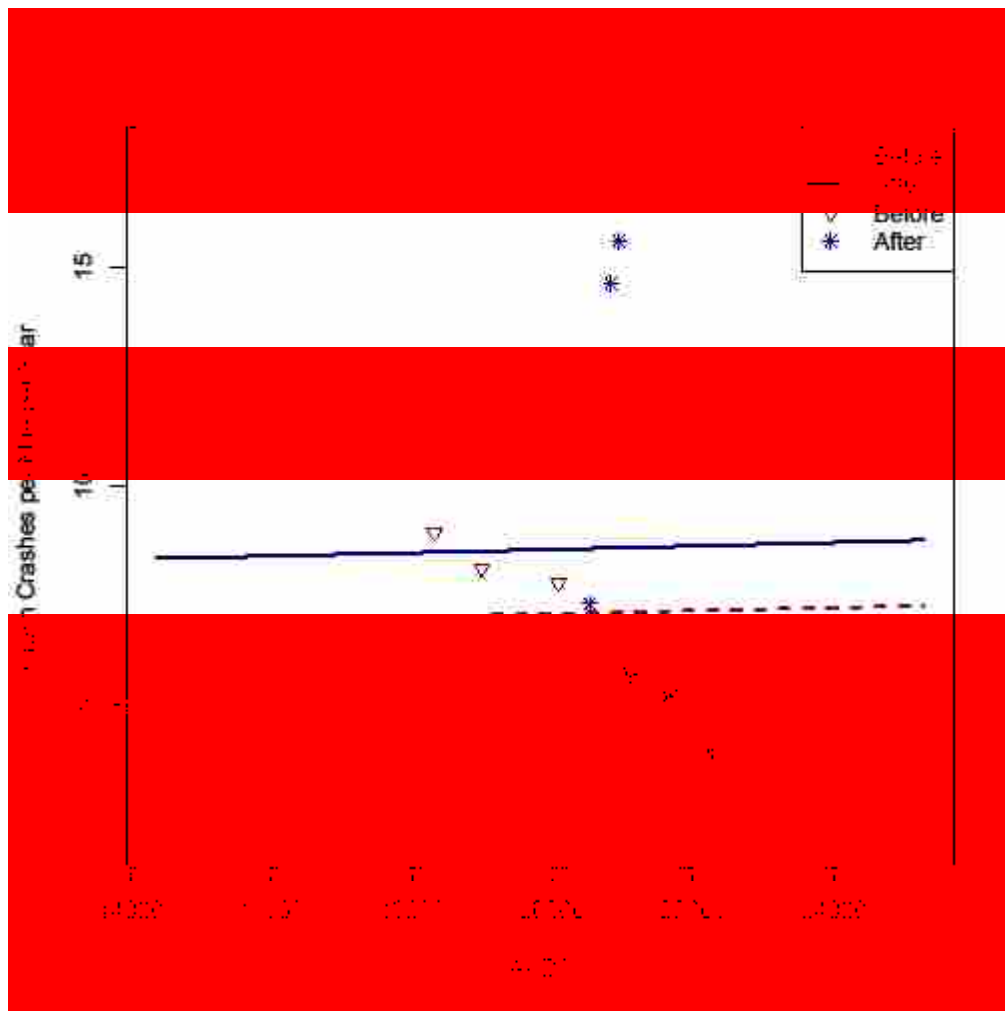


Figure 6-7. Overall crashes on I-15 between Pintura and Kolob Canyons.

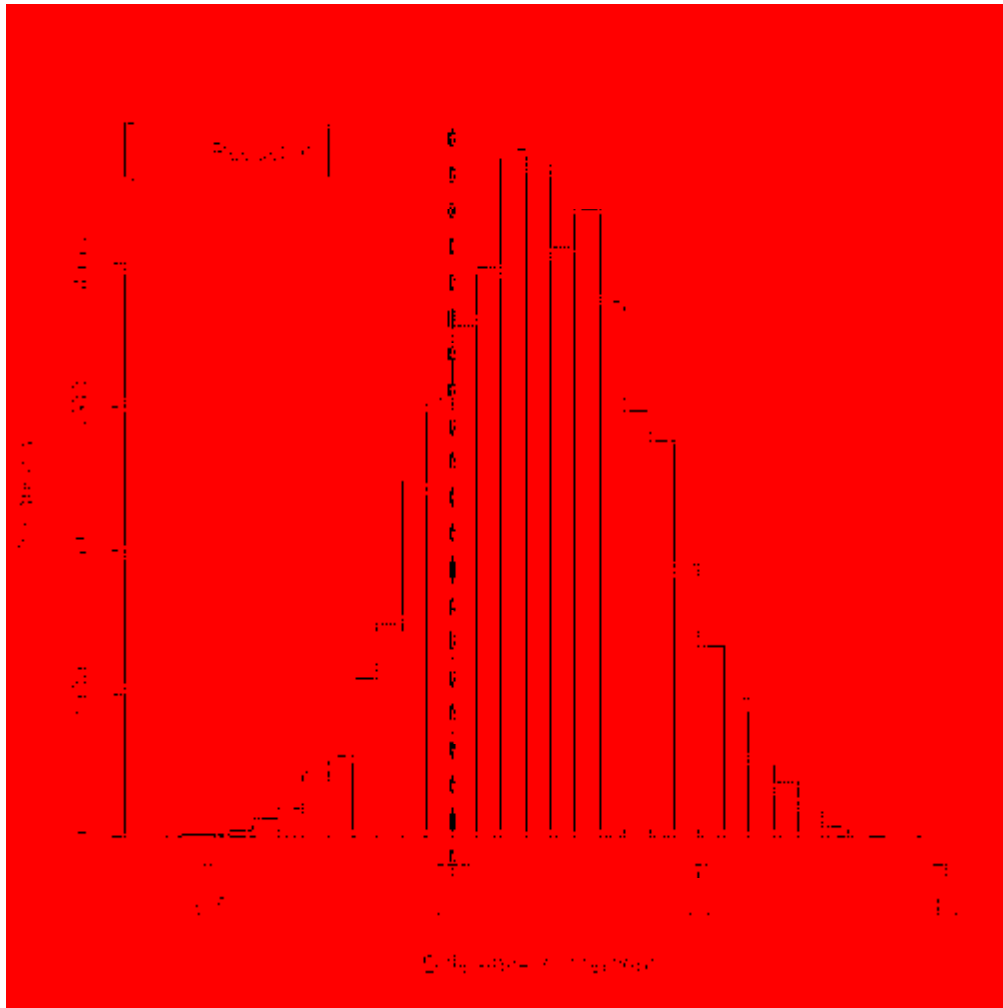


Figure 6-8. Distribution of differences for overall crashes on I-15 between Pintura and Kolob Canyons.

The severe crash analysis results for this segment showed promising results. The results indicated that severe crashes decreased by 79.9 percent after the installation of the cable barrier. Figure 6-9 displays the crash frequency of severe crashes for the before and after periods.

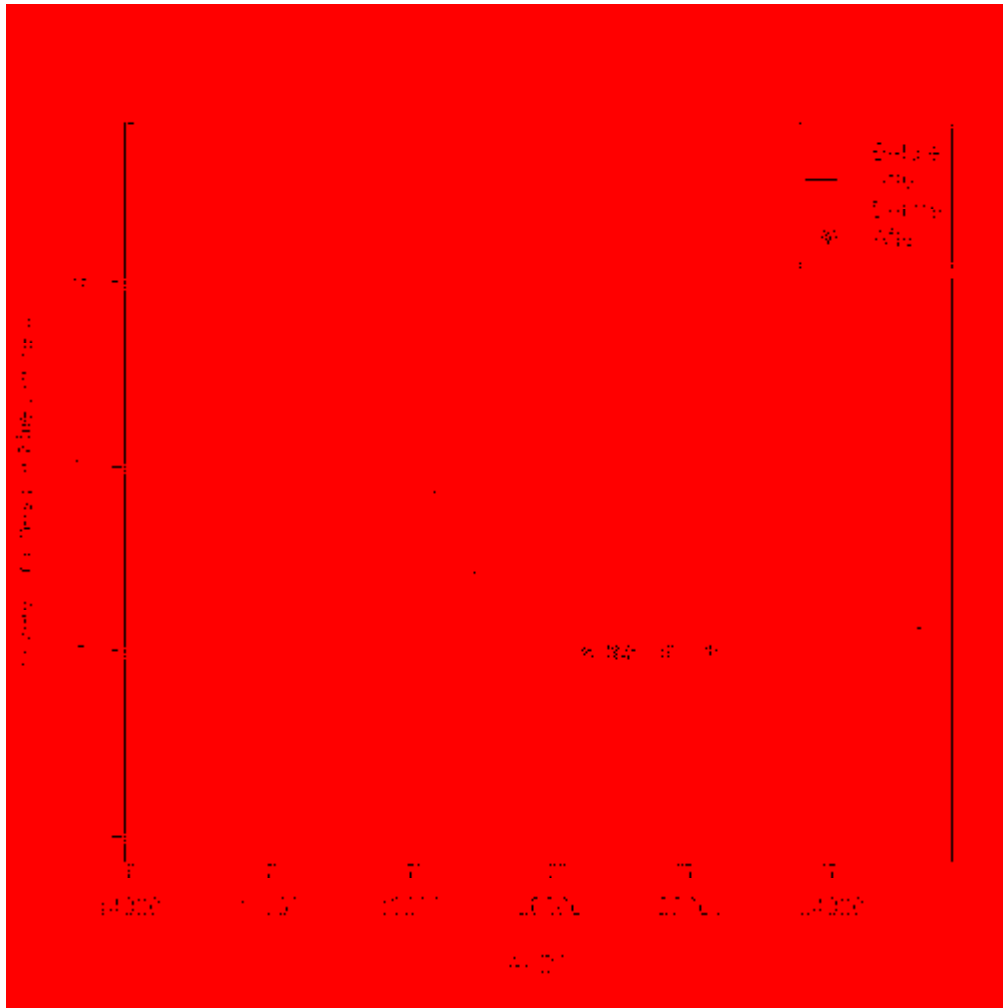


Figure 6-9. Severe crashes on I-15 between Pintura and Kolob Canyons.

Figure 6-10 shows the probability distribution of the difference between the before and after periods for the severe crash analysis for this segment of I-15. The probability a decrease occurred at this site was 99.7 percent, as represented by the gray portion of the distribution shown in Figure 6-10. These results provide convincing evidence that a decrease in severe crash frequency occurred at this site after the installation of the cable barrier.

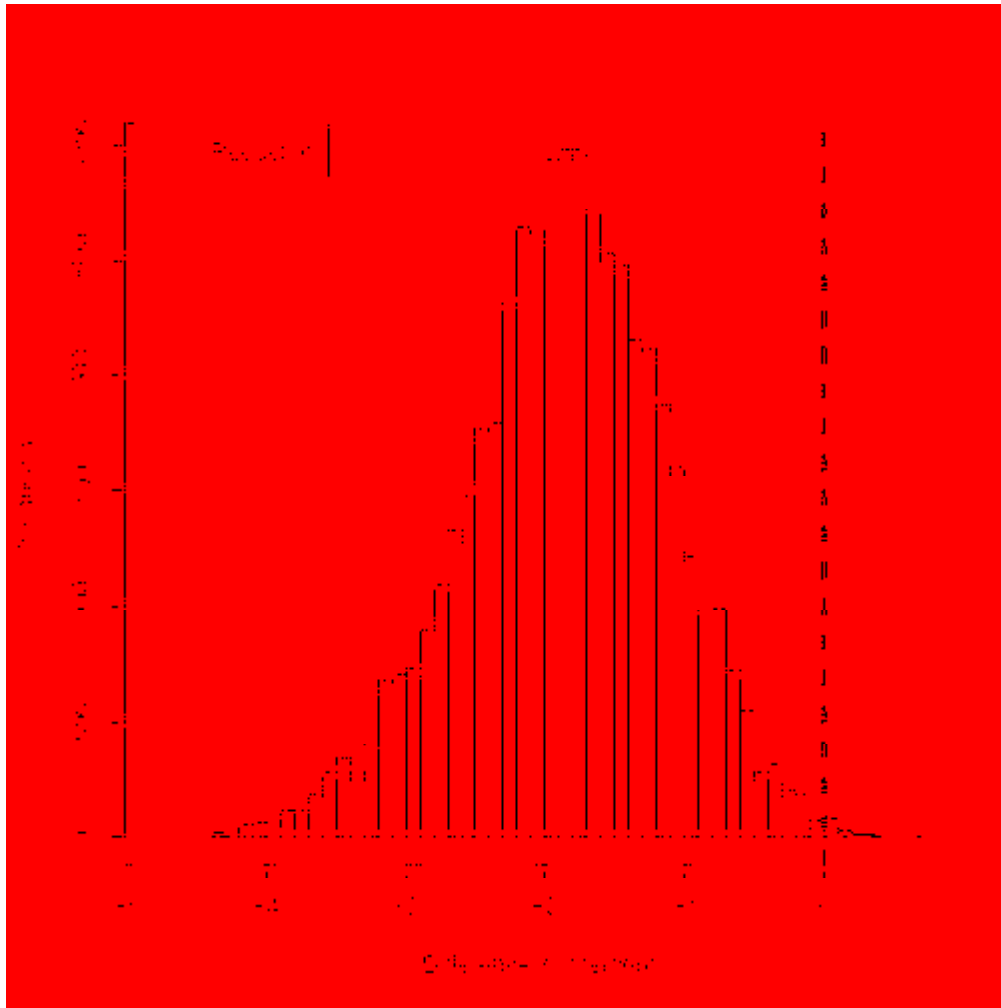


Figure 6-10. Distribution of differences for severe crashes on I-15 between Pintura and Kolob Canyons.

The cross-median crash analysis results for this segment were also very promising. The results indicated that cross-median crash frequency decreased by 69.2 percent after the installation of the cable barrier. Figure 6-11 displays the crash frequency of cross-median crashes for the before and after periods.

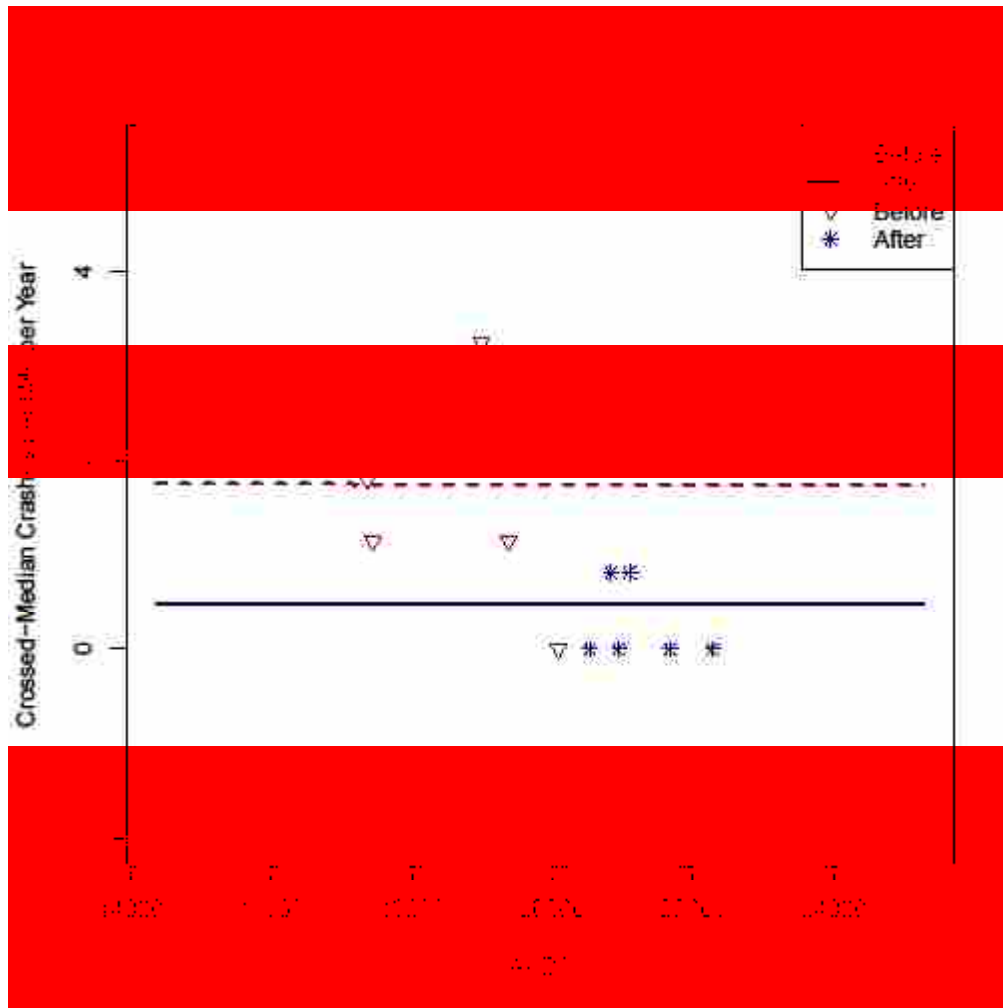


Figure 6-11. Cross-median crashes on I-15 between Pintura and Kolob Canyons.

Figure 6-12 shows the probability distribution of the difference between the before and after periods for the cross-median crash analysis for this segment of I-15. The probability a decrease occurred at this site was 99 percent, as represented by the gray portion of the distribution shown in Figure 6-12. These results provide convincing evidence that a decrease in cross-median crash frequency occurred at this site after the installation of the cable barrier.

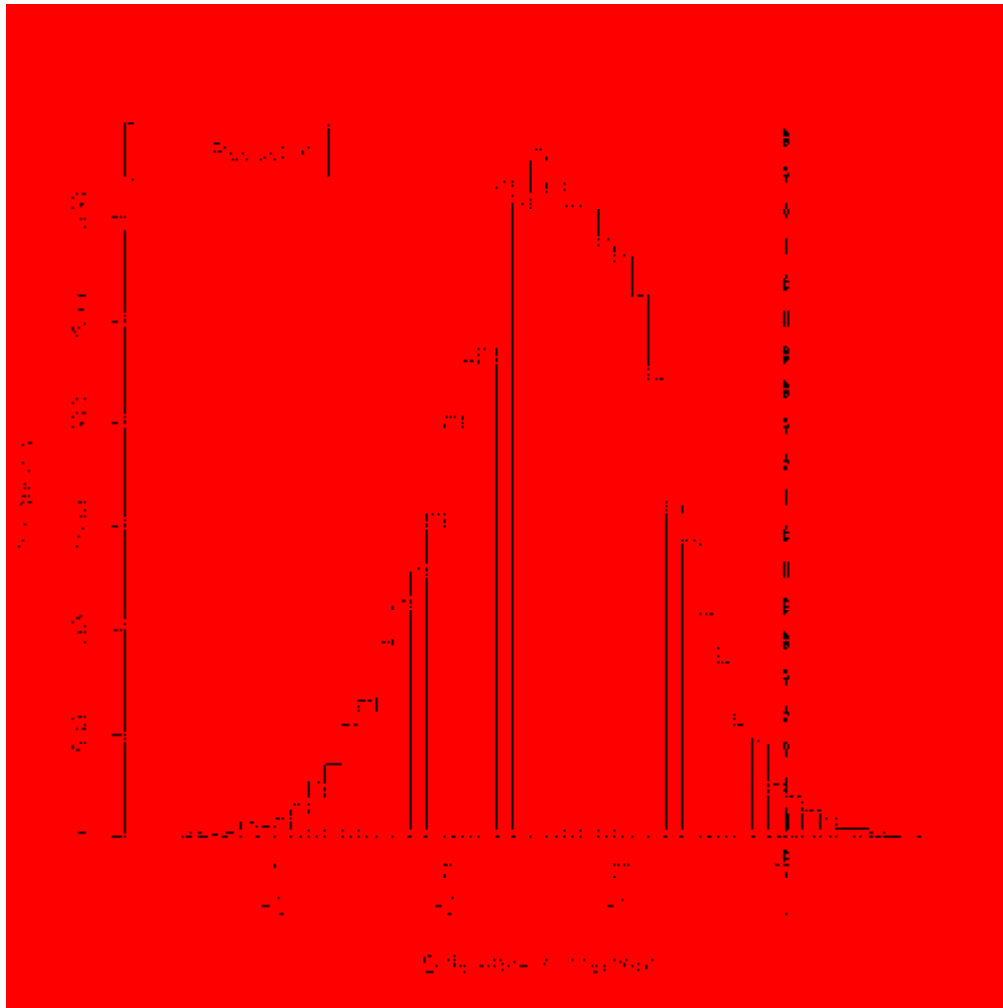


Figure 6-12. Distribution of differences for cross-median crashes on I-15 between Pintura and Kolob Canyons.

6.1.3 I-15 Spanish Fork to SR 75

In 2005 a cable barrier was installed along the section of I-15 between Spanish Fork and SR 75. This section is a 4 mile segment of I-15 located in the south end of Utah County. This section summarizes the results of the analysis performed before and after the cable barrier was installed. The before period used in the analysis is from 2002 to 2004 and the after period is from 2006 to 2008.

The results of the overall crash analysis are displayed graphically in Figure 6-13. The results of the overall crash analysis for this segment show a 93 percent increase in the overall crash frequency after the cable barrier was installed. The corresponding distribution of the differences for the overall crash analysis are shown in Figure 6-14.

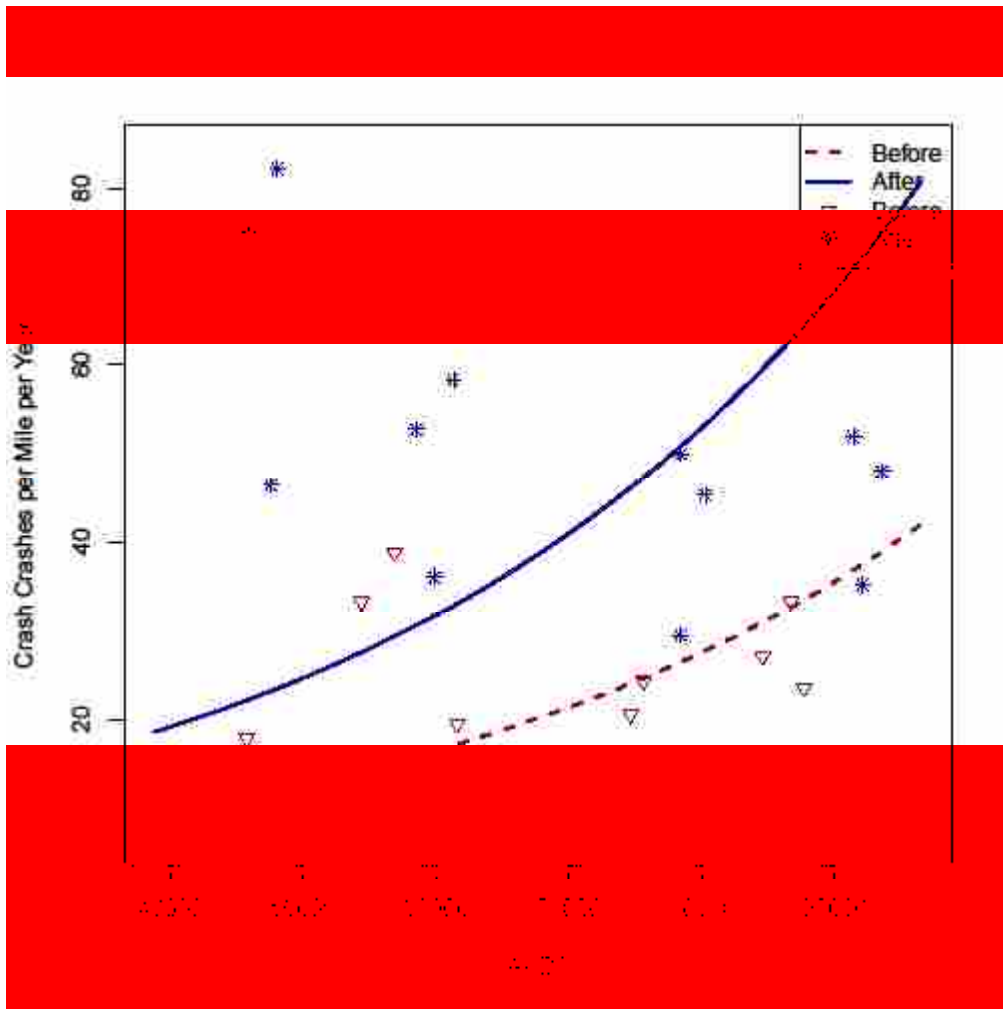


Figure 6-13. Overall crashes on I-15 between Spanish Fork and SR 75.

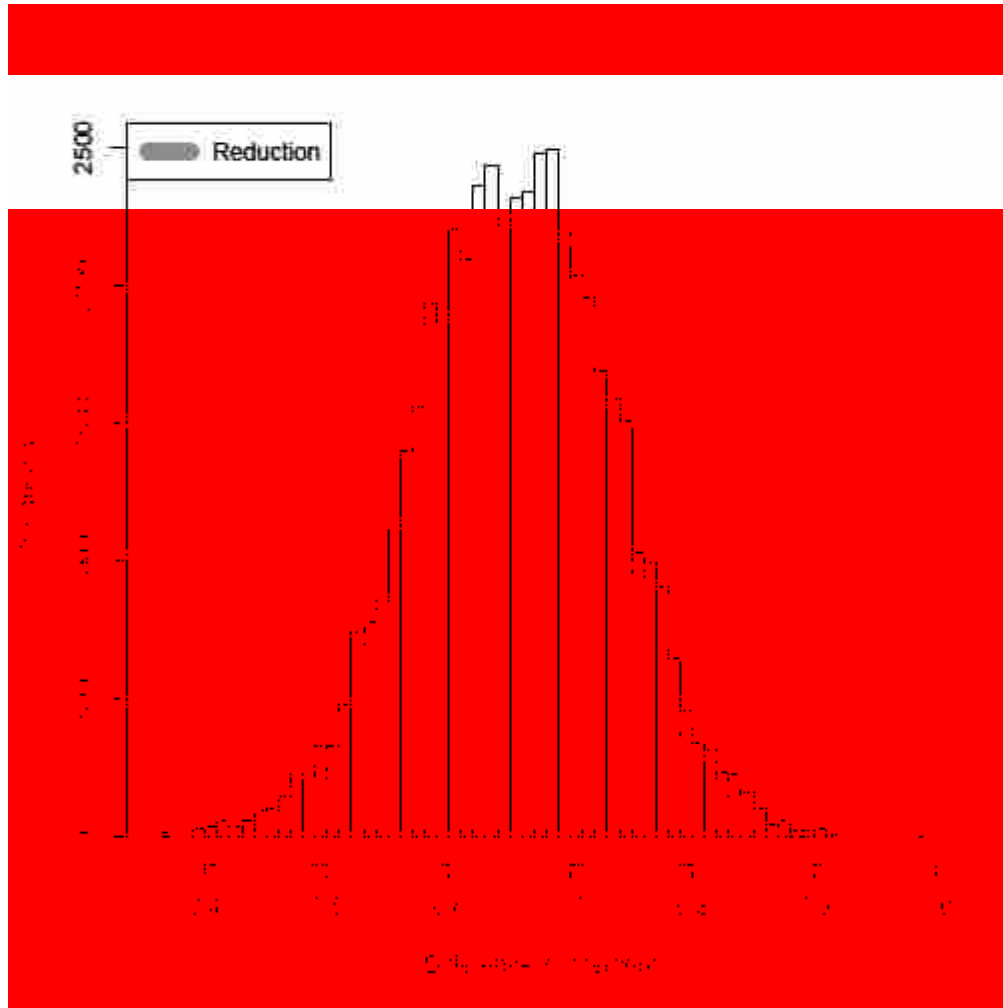


Figure 6-14. Distribution of differences for overall crashes on I-15 between Spanish Fork and SR 75.

The entire distribution was greater than zero, indicating a 100 percent probability that an increase in the overall crash frequency occurred after the installation of the cable barrier. However, it is unlikely the increase is a direct result of the cable barrier. It is more likely that the increase in overall crashes is the product of increased traffic volumes and other contributing factors. The results are useful as background information to show an increase in crashes overall.

The results of the severe crash analysis for this segment of I-15 indicate that the installation of the cable barrier had no impact on severe crash frequency for this segment. These

results are displayed in Figure 6-15. The analysis indicated a 6.5 percent decrease in severe crash frequency after the installation of the cable barrier.

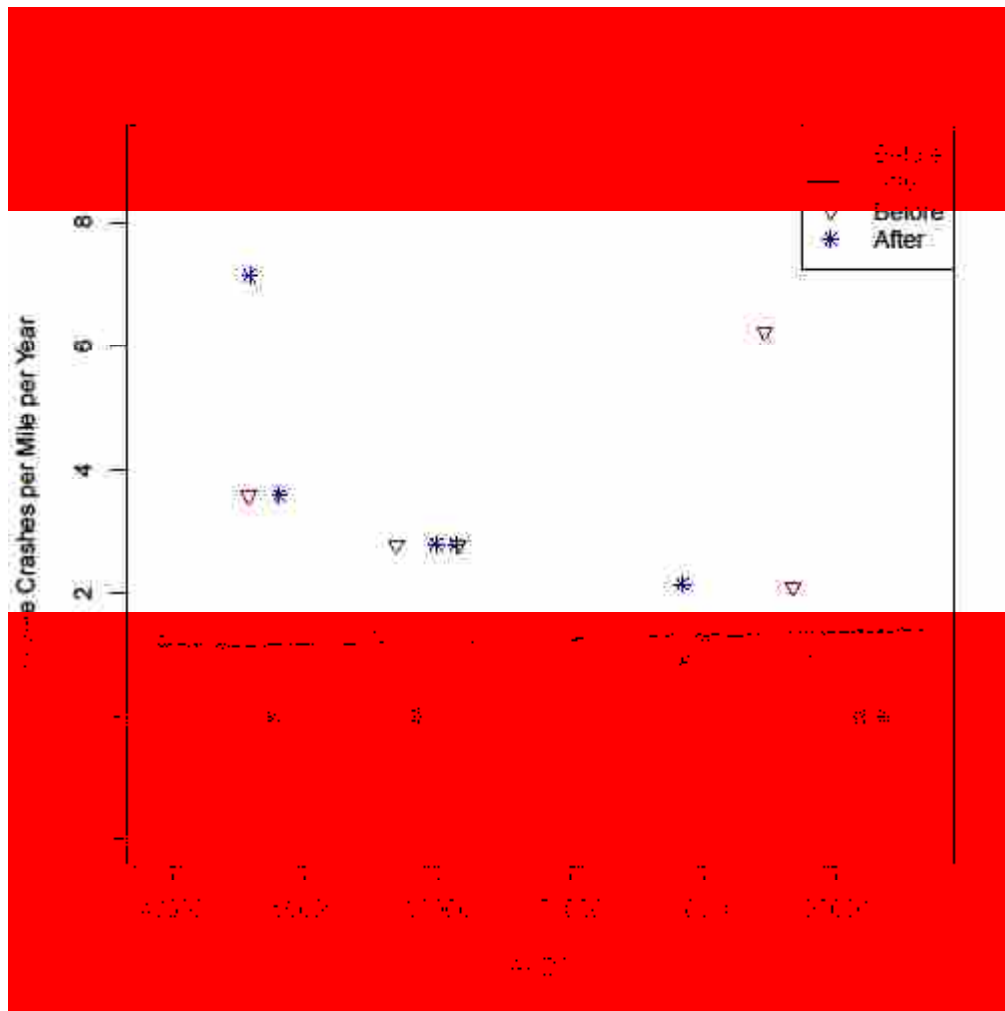


Figure 6-15. Severe crashes on I-15 between Spanish Fork and SR 75.

Figure 6-16 shows the corresponding distribution of differences for the severe crash analysis for this segment of I-15. The results of the analysis indicate a 64.2 percent probability a decrease in severe crash frequency occurred after the installation of the cable barrier. Therefore, even though the analysis results suggest a decrease may have occurred, the probability was determined to be too low to be conclusive.

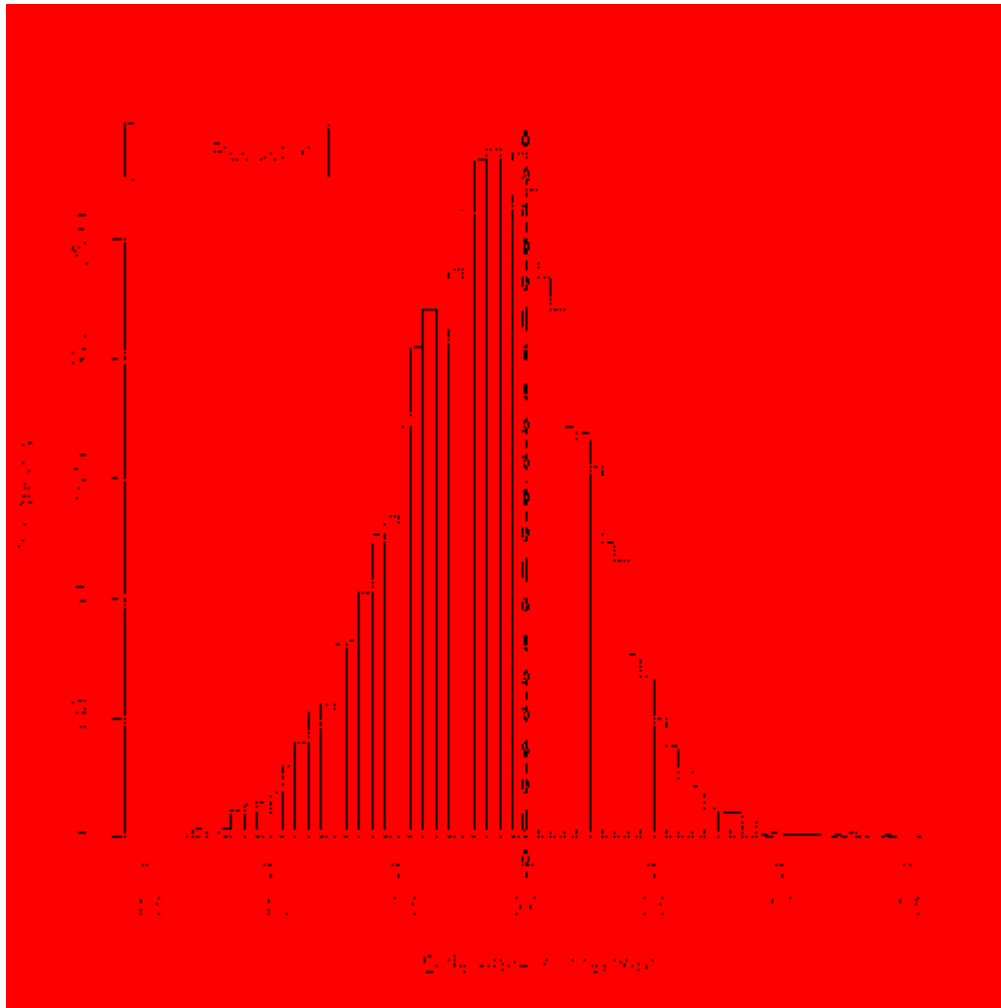


Figure 6-16. Distribution of differences of severe crashes on I-15 between Spanish Fork and SR 75.

The results of the cross-median analysis were more promising than the severe crash analysis for this segment. Figure 6-17 displays the crash frequency of cross-median crashes for the before and after periods as a function of AADT. The analysis results indicate that cross-median crash frequency decreased by 51.5 percent after the cable barrier was installed.

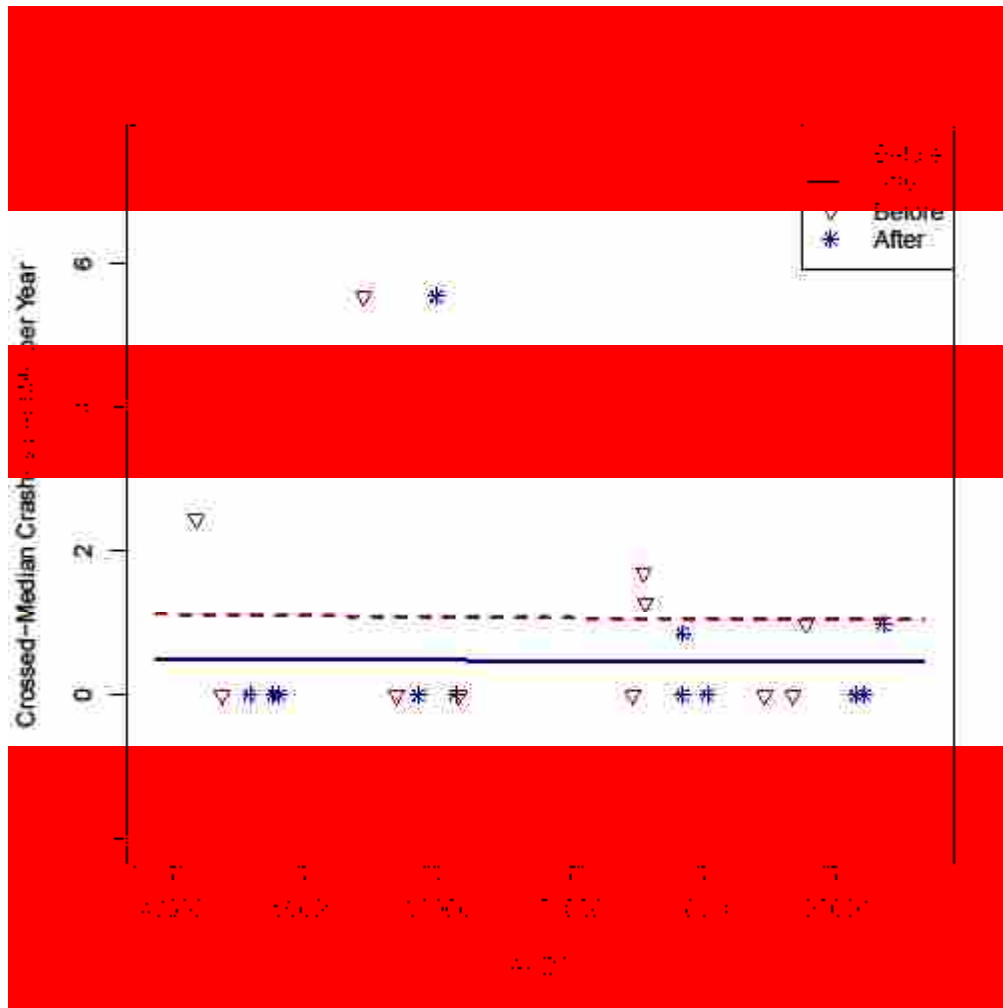


Figure 6-17. Severe crashes on I-15 between Spanish Fork and SR 75.

Figure 6-18 shows the corresponding probability distribution of the difference between the before and after periods for cross-median crashes for this segment. An estimated 96.2 percent of the probability distribution for this site was less than zero. This can be interpreted to mean that there was a 96.2 percent probability that a decrease in cross-median crashes occurred.

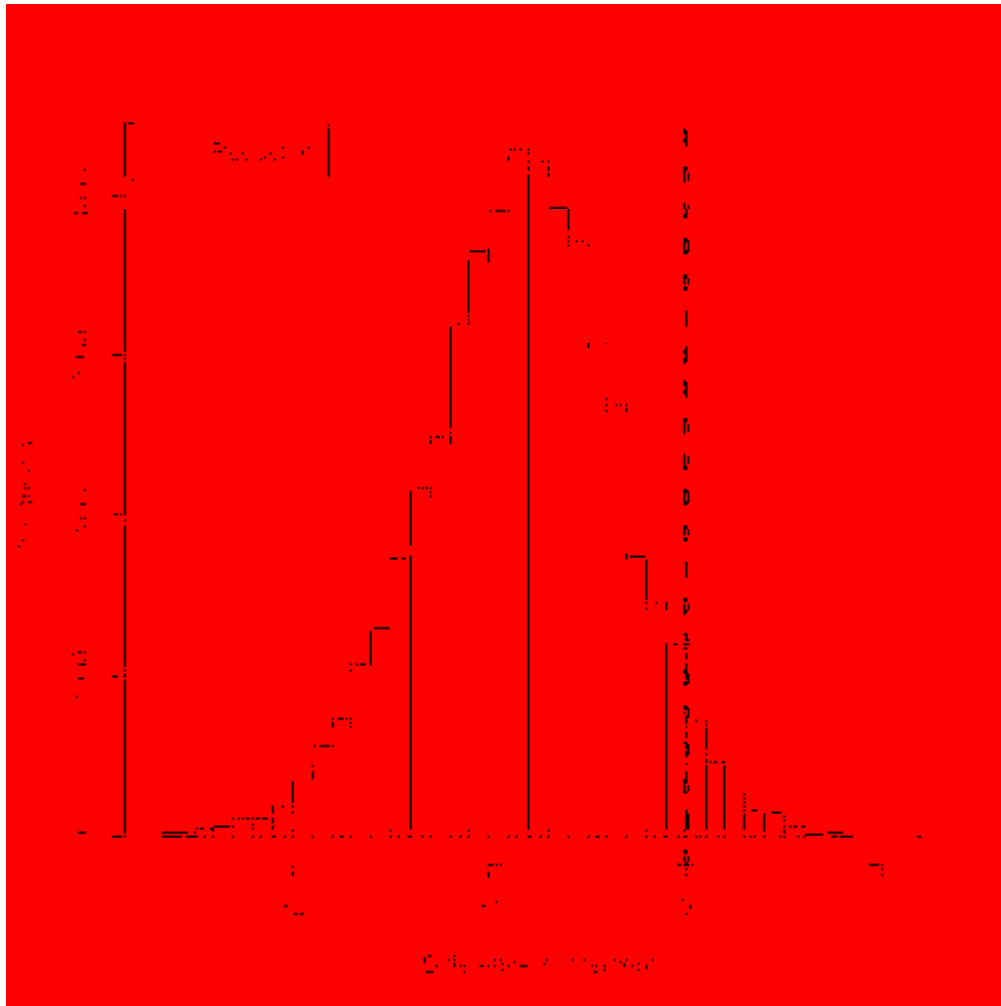


Figure 6-18. Distribution of differences for cross-median crashes on I-15 between Spanish Fork and SR 75.

6.1.4 I-15 South Layton to Syracuse

This site is a segment of I-15 located in Davis County north of Salt Lake. A cable barrier was installed at a 4 mile segment between South Layton and Syracuse. The project was completed in 2006. This section summarizes the results of the analysis performed before and after the cable barrier was installed. The before period used in the analysis is from 2002 to 2005 and the after period is from 2007 to 2008.

Figure 6-19 displays the crash frequency of the overall crash analysis for the before and after periods as a function of AADT. Figure 6-20 shows the probability distribution of the difference between the before and after periods for overall crashes.

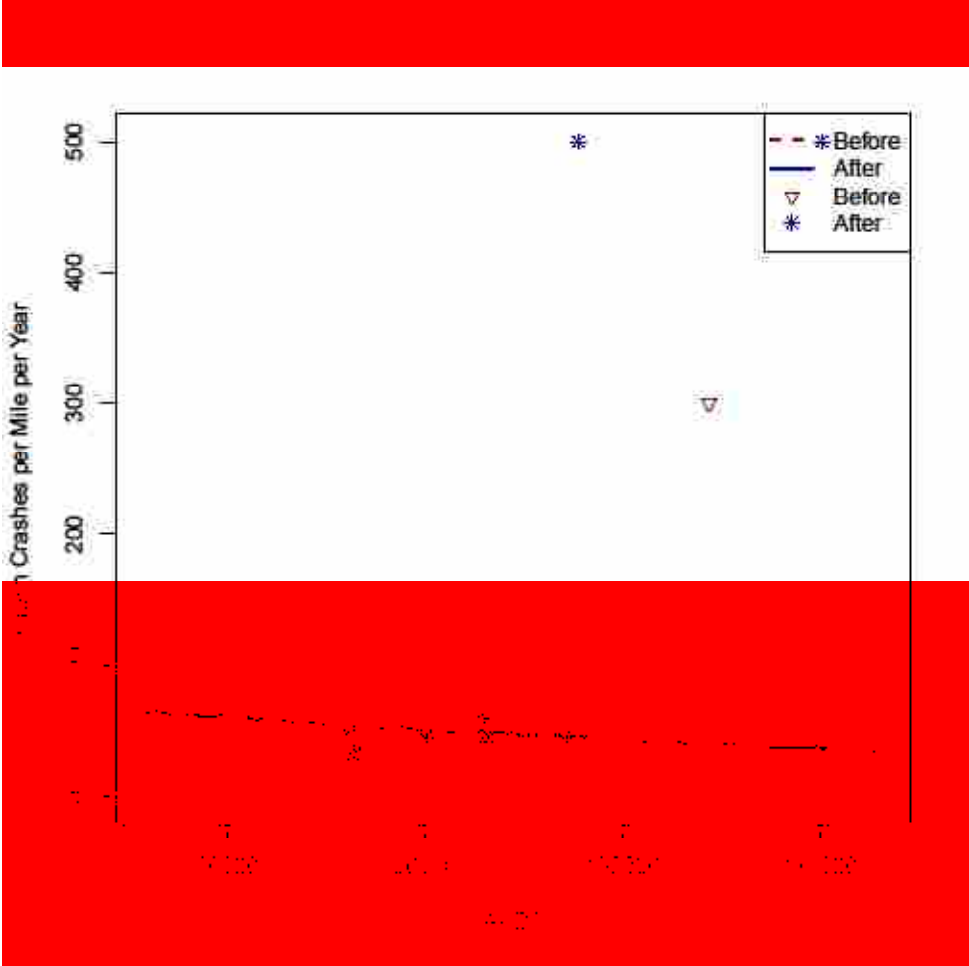


Figure 6-19. Overall crashes on I-15 from South Layton to Syracuse.

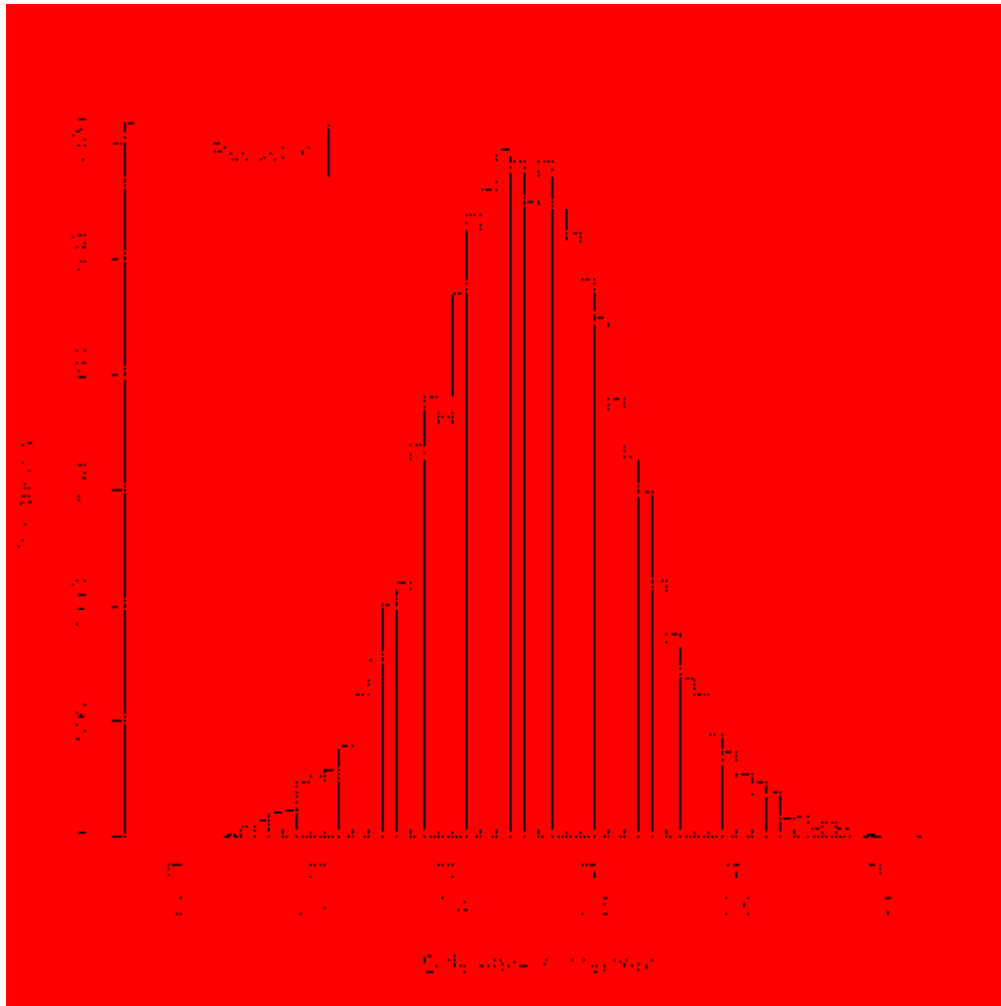


Figure 6-20. Distribution of differences for overall crashes on I-15 between South Layton and Syracuse.

The entire distribution of the differences for the overall analysis was greater than zero, as shown in Figure 6-20. This can be interpreted as a 100 percent probability that an increase occurred after the installation of the cable barrier. The corresponding increase in overall crash frequency was 57.9 percent. As noted previously, it is anticipated the increase in overall crash frequency is most likely the result of an increase in traffic volumes or factors other than the cable barrier. The analysis also revealed an outlier for both the before and after periods. These

two sites should be analyzed in the future using the analysis procedure developed in this research to address the specific causes of the crashes.

The results of the severe crash analysis for this segment provide more promising results. Figure 6-21 displays the crash frequency of severe crashes for the before and after periods as a function of AADT. The results of the analysis indicate that the severe crash frequency decreased by 45.4 percent for this segment after a cable barrier was installed.

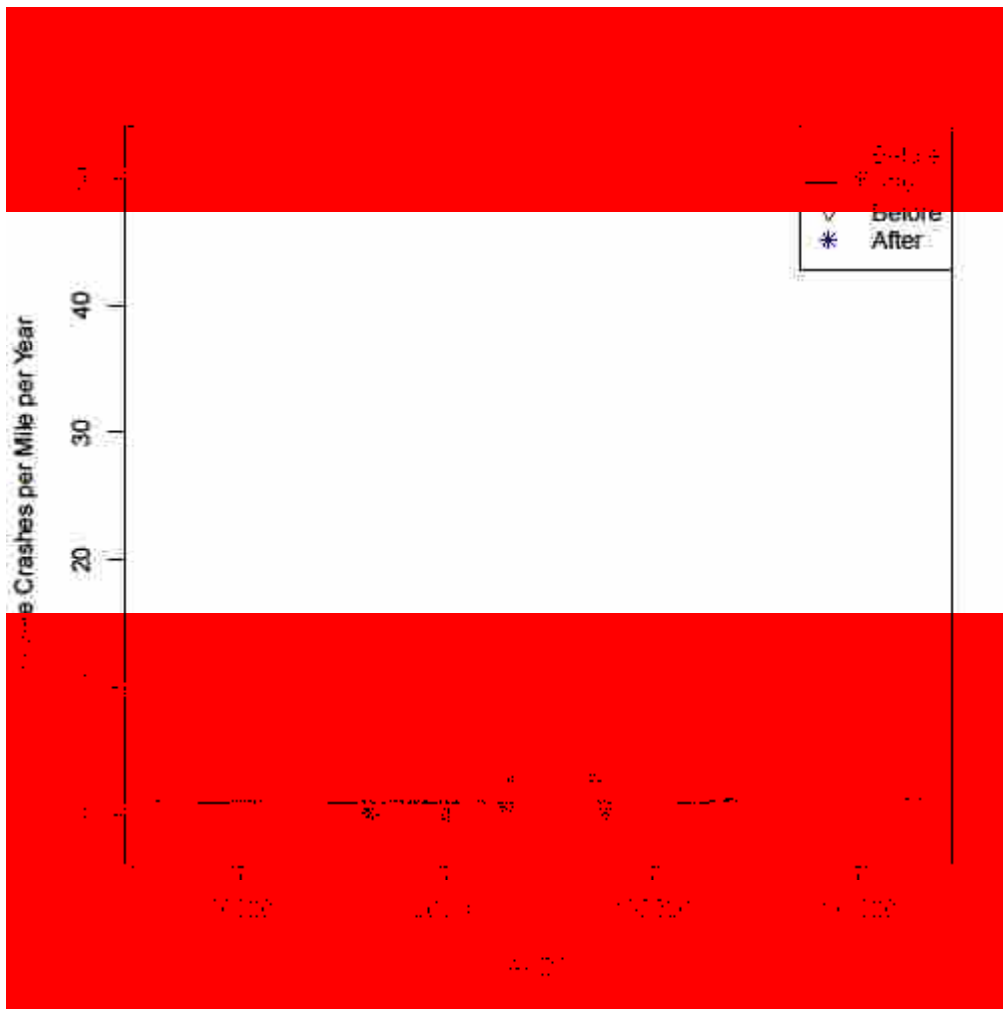


Figure 6-21. Severe crashes on I-15 from South Layton to Syracuse.

Figure 6-22 shows the probability distribution of the difference between the before and after periods for severe crashes. The results of the analysis indicate a very strong probability that the installation of the cable barrier had impact on severe crashes at this site. The probability that a decrease occurred was 96.5 percent as represented by the grayed portion of Figure 6-22.

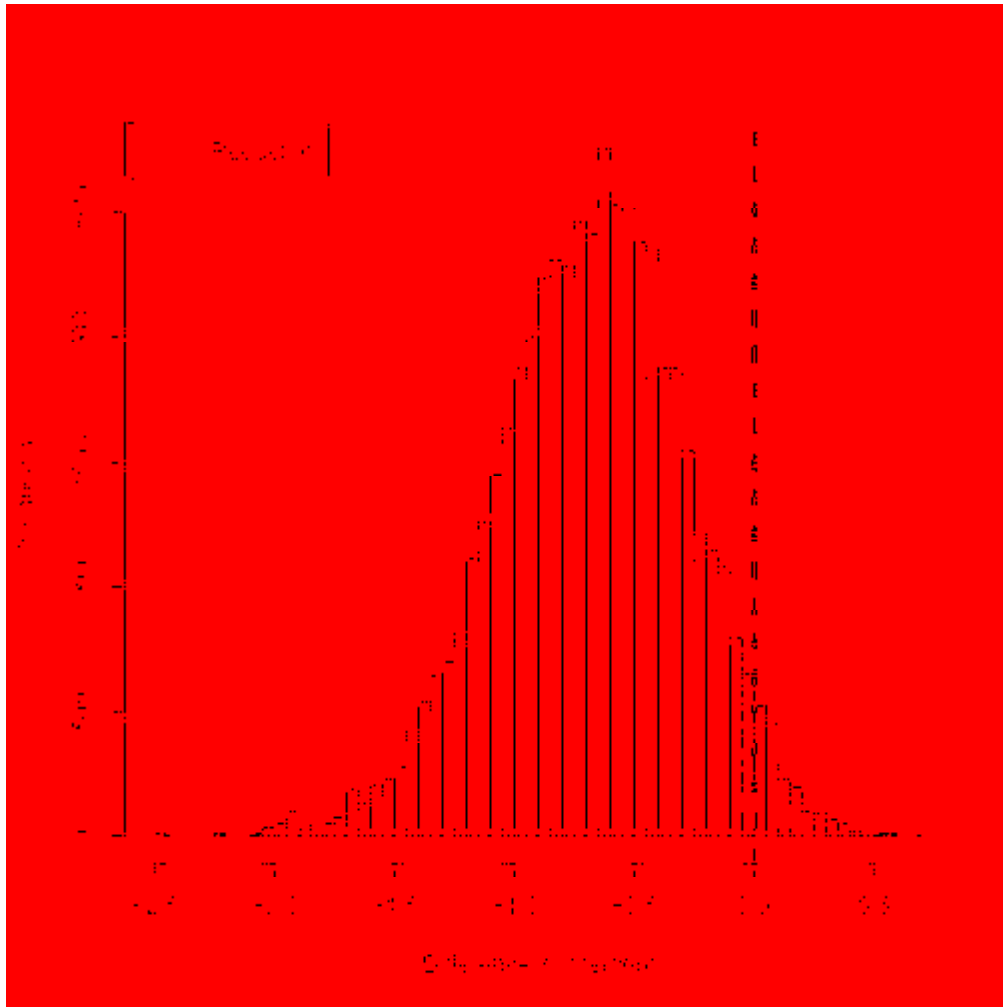


Figure 6-22. Distribution of differences for severe crashes on I-15 between South Layton and Syracuse.

Figure 6-23 displays the crash frequency of cross-median crashes for the before and after periods for this segment. The results of the analysis showed that cross-median crash frequency decreased by 48.6 percent after the cable barrier was installed.

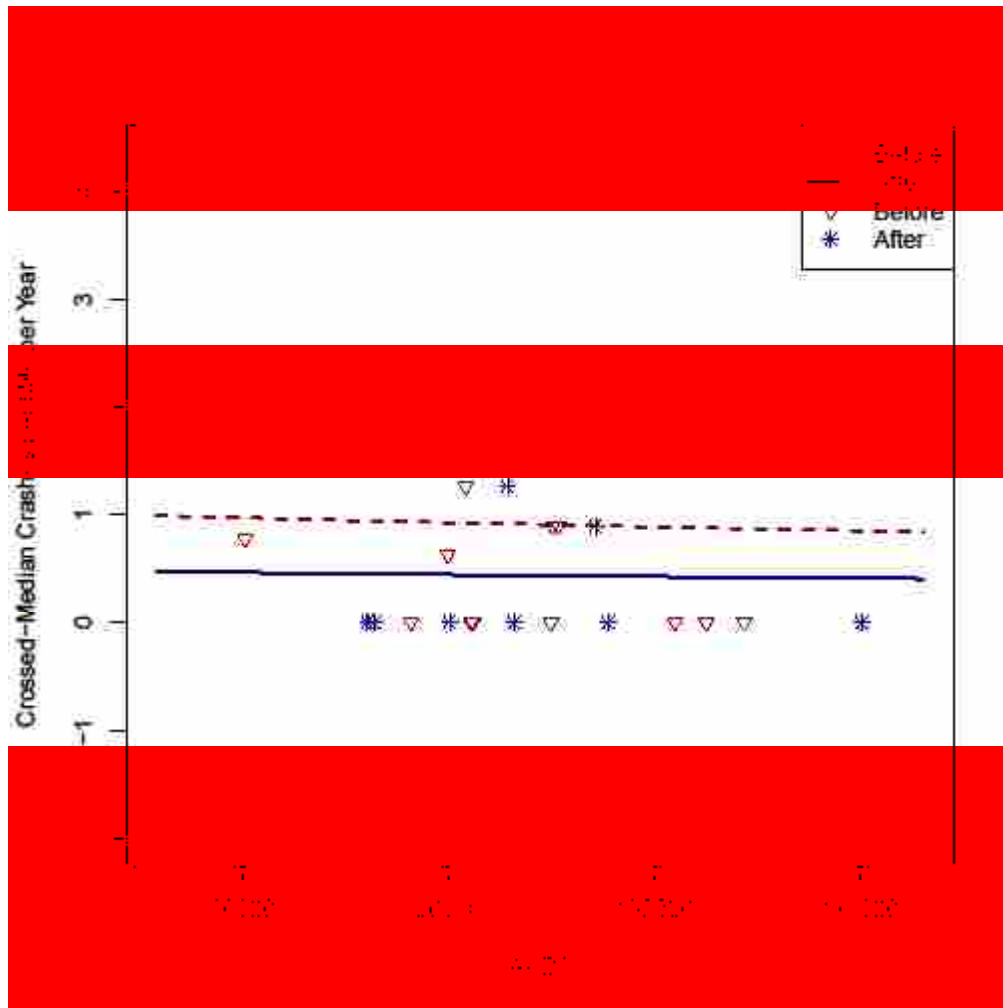


Figure 6-23. Cross-median crashes on I-15 from South Layton to Syracuse.

Figure 6-24 shows the corresponding probability distribution of the difference between the before and after periods for cross-median crashes. The results of the cross-median analysis indicate a very strong possibility that the installation of the cable barrier also had a substantial impact on cross median crashes at this site. The probability that a decrease occurred was 93.4 percent as represented by the grayed portion of Figure 6-24.

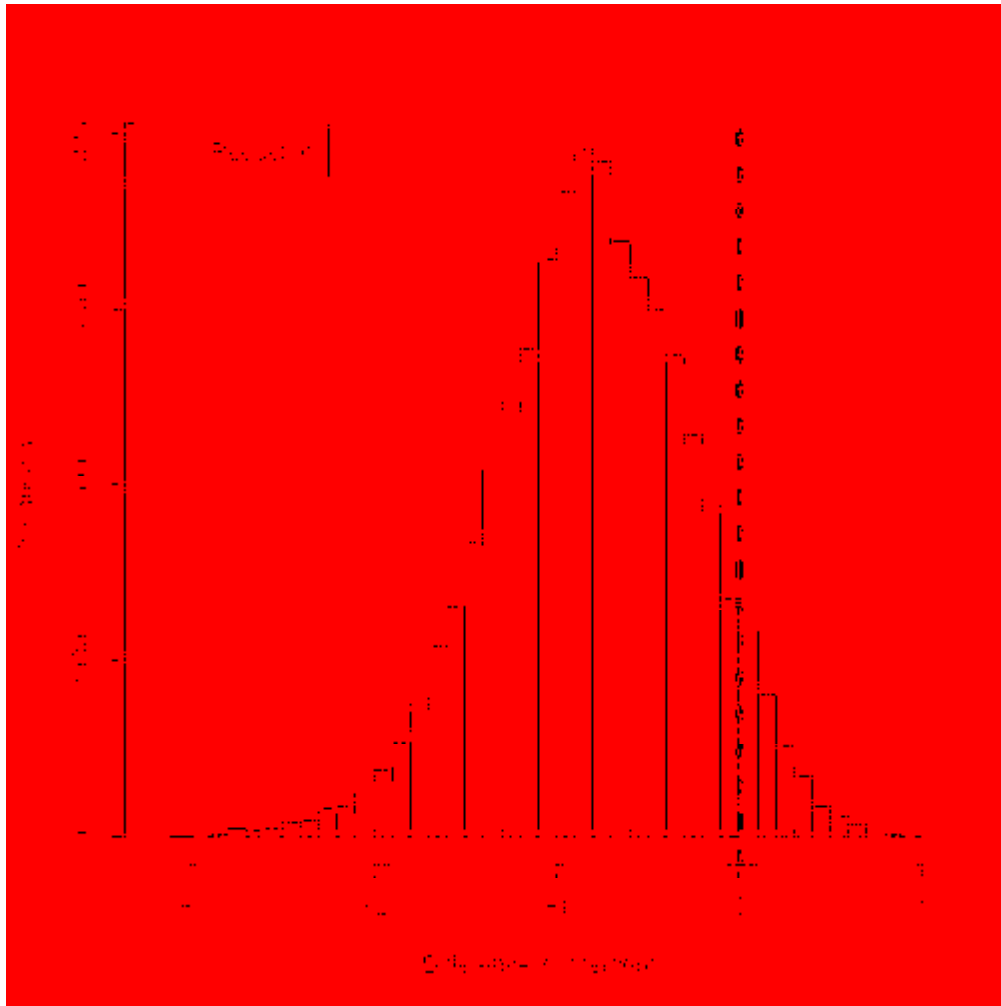


Figure 6-24. Distribution of differences for cross-median on I-15 between South Layton and Syracuse.

6.1.5 I-15 600 North to 2300 North in Salt Lake

In 2007, a cable barrier was installed along a segment of I-15 located in just north of Salt Lake. A cable barrier was installed for a 3 mile segment between 600 North and 2300 North. This section summarizes the results of the analysis performed before and after the cable barrier was installed. The before period used in the analysis is from 2002 to 2006. Only one year of after data was available, 2008.

Figure 6-25 displays the crash frequency of all crashes for the before and after periods as a function of AADT. Figure 6-26 shows the corresponding probability distribution of the difference between the before and after periods for all crashes.

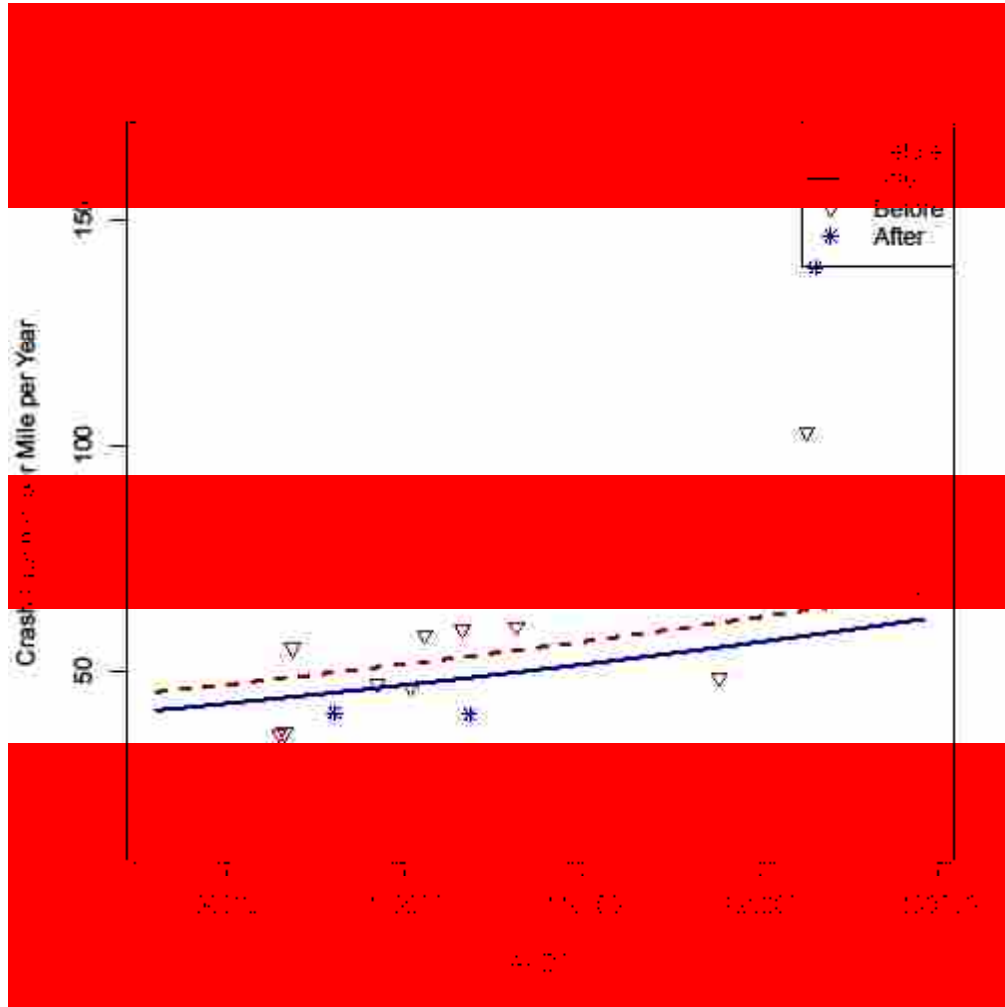


Figure 6-25. Overall crashes on I-15 between 600 North and 2300 North.

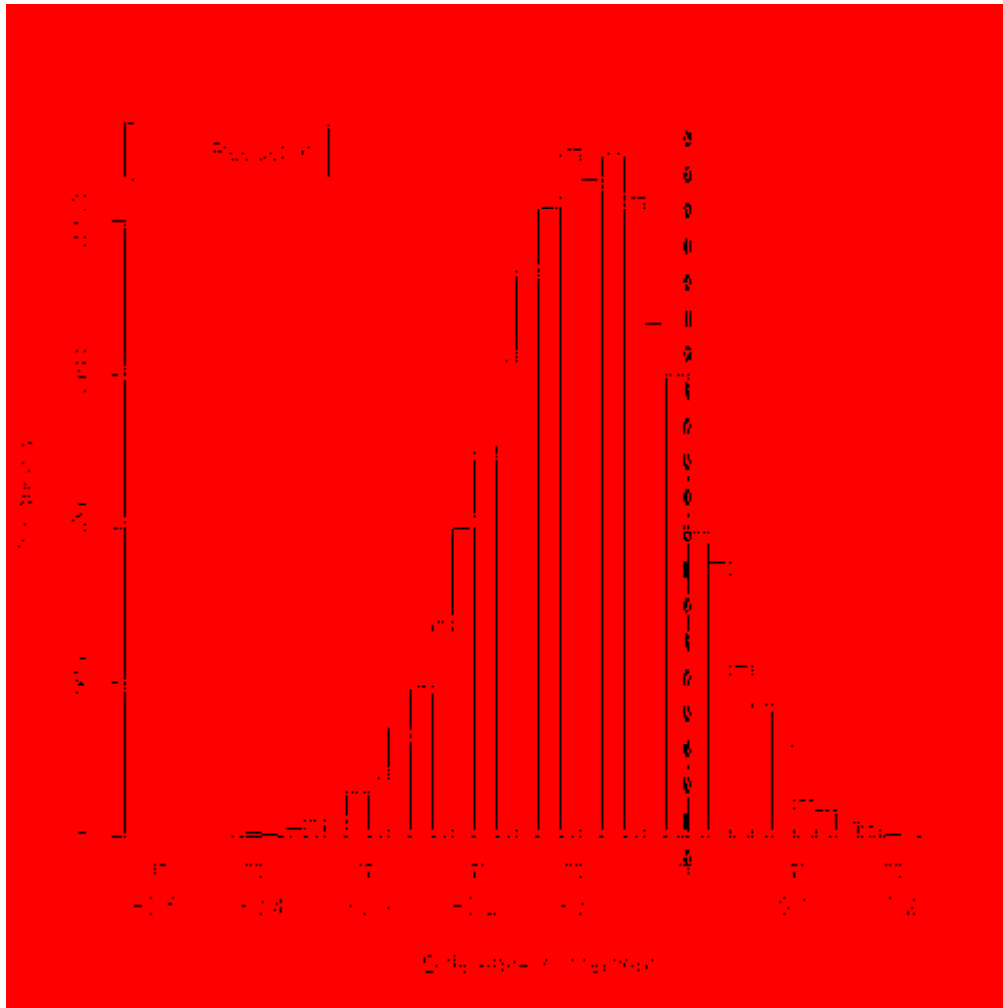


Figure 6-26. Distribution of differences for overall crashes on I-15 between 600 North and 2300 North.

The analysis showed the probability of a decrease was 86.2 percent for this segment. This site shows a greater probability that an increase in overall crashes occurred after the cable barrier was installed. The corresponding decrease in overall crash frequency was only 8.8 percent. However, it would be unreasonable to assume any reduction in overall crashes was the result of the cable barrier installation.

Figure 6-27 displays the crash frequency of severe crashes for the before and after periods as a function of AADT. The results of the analysis indicate that the severe crash frequency of this segment decreased by 62.2 percent after a cable barrier was installed.

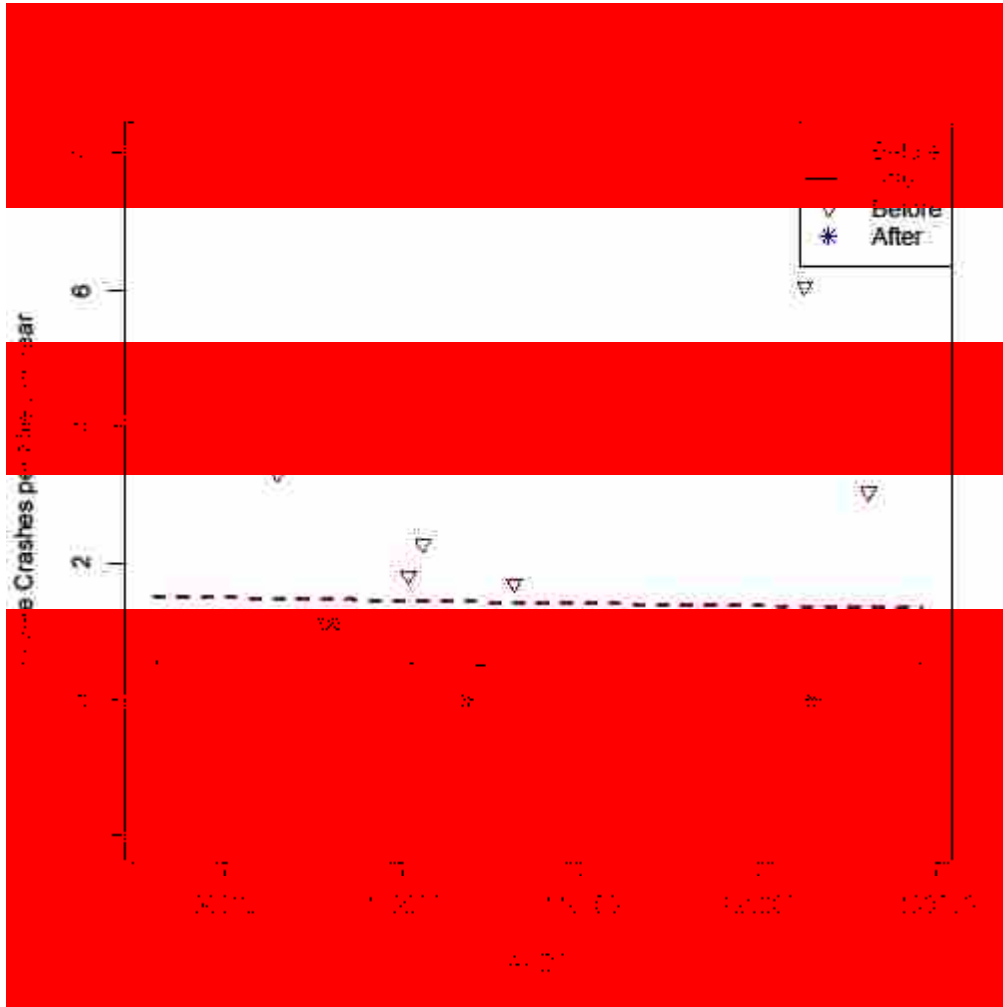


Figure 6-27. Severe crashes on I-15 between 600 North and 2300 North.

Figure 6-28 shows the probability distribution of the difference between the before and after periods for severe crashes. The probability a decrease in severe crash frequency occurred at this site was 96.7 percent as represented by the gray portion of the distribution shown in Figure 6-28.

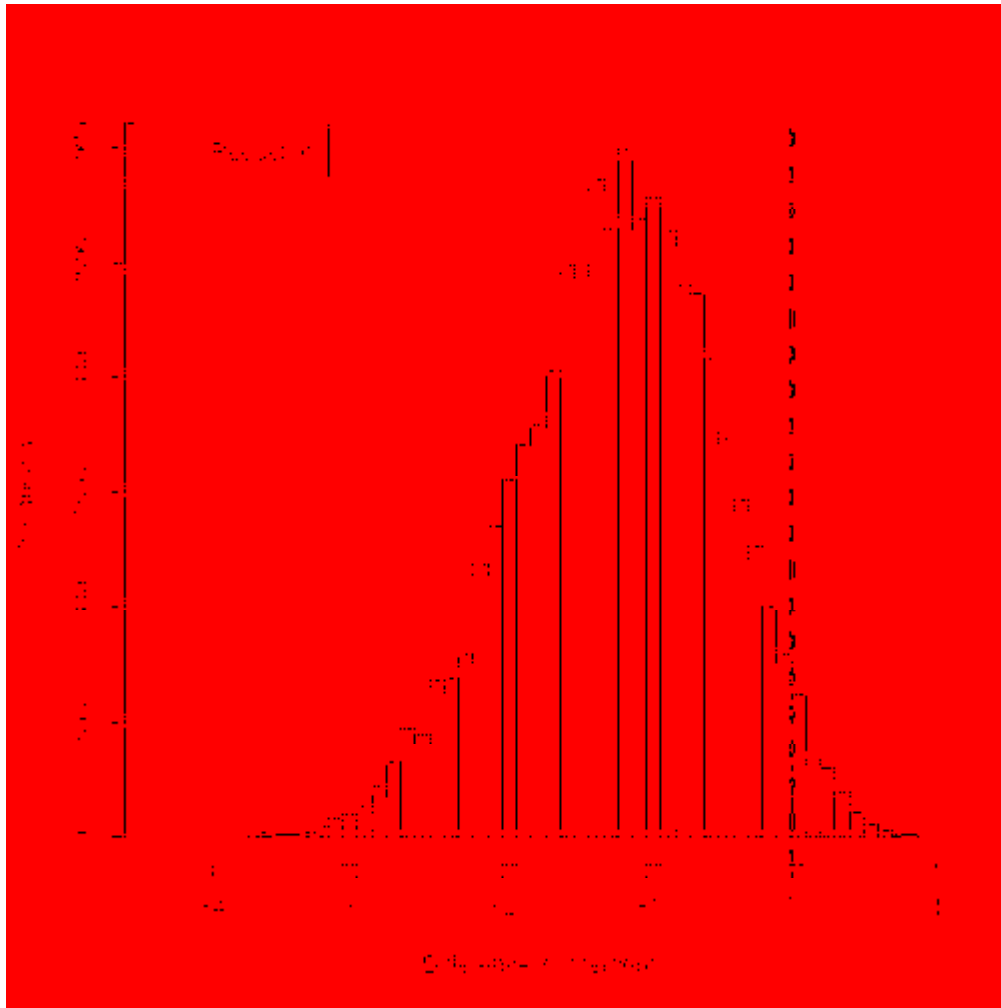


Figure 6-28. Distribution of differences for severe crashes on I-15 between 600 North and 2300 North.

The cross-median analysis showed a similar reduction in frequency. Figure 6-29 displays the crash frequency of cross-median crashes for the before and after periods as a function of AADT.

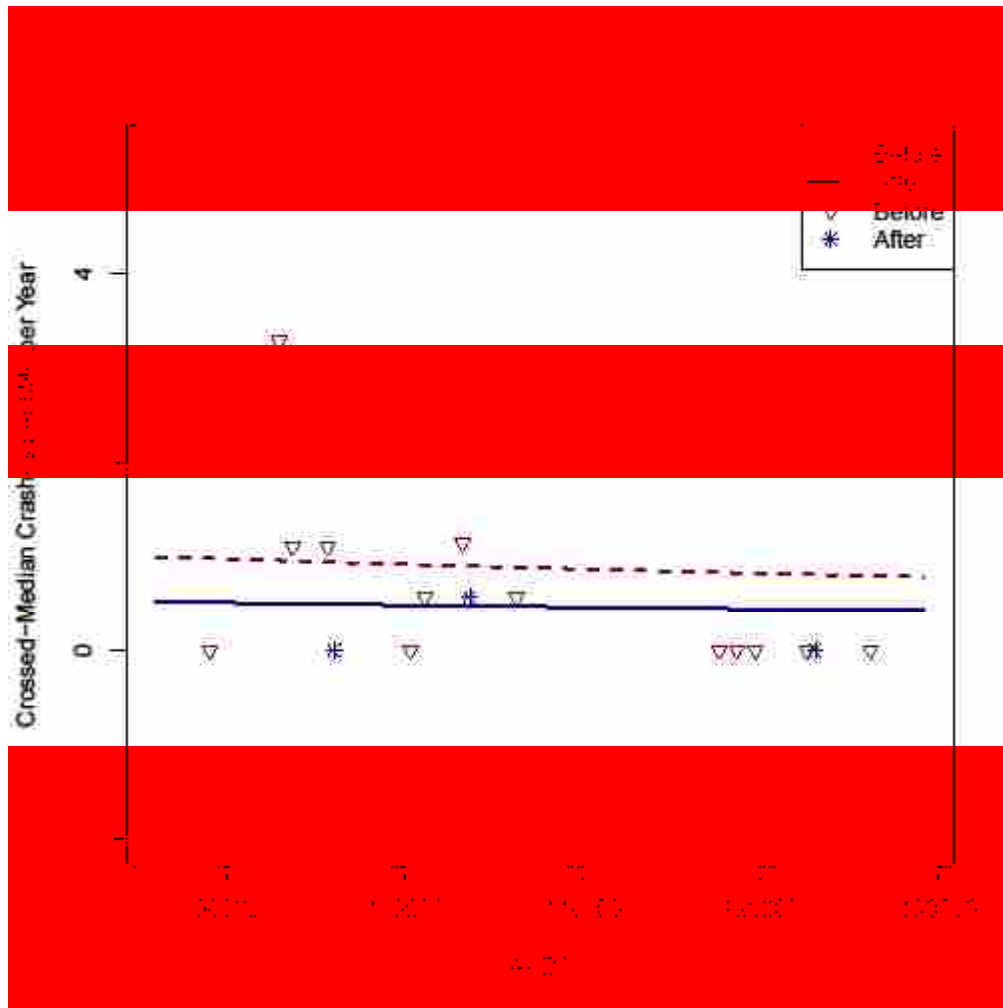


Figure 6-29. Cross-median crashes on I-15 between 600 North and 2300 North.

The analysis indicated that this segment experienced a 43.2 percent reduction in cross-median crash frequency. The corresponding probability was fairly strong at 86.5 percent as represented by the gray portion of the probability distribution shown in Figure 6-30.

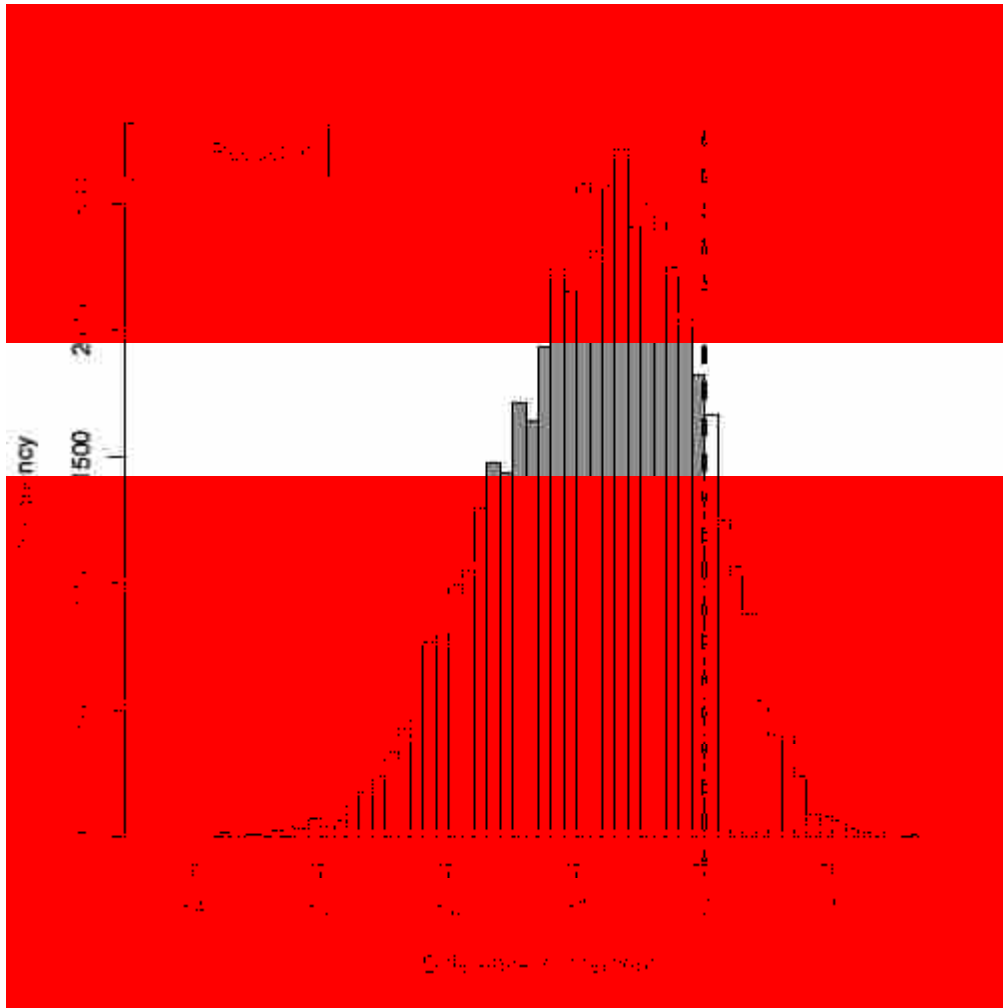


Figure 6-30. Distribution of differences for cross-median crashes on I-15 between 600 North and 2300 North.

6.1.6 I-215E 3100 South to 3800 South in Salt Lake

In 2007 a cable barrier was installed along the east side of I-215 in Salt Lake. This section is a 1 mile segment located between 3100 South and 3800 South. This section summarizes the results of the analysis performed before and after the raised median was installed. The before period used in the analysis is from 2002 to 2006. Only one year of after data was available, 2008.

Figure 6-31 displays the crash frequency of all crashes for the before and after periods as a function of AADT. The results of the analysis of this segment provide differing results from many other sites. The results indicate that the overall crash frequency decreased for this segment after the cable barrier was installed.

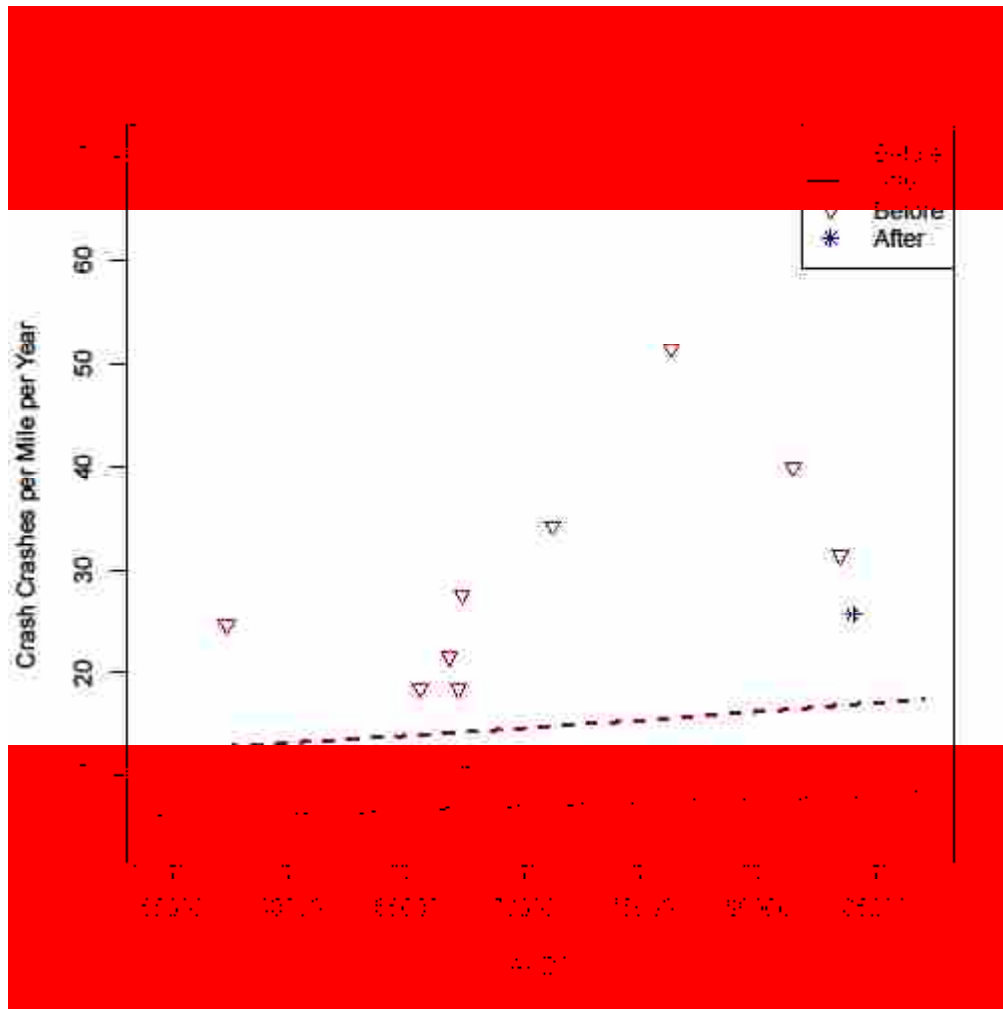


Figure 6-31. Overall crashes on I-215 East.

Figure 6-32 shows the corresponding probability distribution of the difference between the before and after periods for all crashes.

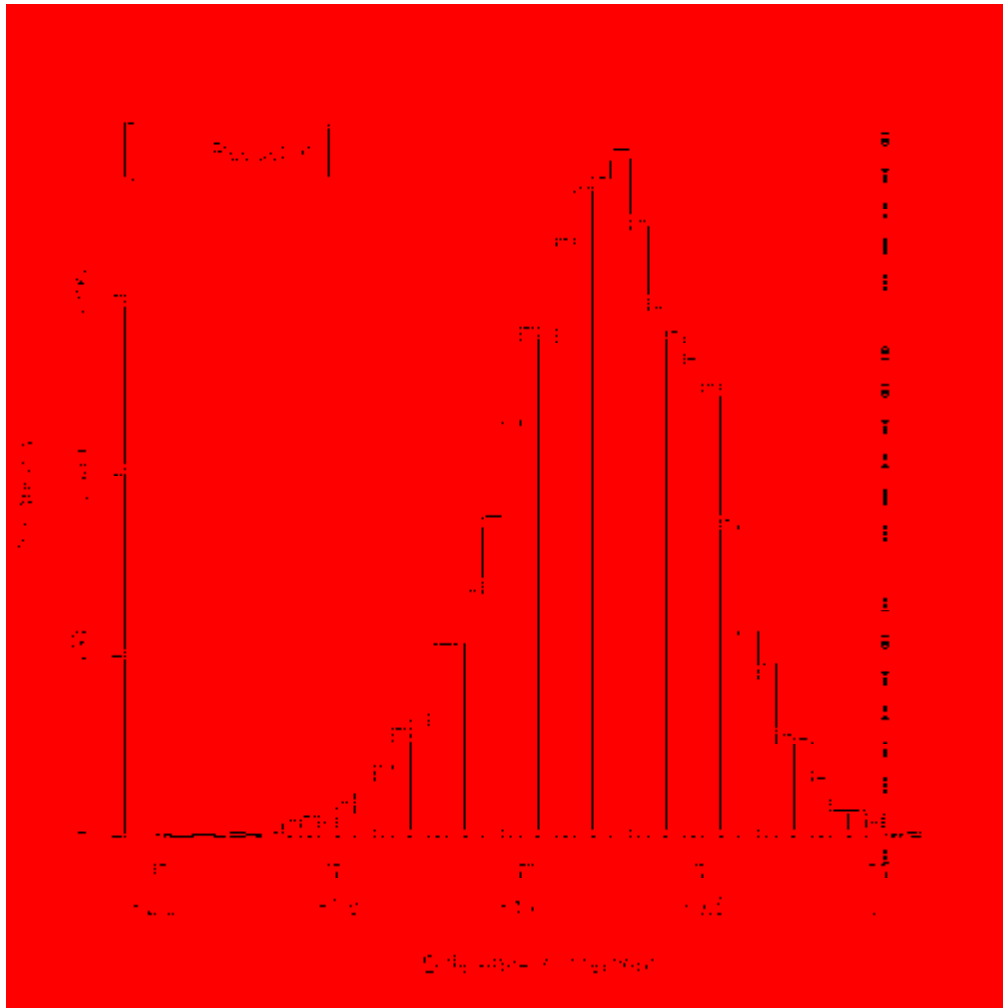


Figure 6-32. Distribution of differences in overall crashes for I-215 East.

The analysis showed this segment had a 99.9 percent probability that a decrease in overall crashes occurred as represented by the gray portion of the distribution shown in Figure 6-32. The corresponding reduction was a 52.2 decrease in overall crash frequency. While it is probable that the decrease in overall crash frequency was possibly the result of factors the cable barrier installation may have contributed the reduction in overall crash frequency.

Figure 6-33 displays the crash frequency of severe crashes for the before and after periods as a function of AADT. The analysis showed that this segment experienced a 49.4 percent reduction in severe crash frequency after a cable barrier was installed.

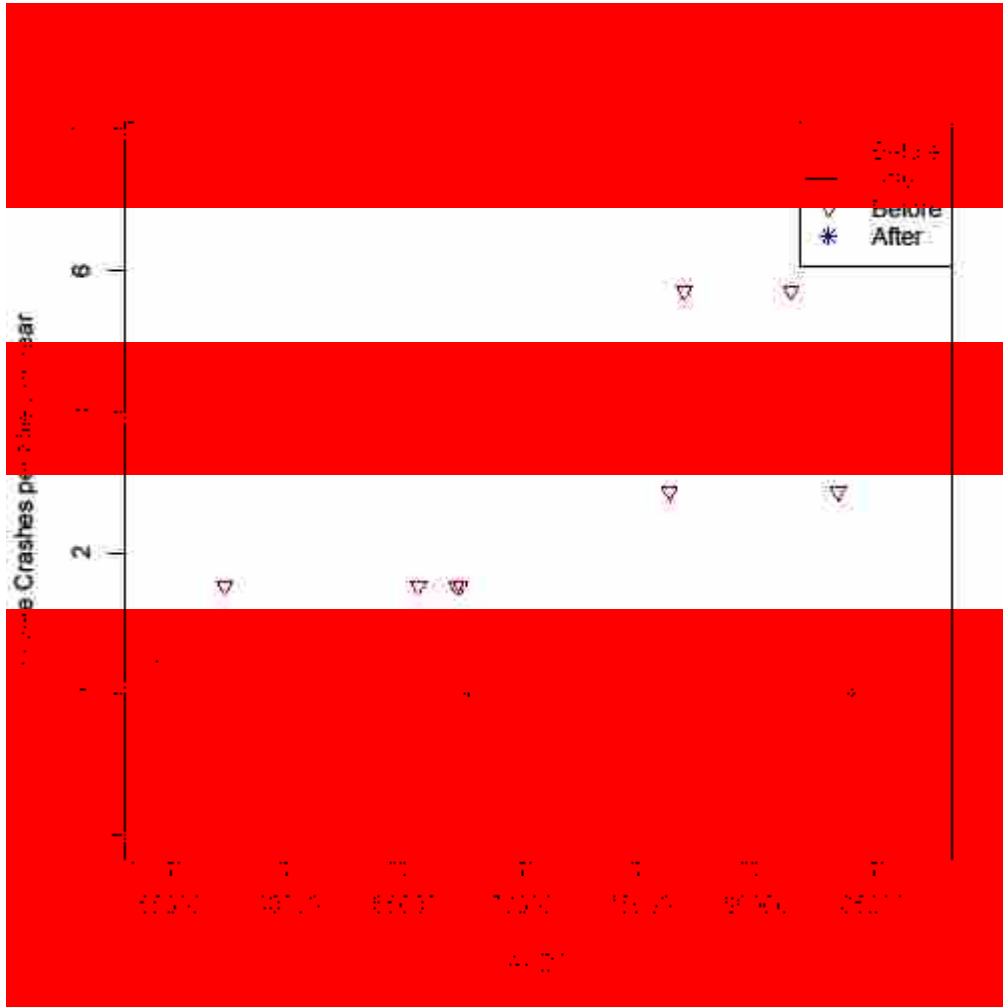


Figure 6-33. Severe crashes on I-215 East.

Figure 6-34 shows the corresponding probability distribution of the difference between the before and after periods for severe crashes. The results of the analysis indicate that there was a 88.9 percent probability that severe crashes decreased by 49.4 percent after the installation of the cable barrier as represented by the grayed portion of Figure 6-34. However, due to the

limitations of the available data, all severe crashes were considered in the analysis and not just those directly related to cable barriers. Therefore, while it is likely that the cable barrier contributed in part to the reduction in severe crashes at this site, it is unlikely it was the sole factor.

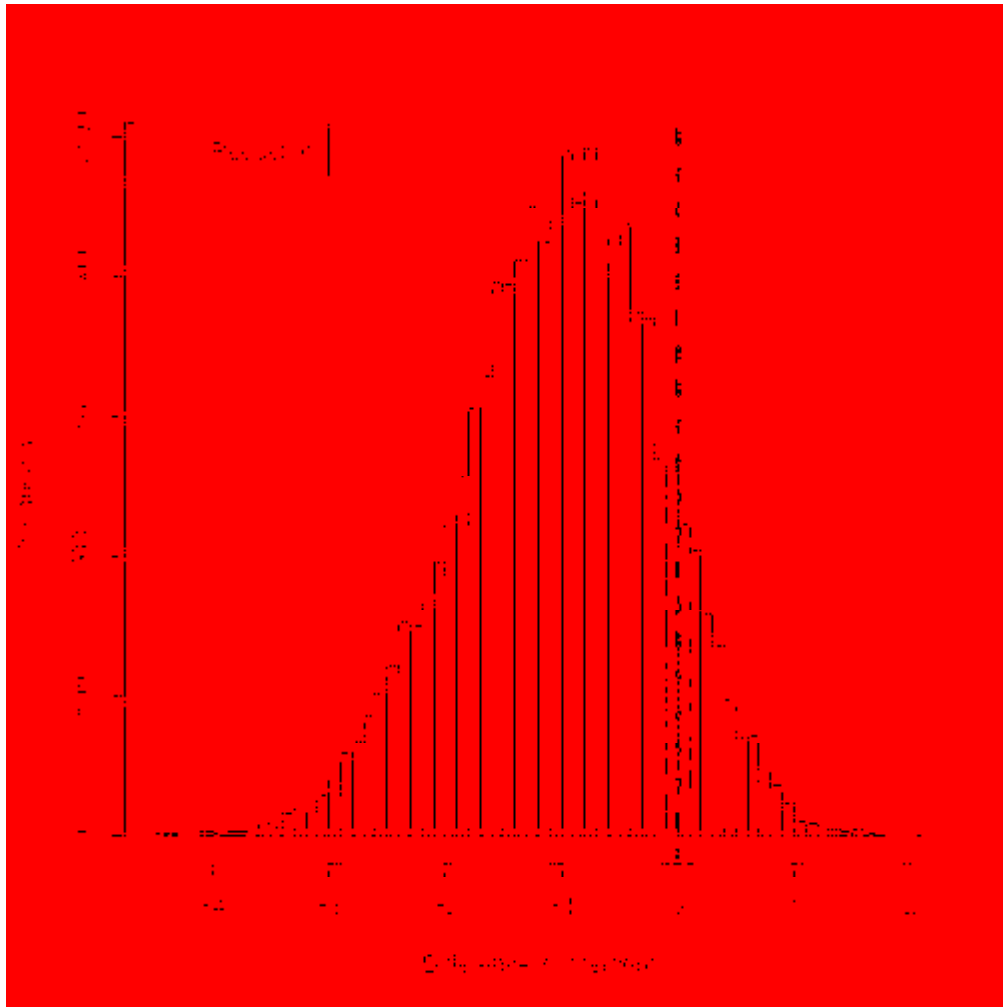


Figure 6-34. Distribution of differences in severe crashes for I-215 East.

The results of the cross-median analysis provide similarly promising results. Figure 6-35 displays the crash frequency of cross-median crashes for the before and after periods as a function of AADT. The results show that cross-median crash frequency decreased by 34.7

percent for this segment. The corresponding probability was 81.3 percent as represented by the gray portion of the distribution shown in Figure 6-36.

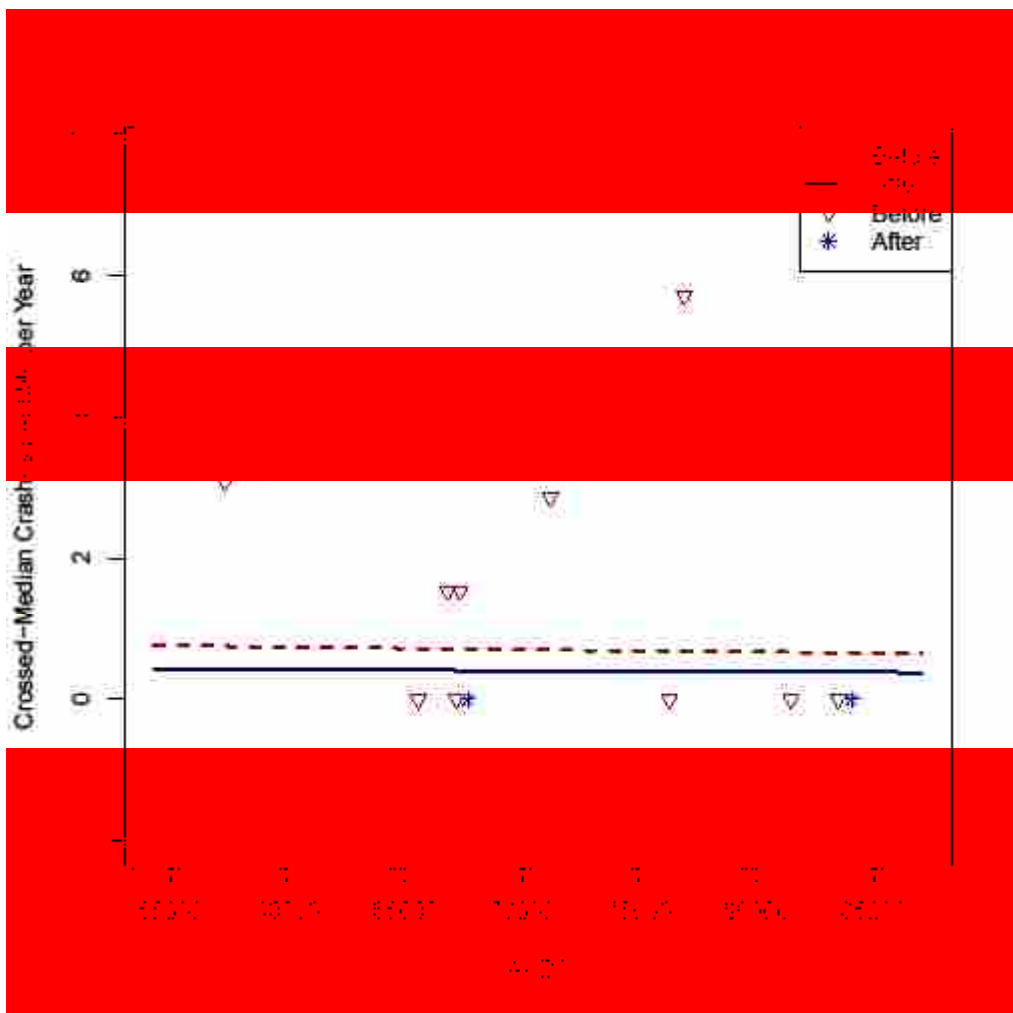


Figure 6-35. Cross-median crashes on I-215 East.

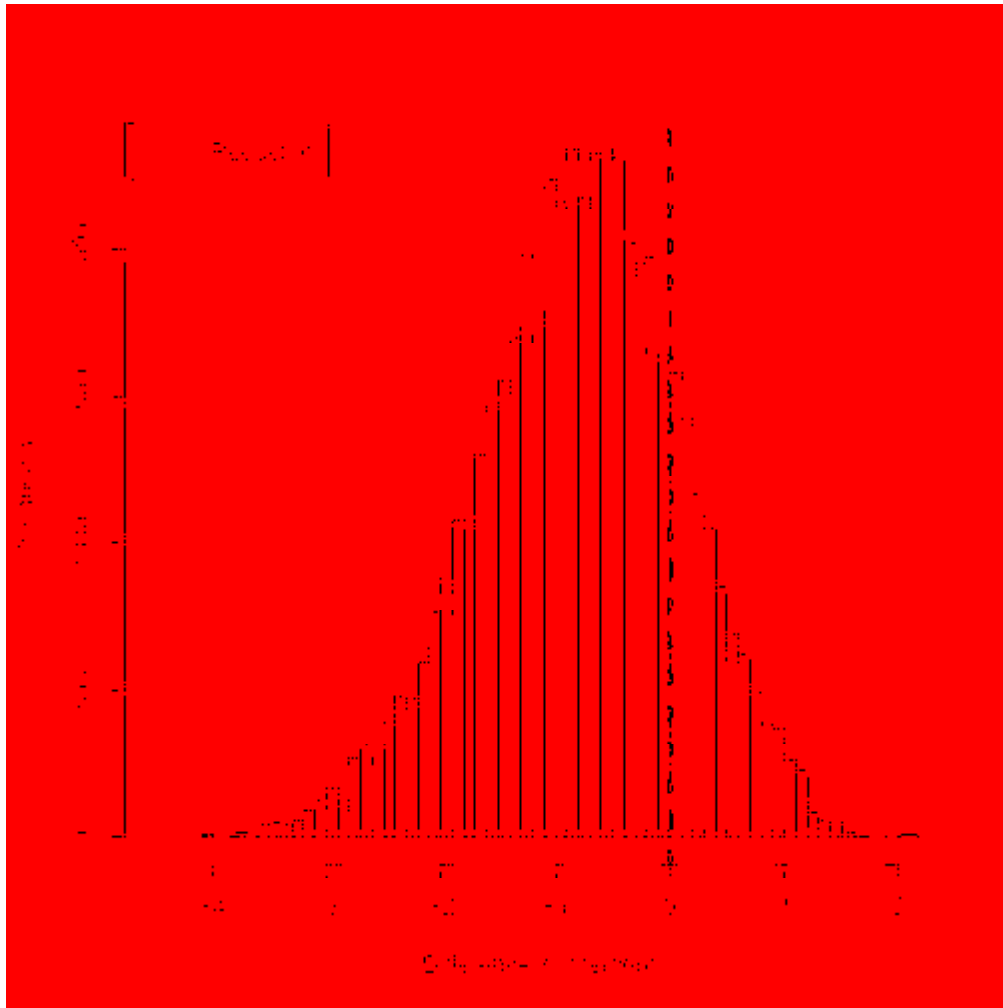


Figure 6-36. Distribution of differences in cross-median crashes for I-215 East.

6.1.7 I-215W 2100 South to 4500 South Salt Lake

In 2007 a cable barrier was also installed along the west side of I-215 in Salt Lake. This section is a 2.5 mile segment located between 2100 South and 4500 South. This section summarizes the results of the analysis performed before and after the cable barrier was installed. The before period used in the analysis is from 2002 to 2006. Only one year of after data was available, 2008.

Figure 6-37 displays the crash frequency of all crashes for the before and after periods as a function of AADT. The results of the analysis indicate that the overall crash frequency increased by 60.3 percent after the cable barrier was installed. As stated previously, it is anticipated that this increase is the product of other contributing factors rather than the cable barrier installation. The results are included here strictly for background information.

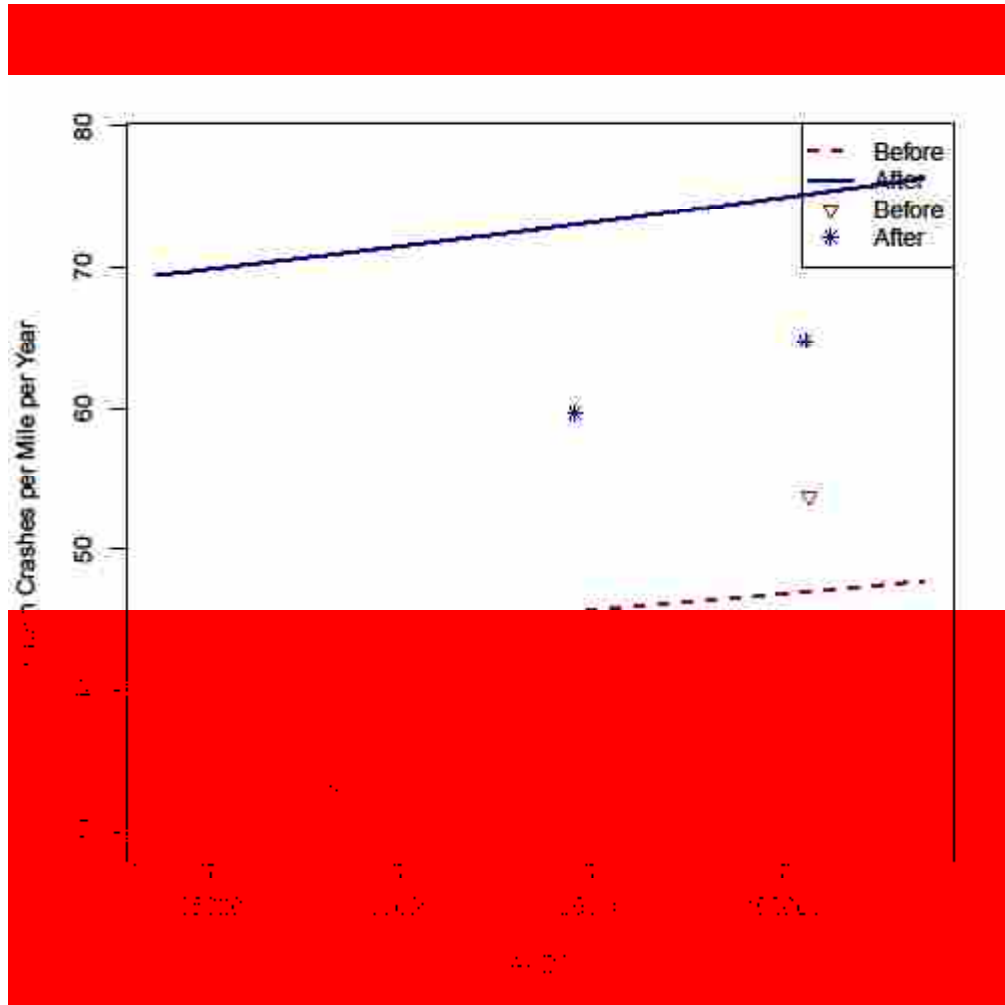


Figure 6-37. Overall crashes on I-215 West.

Figure 6-38 shows the probability distribution of the difference between the before and after periods for all crashes. The entire distribution for the differences for the overall crashes for this segment is greater than zero indicating a 100 percent probability of an increase occurred after the cable barrier was installed.

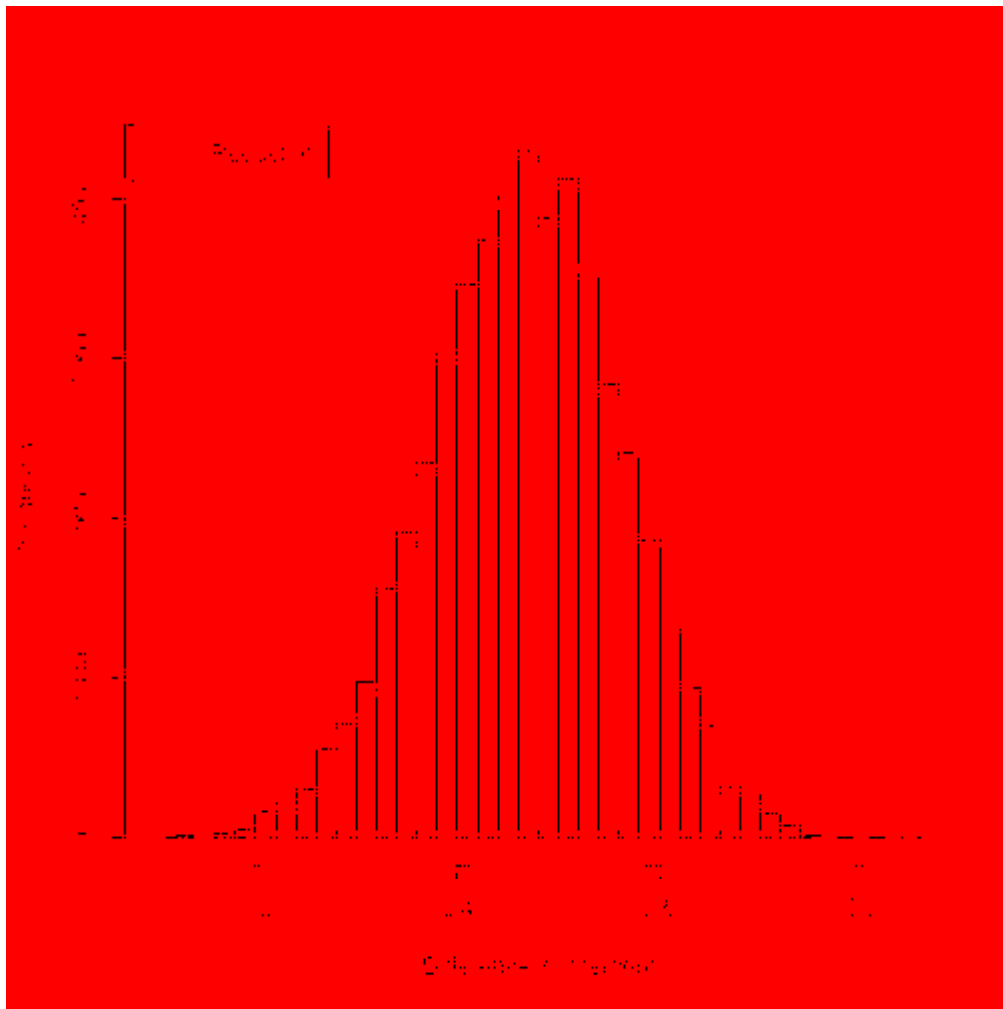


Figure 6-38. Distribution of differences for overall crashes on I-215 West.

The results of the severe crash analysis show much more promising results. Figure 6-39 displays the crash frequency of severe crashes for the before and after periods as a function of AADT. The analysis results indicate that this segment experienced a 52.6 percent reduction in

severe crash frequency after the cable barrier was installed. Since the analysis considered all severe crashes and not just those impacted by the cable barrier, it would be inappropriate to assume the cable barrier had an impact on all severe crashes. However, it is likely the cable barrier contributed at least in part to the reduction in severe crashes.

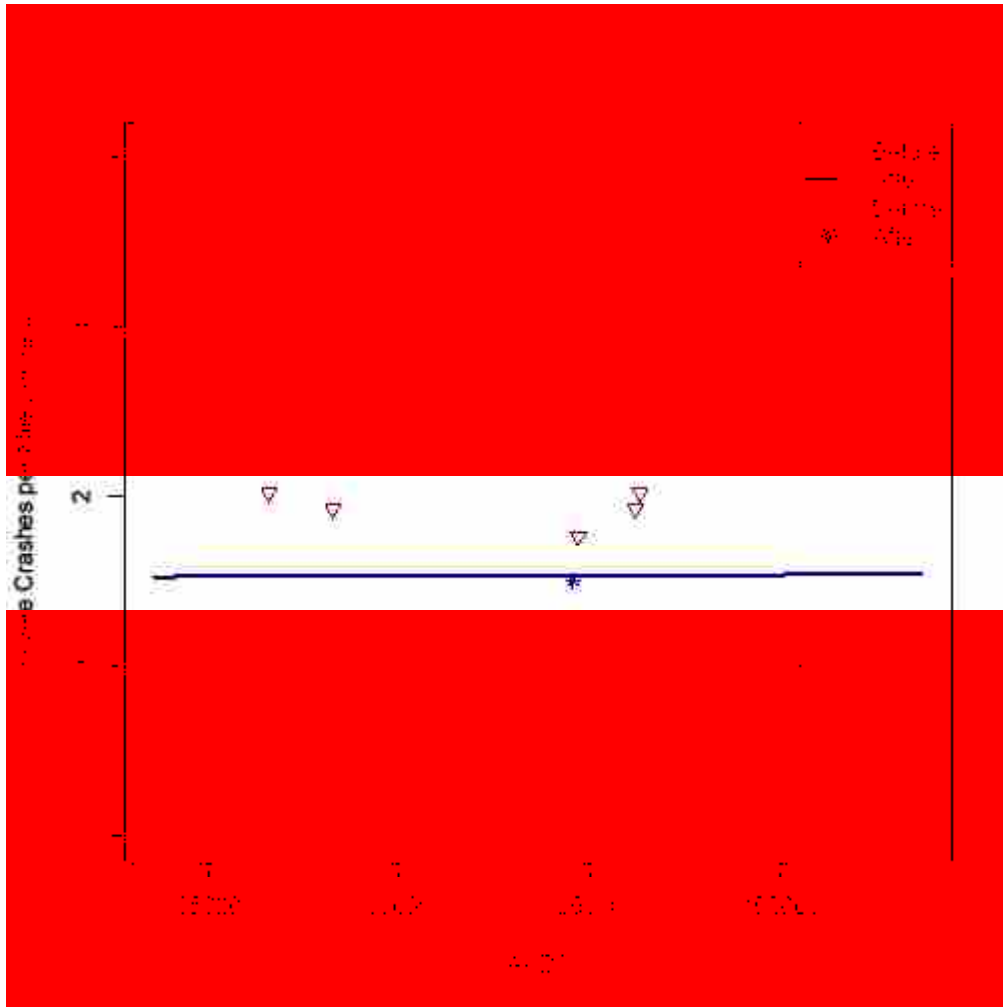


Figure 6-39. Severe crashes on I-215 West.

Figure 6-40 shows the probability distribution of the differences between the before and after periods for severe crashes. The probability that a decrease occurred along this segment was 94.9 percent as represented by the grayed portion of Figure 6-40.

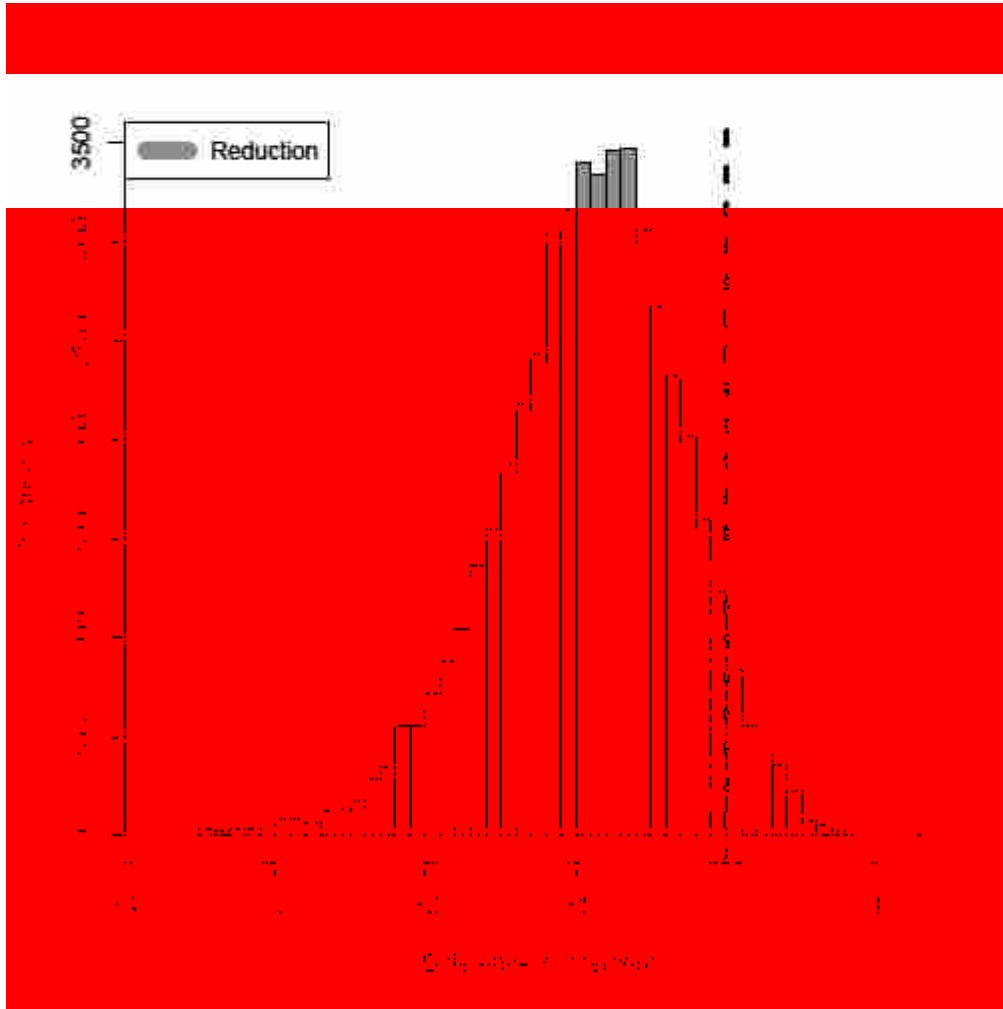


Figure 6-40. Distribution of differences for severe crashes on I-215 West.

The analysis of the cross-median crashes for this segment provided similarly promising results. Figure 6-41 displays the crash frequency of cross-median crashes for the before and after periods as a function of AADT.

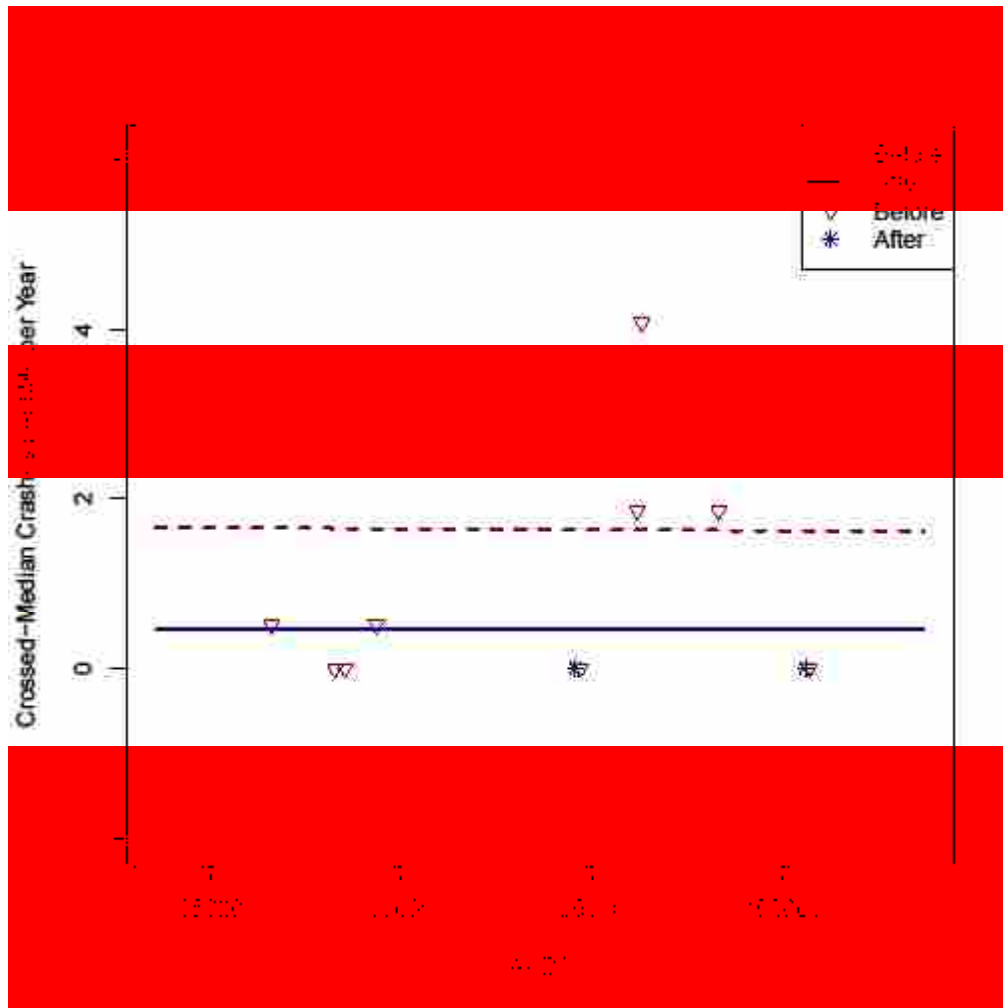


Figure 6-41. Cross-median crashes on I-215 West.

The results of the analysis indicated that cross-median crash frequency decreased by 70.8 percent following the installation of the cable barrier. The probability that a decrease occurred was 97.8 percent as represented by the grayed portion of the corresponding probability distribution shown in Figure 6-42.

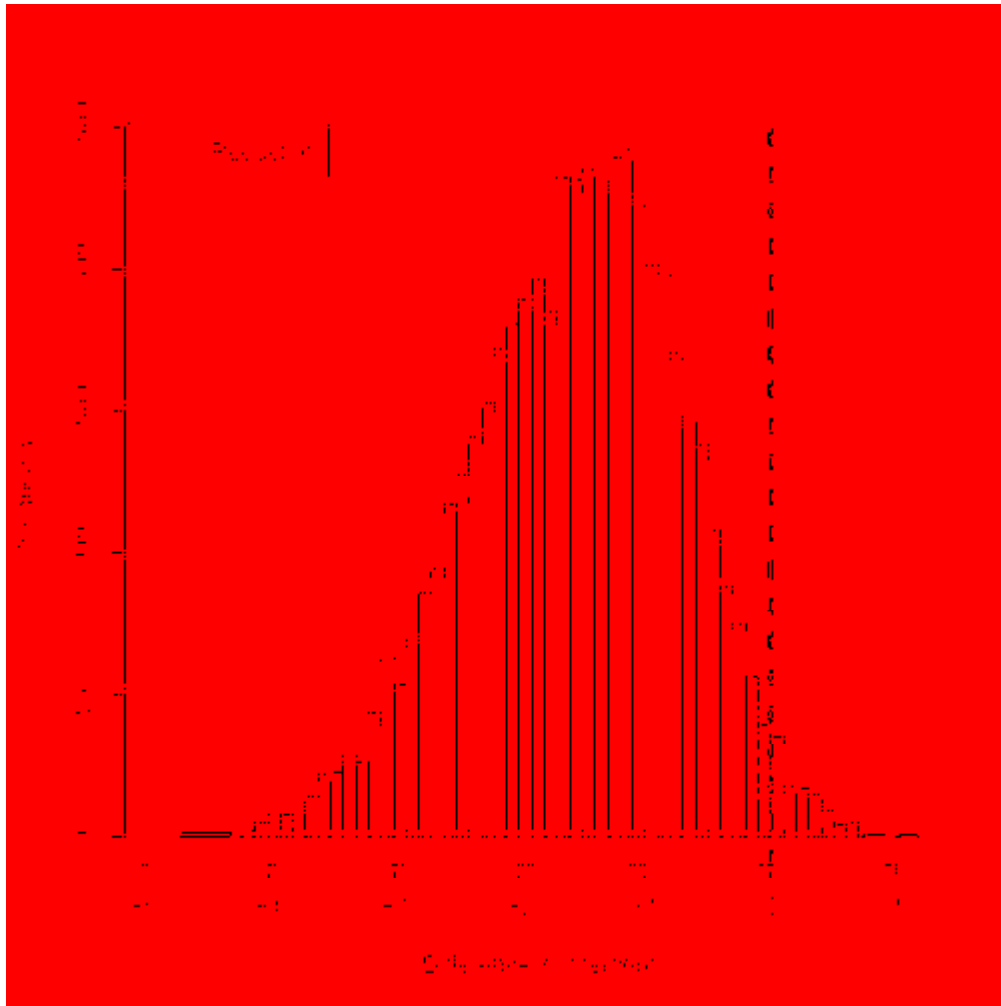


Figure 6-42. Distribution of differences for cross-median crashes on I-215 West.

6.1.8 I-80 Lamb's Canyon Interchange

In 2007, a cable barrier was installed along a short segment of I-80 at the Lamb's Canyon interchange in Parley's Canyon east of Salt Lake. This section summarizes the results of the analysis performed before and after the cable barrier was installed. The before period used in the analysis is from 2002 to 2006. Data from 2008 was the only available year of after data.

Figure 6-42 displays the crash frequency of all crashes for the before and after periods as a function of AADT. The results indicate that this segment experienced an increase in overall

crash frequency of 85.3 percent after the cable barrier was installed. However, the corresponding probability was surprisingly low.

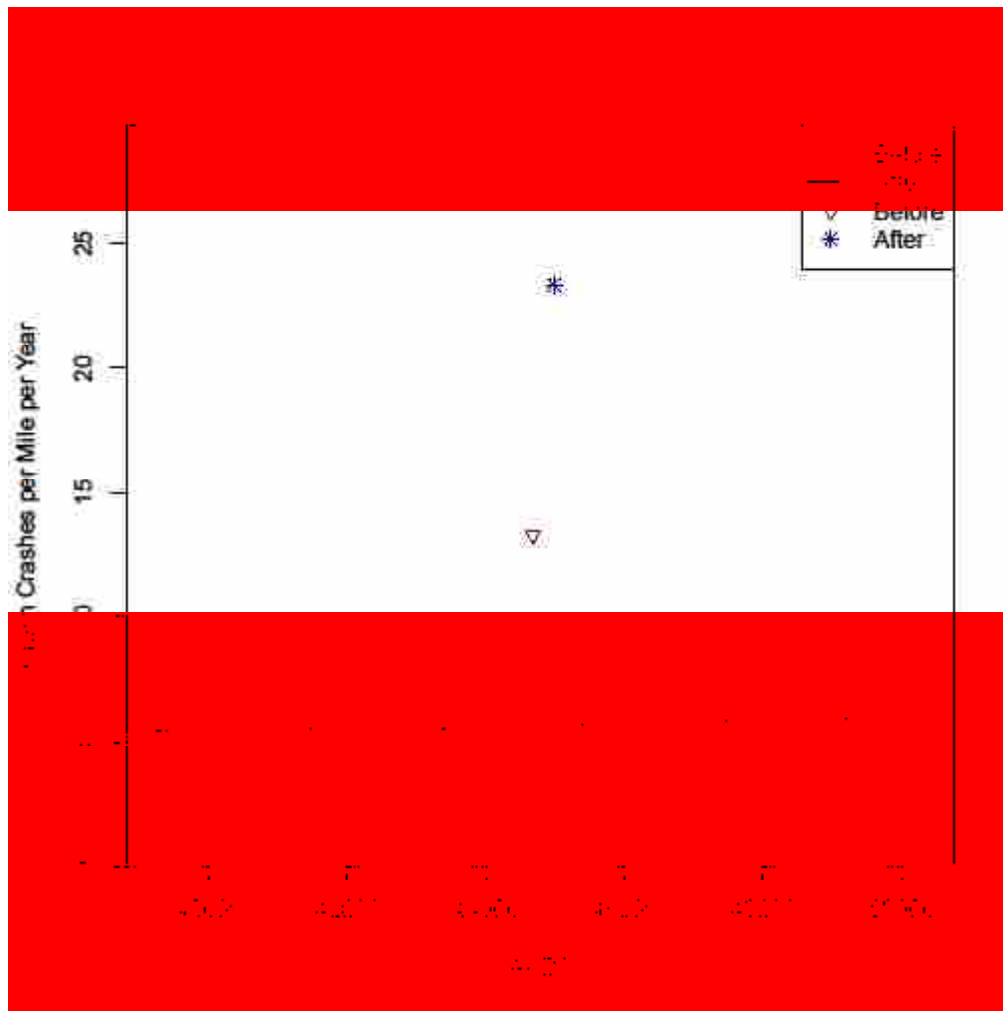


Figure 6-43. Overall crashes on I-80.

Figure 6-43 shows the probability distribution of the differences between the before and after periods for all crashes. The probability a decrease in overall crash frequency occurred at this site was only 13.7 percent as represented by the gray portion of the distribution in Figure 6-44. The low probability is possibly the result of the limited data points available for analysis for this segment.

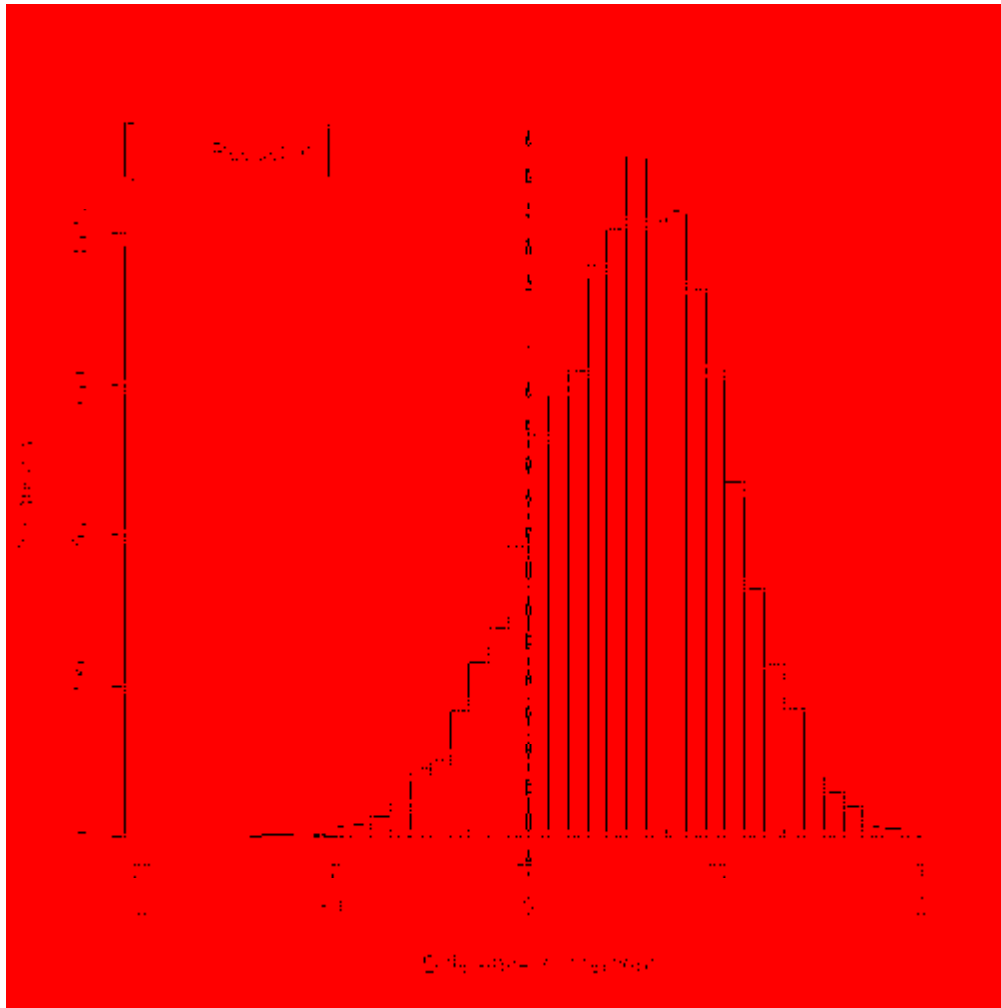


Figure 6-44. Distribution of differences for overall crashes on I-80.

Figure 6-45 displays the crash frequency of severe crashes for the before and after periods as a function of AADT. The severe crash analysis indicates a dramatic increase in severe crash frequency. However, similarly to the overall analysis, it is estimated these results are skewed by the limited data available.

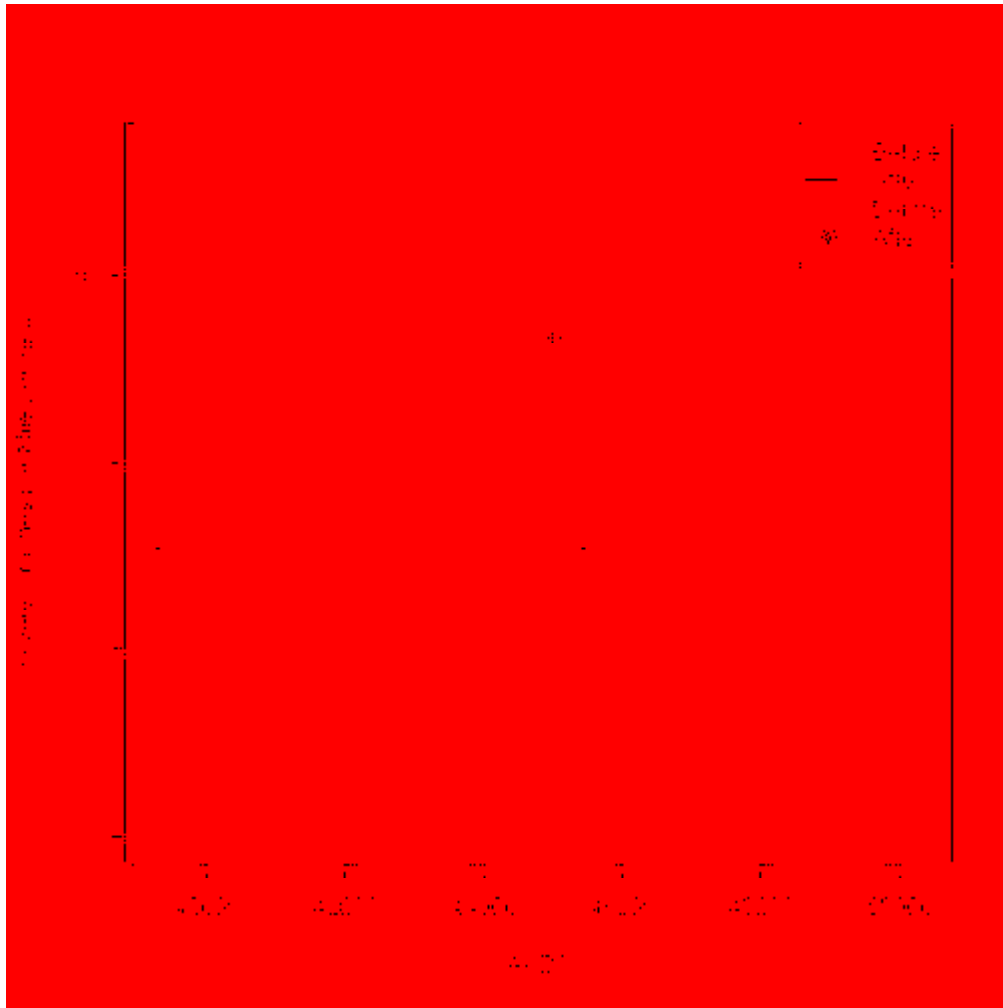


Figure 6-45. Severe crashes on I-80.

Figure 6-46 shows the probability distribution of the differences between the before and after periods for severe crashes. The probability a decrease occurred at this site was only 9.5 percent indicating a stronger probability that an increase in severe crashes occurred. The probability is represented as the gray portion of the distribution in Figure 6-46.

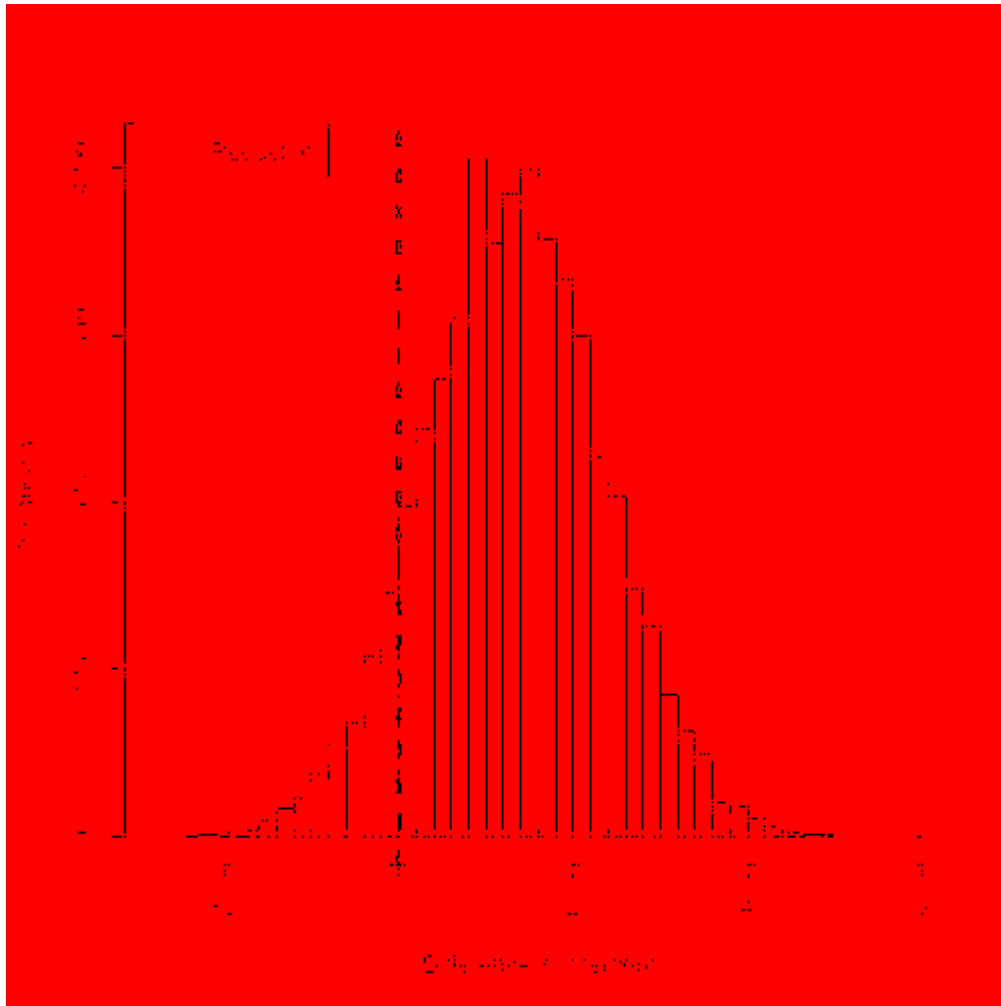


Figure 6-46. Distribution of differences for severe crashes on I-80.

The cross-median results for this segment are also mixed. Figure 6-47 displays the crash frequency of cross-median crashes for the before and after periods as a function of AADT. Figure 6-48 shows the corresponding distribution of differences for cross-median crashes for this segment of I-80.

The results indicate a dramatic increase in cross-median crashes occurred along this segment after a cable barrier was installed. However, the probability of a difference occurring, as represented by the gray portion of Figure 6-48, was too low to make any confident

conclusions. Like the other results for this site, it is assumed that these results are impacted by the limited data available.

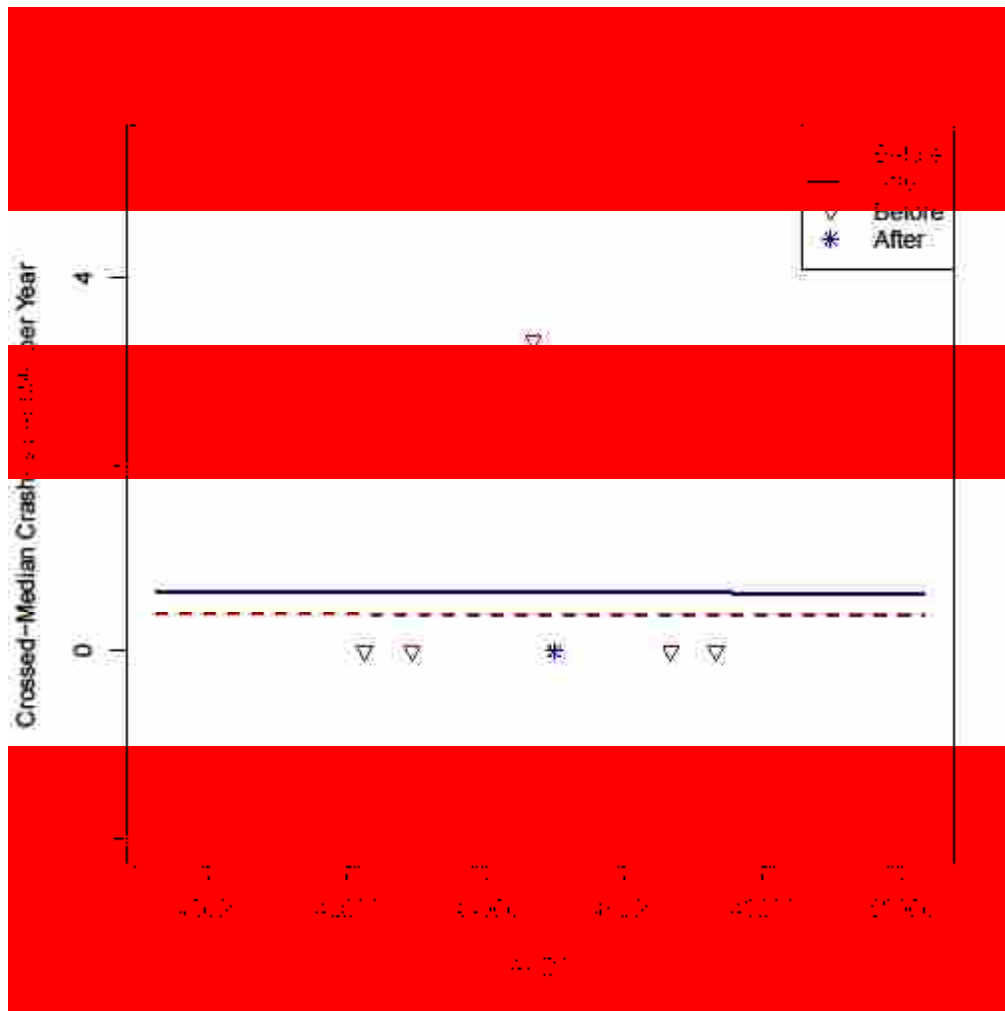


Figure 6-47. Cross-median crashes on I-80.

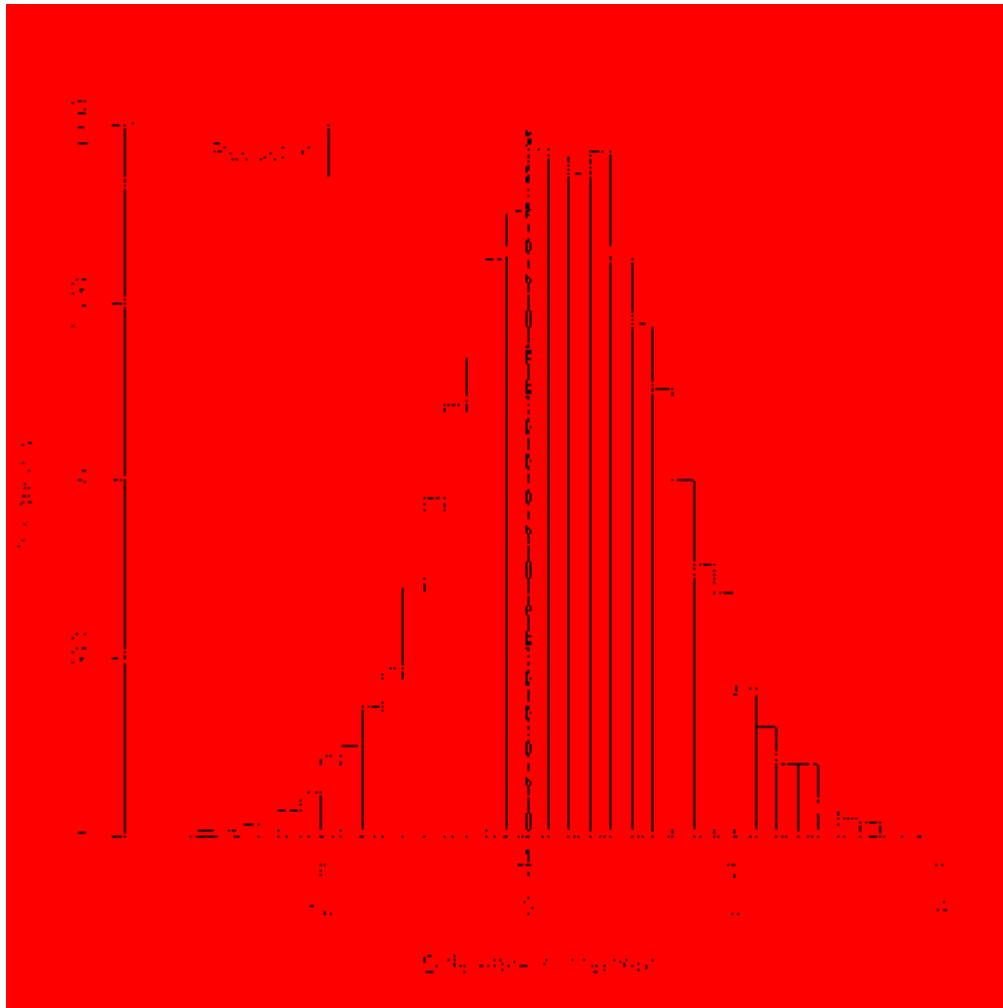


Figure 6-48. Distribution of differences for cross-median crashes on I-80.

6.2 Overall Cable Barrier Results

This section summarizes the results of the overall analysis performed on all sites where cable barriers were installed on Utah highways. Figure 6-49 displays the crash frequency of overall crashes for the before and after periods as a function of AADT. Figure 6-50 shows the corresponding probability distribution of the differences between the before and after periods for overall crashes.

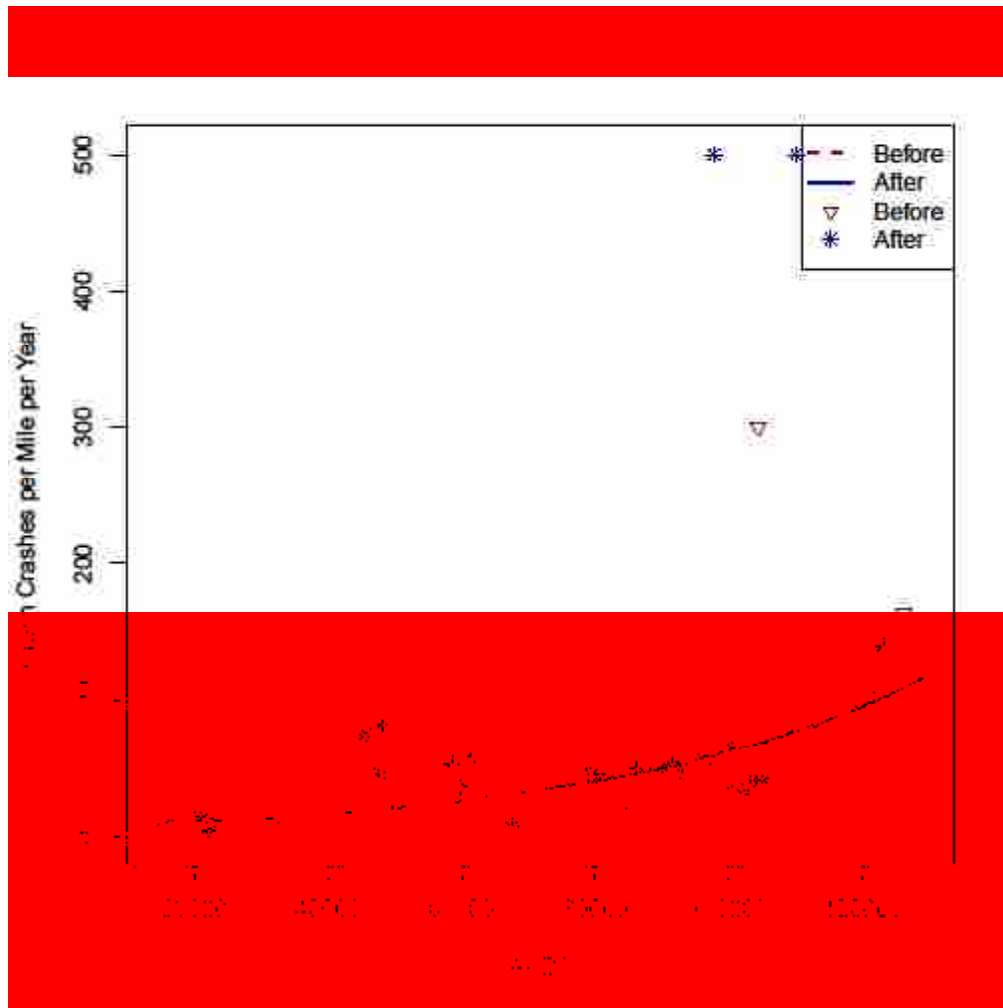


Figure 6-49. Overall crashes on all cable barrier sites.

The analysis of overall crashes at sites where cable barriers have been installed provides interesting results. As shown in Figure 6-49, the analysis indicates that the overall crash frequency increased by 47.4 percent after the installation of the cable barrier. The entire distribution of the differences shown in Figure 6-50 is greater than zero, indicating a 100 percent probability there was an increase in overall crashes after the cable barrier was installed. However, since the analysis considers all crashes and not just those impacted by the cable barrier, the increase in overall crash frequency is more likely the result of an increase in traffic

volumes or factors other than the installation of a cable barrier. Several outlier locations with an unusually high crash frequency are also revealed in Figure 6-49. Further analysis should be performed on each of those sites to determine improvements that could be made.

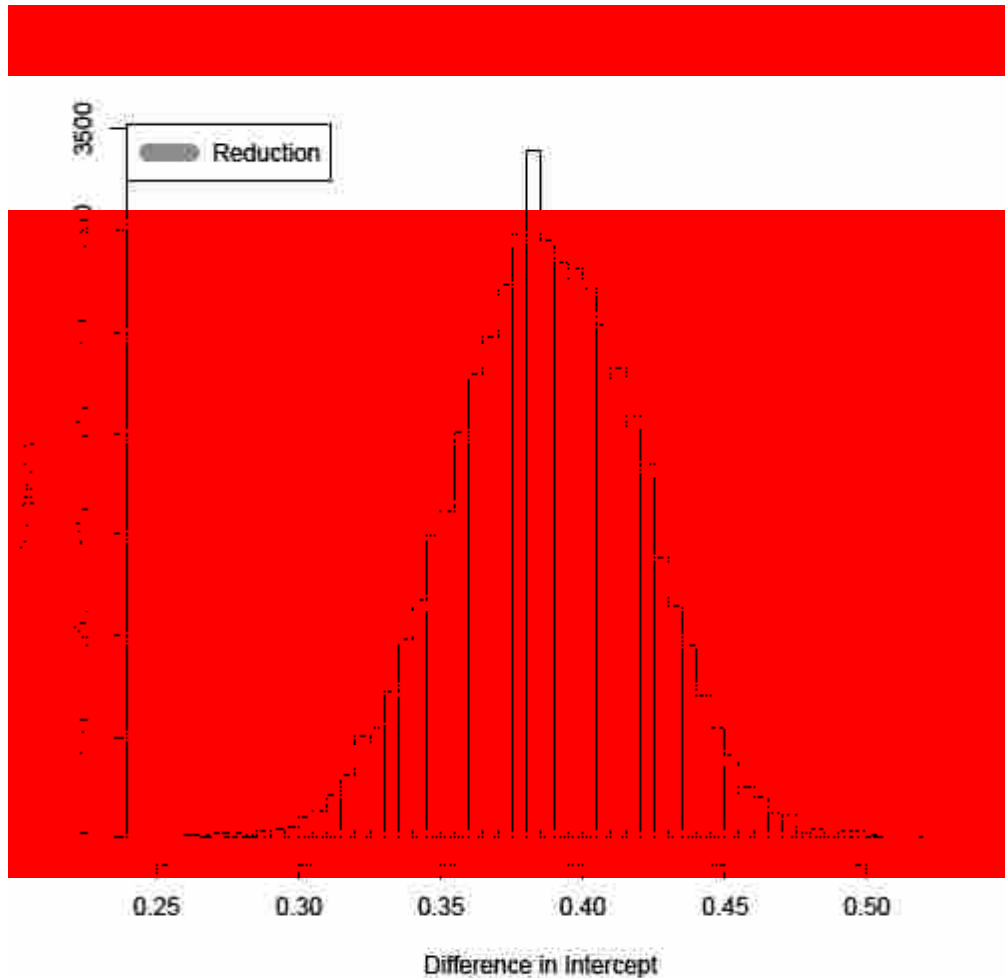


Figure 6-50. Distribution of differences for overall crashes on all cable barrier sites.

Figure 6-51 displays the crash frequency of severe crashes for the before and after periods as a function of AADT. Figure 6-52 shows the corresponding probability distribution of the differences between the before and after periods for severe crashes.

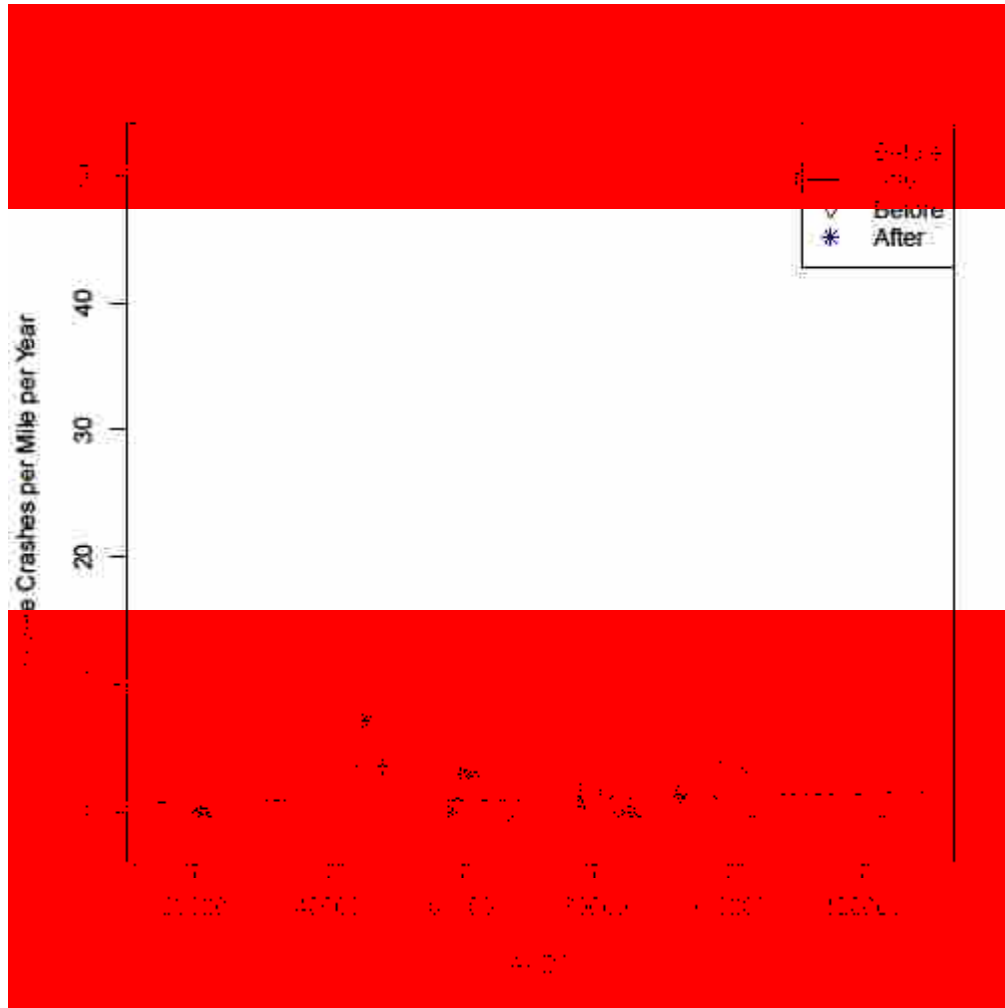


Figure 6-51. Severe crashes on all cable barrier sites.

The results of the analysis indicate that the severe crash frequency decreased by 30.9 percent after the installation of the cable barrier. The probability that a decrease occurred was 98.7 percent as represented by the grayed portion of Figure 6-52, indicating a fairly strong probability the frequency of severe crashes decreased after cable barriers were installed. While the cable barrier installation may not be the sole contributing factor since all severe crashes were considered, it is likely the cable barrier contributed greatly to the reduction in severe crashes. Figure 6-51 also reveals an outlier for both the before and after analysis periods that experienced

an unusually high severe crash frequency. It is possible it is the same locations. Further analysis should be performed to determine any improvements that could be made.

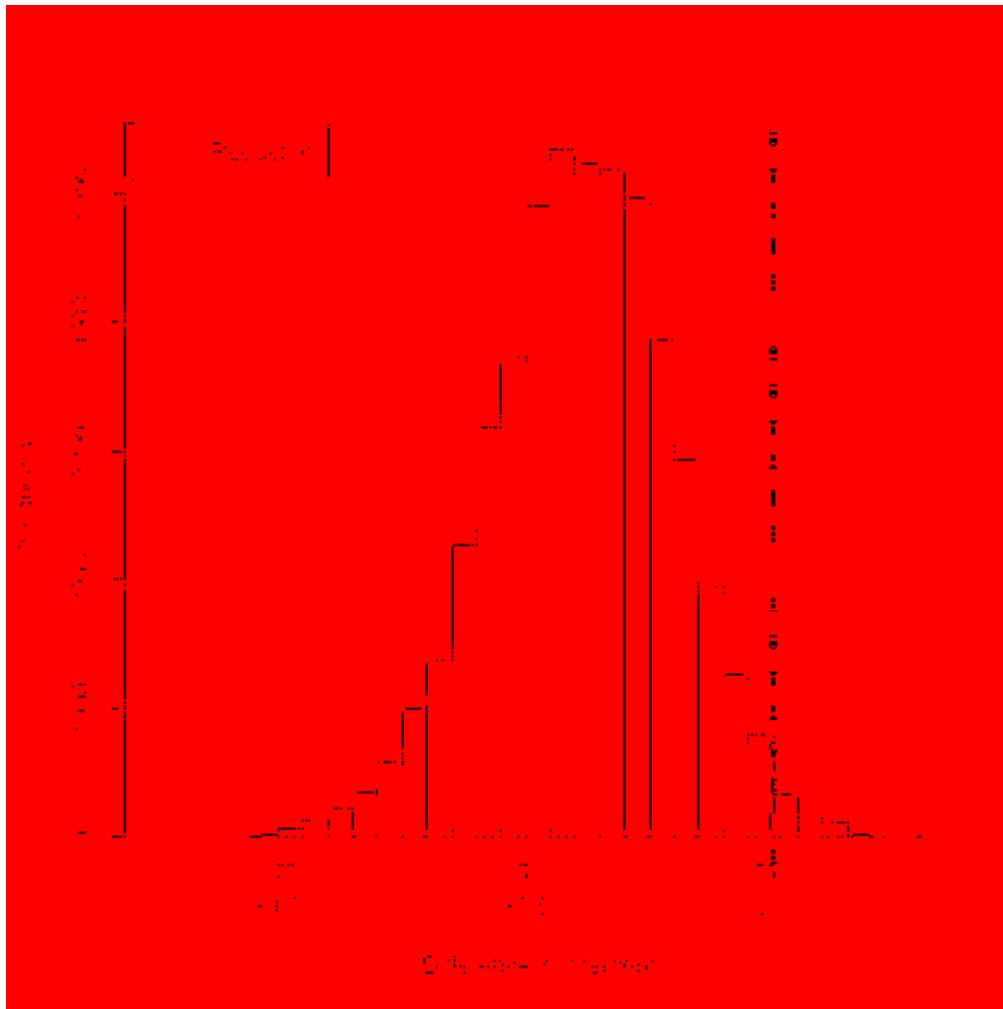


Figure 6-52. Distribution of differences for severe crashes on all cable barrier sites.

Figure 6-53 displays the crash frequency of cross-median crashes for the before and after periods as a function of AADT. The results of the analysis indicate that the cross-median crash frequency decreased by 59.5 percent after the installation of the cable barrier.

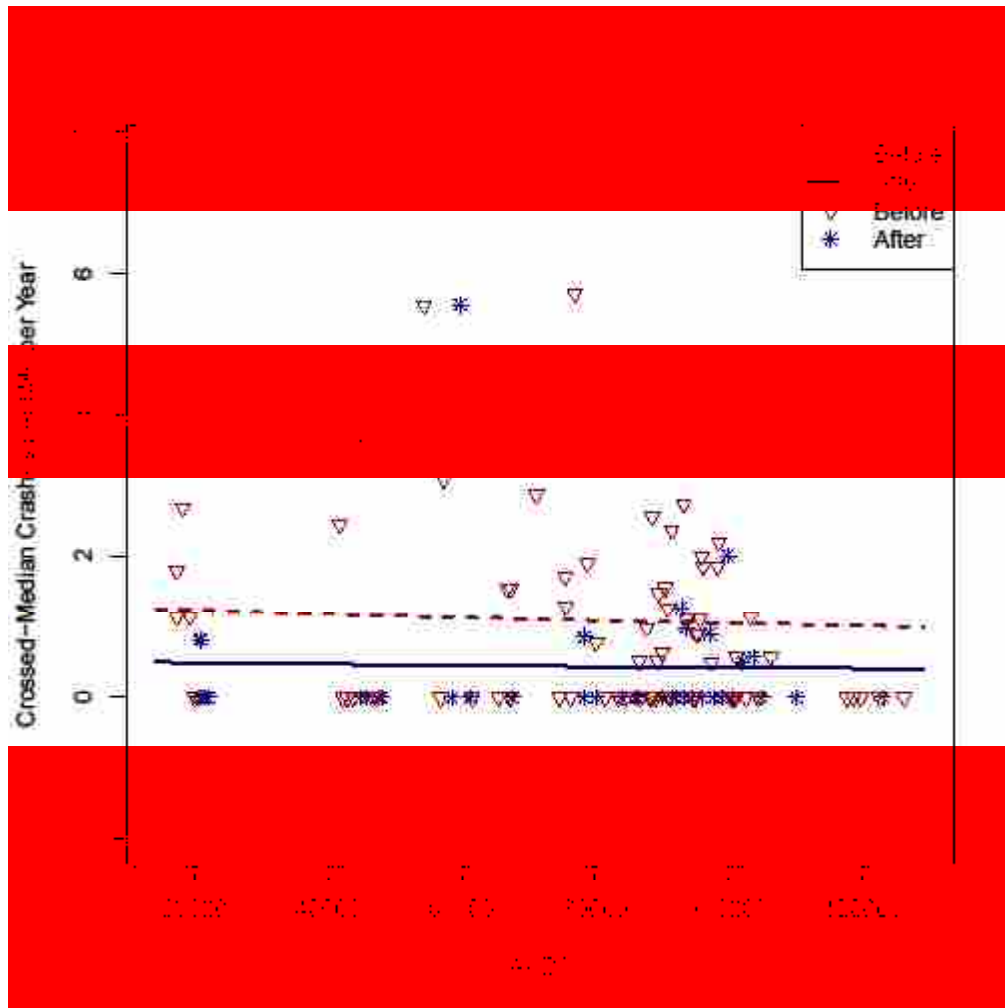


Figure 6-53. Cross-median crashes on all cable barrier sites.

Figure 6-54 shows the corresponding probability distribution of the differences between the before and after periods for cross-median crashes. The entire distribution of differences was less than zero indicating a 100 percent probability a decrease occurred as represented by the grayed portion of Figure 6-54.

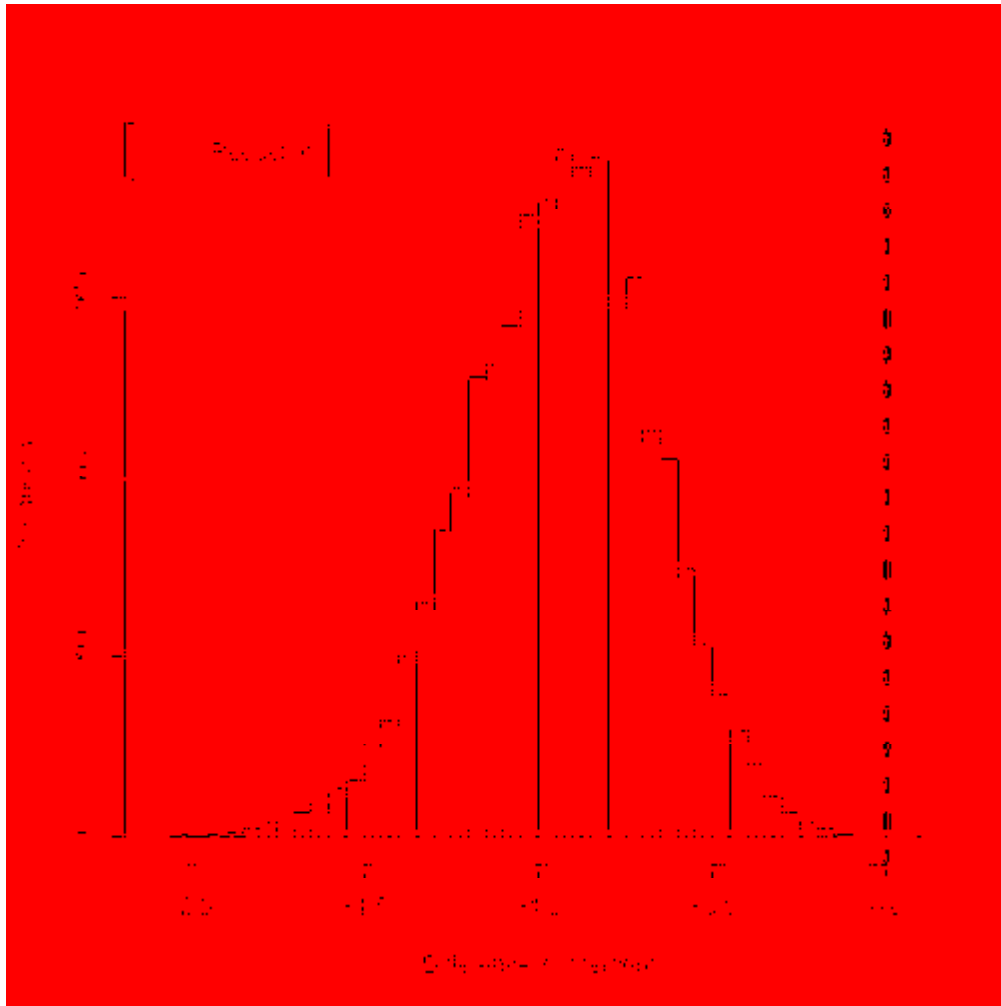


Figure 6-54. Distribution of differences for cross-median crashes on all cable barrier sites.

6.3 Chapter Summary

A summary of the results of the analysis performed on sites where cable barriers have been installed are presented in this chapter. An analysis was performed on individual locations as well as an analysis of data for all locations grouped together. In each case decrease or increase in overall and severe crash frequency was presented. Additionally, the corresponding distribution of differences was presented.

The analysis showed a high probability the overall crash frequency increased after the installation of a cable barrier at six of the eight study sites. These results were expected since cable barriers are not designed to prevent crashes but rather reduce crash severity. Table 6-2 provides a summary of the impact of cable barriers on overall crash frequency.

Table 6-2. Summary of Overall Cable Barrier Crashes

Location	State Route	Year Installed	Probability of Decrease	Percent Change
Provo S-curves to University Parkway	I-15	2004	0.2%	39.1%
Between Pintura and Kolob Canyons	I-15	2005	19.1%	23.4%
Spanish Fork to SR 75	I-15	2005	0.0%	93.0%
South Layton to Syracuse	I-15	2006	0.0%	57.9%
600 N to 2300 N - Salt Lake	I-15	2007	86.2%	-8.8%
3100 S to 3800 S - Salt Lake	I-215 E	2007	99.9%	-52.2%
2100 S to 4500 S - Salt Lake	I-215 W	2007	0.0%	60.3%
Lamb's Canyon Interchange	I-80	2007	13.7%	85.3%

In contrast, the severe crash analyses of the individual locations where cable barrier have been installed show much more promising results. The analysis showed a high probability the overall crash frequency increased after the installation of a cable barrier at all but one of the sites (I-80 Lamb's Canyon). Though the installation of a cable barrier may not be the only factor in reducing the crash severity, it certainly contributed. Table 6-3 provides a summary of the impact of cable barriers on severe crashes for each site.

Table 6-3. Summary of Severe Cable Barrier Crashes

Location	State Route	Year Installed	Probability of Decrease	Percent Change
Provo S-curves to University Parkway	I-15	2004	74.3%	-16.4%
Between Pintura and Kolob Canyons	I-15	2005	99.7%	-79.9%
Spanish Fork to SR 75	I-15	2005	64.2%	-6.5%
South Layton to Syracuse	I-15	2006	96.5%	-45.4%
600 N to 2300 N - Salt Lake	I-15	2007	96.7%	-62.2%
3100 S to 3800 S - Salt Lake	I-215 E	2007	88.9%	-49.4%
2100 S to 4500 S - Salt Lake	I-215 W	2007	94.9%	-52.6%
Lamb's Canyon Interchange	I-80	2007	9.5%	543.0%

The cross-median crash analysis of the individual locations where cable barrier have been installed also showed promising results. The analysis showed a high probability cross-median crash frequency decreased after the installation of a cable barrier at all but one of the sites (I-80 Lamb’s Canyon). It is anticipated that the reduction in cross-median crashes contributed to the reduction in crash severity. Table 6-4 provides a summary of the impact of cable barriers on cross-median crashes for each site.

Table 6-4. Summary of Cross-median Cable Barrier Crashes

Location	State Route	Year Installed	Probability of Decrease	Percent Change
Provo S-curves to University Parkway	I-15	2004	82.2%	-31.0%
Between Pintura and Kolob Canyons	I-15	2005	99.0%	-69.2%
Spanish Fork to SR 75	I-15	2005	96.2%	-51.5%
South Layton to Syracuse	I-15	2006	93.4%	-48.6%
600 N to 2300 N - Salt Lake	I-15	2007	86.5%	-43.2%
3100 S to 3800 S - Salt Lake	I-215 E	2007	81.3%	-34.7%
2100 S to 4500 S - Salt Lake	I-215 W	2007	97.8%	-70.8%
Lamb's Canyon Interchange	I-80	2007	37.0%	137.6%

The combined analysis from all analysis sites grouped together showed 100 percent probability overall crashes increased by 47.4 percent. The severe crash analysis results on all sites showed more promising results indicating a 98.7 percent probability that severe crashes reduced by 30.9 percent, while the cross-median crash analysis indicated cross-median crashes were reduced by 59.5 percent after a cable barrier was installed with a 100 percent probability of decrease. These results are summarized in Table 5-9.

Table 6-5. Results of All Cable Barrier Sites

Type	Probability of Decrease	Percent Change
Overall	0.0%	47.4%
Severe	98.7%	-30.9%
Cross-median	100.0%	-59.5%

The analysis also revealed several outlier locations that experienced an unusually high crash frequency. It is recommended further analysis be performed on these sites to identify reasons why that location experiences such a high frequency.

7 CONCLUSIONS

The purpose of this study was to develop a procedure for data collection and analysis that could be used to determine the effectiveness of roadway safety measures. The preceding chapters have outlined the background of methods used in safety analysis. The analysis procedure using a hierarchical Bayesian model has been set forth to analyze the impact of safety improvements. The model is able to estimate the reduction or increase in crash frequency as well the corresponding probability a change occurred. The procedure developed in this report was applied to raised medians and cable barriers to determine the effectiveness each had on the overall crash frequency and severity of crashes on Utah roadways. The results of the study show a reduction in the overall frequency and severity of crashes. This chapter summarizes the findings and conclusions of the research and provides suggestions for future research possibilities.

7.1 Findings and Conclusions

The analysis in this report was performed using a hierarchical Bayesian model developed as part of the project. The model is a valuable tool with many different applications in transportation safety studies. As part of this project, the model was applied to raised median and cable barrier locations throughout the state of Utah. This study analyzed the effectiveness of raised medians and cable barriers of roadway safety by determining the effect each has on crash frequency and severity at selected locations. An analysis was performed on individual locations

as where raised medians and cable barriers have been installed as well as all locations grouped together.

The results of the raised median analysis indicated a significant improvement on both crash frequency and crash severity where a raised median was installed. Results from all sites combined show that the overall crash frequency was reduced by 34.8 percent and crash severity was reduced by 46.8 percent where raised medians were installed. The reduction in crash severity is anticipated to be a result in the change in types of collisions. This study provides evidence that installing raised medians is an effective technique to reduce crash frequency, particularly severe crashes caused by sideswipes or head on collisions.

The results of the cable barrier analysis indicated that the installation of cable barriers had a significant impact on crash severity and cross-median crashes. The analysis results indicated crash severity was reduced by 30.9 percent and cross-median crashes were reduced by 59.5 percent at locations where cable barriers were installed. However, the analysis showed that cable barrier were not effective in reducing overall crash frequency. Analysis results from showed that the overall crash frequency increased by 47.4 percent after cable barriers were installed. These results were somewhat expected since cable barriers are not designed to prevent crashes but rather reduce crash severity. It is anticipated that the increase in overall crash frequency is the result of increases in traffic volumes or other factors. These results provide evidence that the installation of cable barriers is an effective safety measure in preventing cross-median crashes and reducing crash severity, but have no influence in overall crash frequency.

The usefulness of the application of the model is shown through its application to these two types of road safety measures. In this study, the impact of raised medians and cable barriers

on overall and severe crash frequency was analyzed. The model can be expanded to determine the impact of other safety measure on various crash types.

Additionally, only AADT and crash data were used as covariates for this study. Additional covariates may be included in the model. Selection of the appropriate covariates to be used depends on the scope of the study being performed.

Finally, one of the important elements of transportation safety planning is identifying locations that experience an unusually high crash frequency. The model outlined in this report can be used to identify outlier sites for various types of crashes. The cable barrier and raised median analysis revealed several outlier locations that experienced an unusually high crash frequency in either overall or severe crashes. Further exploration can be performed to identify any factors that contribute to the unusually high crash frequency that can be mitigated.

7.2 Future Research

The procedure outlined in this report is a valuable tool to be used in transportation safety studies. It is recommended that this procedure be applied to future projects to estimate the effectiveness of other types of safety measures. It is also recommended that future research be performed to expand the model to identify areas of interest where unusually high proportions of particular crash types may occur. The results of such a study would be beneficial to identify and prioritize sites where safety improvements need to be made.

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APPENDIX A. MODELING CODE

```
# Load the MCMC library
  library(MCMCpack)

# Set the prior precision for the parameters.
  precision=1

# Now, let's implement the new model.
  maxaadt <- max(newdata$aadt)
  newdata$headon <- rowSums(newdata[,9:12])
  newdata$fatal <- rowSums(newdata[,7:8])

# Perform the analysis for Crashes
  posterior <- myMCMCpoisson(crash ~ site : I(aadt/maxaadt) +
  site:I(ba==0) + site : ba + offset(log(nmil)) - 1 , data=newdata,
  burnin=10000,mcmc=50000, b0=0, B0=precision )
  plotposterior(posterior,"Crash",newdata)

# Perform the analysis for Severe Crashes
  posteriorfatal <- myMCMCpoisson(fatal ~ site : I(aadt/maxaadt) +
  site:I(ba==0) + site : ba + offset(log(nmil)) - 1 , data=newdata,
  burnin=10000,mcmc=50000, b0=0, B0=precision )
  plotposterior(posteriorfatal,"Severe",newdata)
  posteriorheadon<- myMCMCpoisson(headon ~ site : I(aadt/maxaadt) +
  site:I(ba==0) + site : ba + offset(log(nmil)) - 1 , data=newdata,
  burnin=10000,mcmc=50000, b0=0, B0=precision )

  plotposterior(posteriorheadon,"Crossed-Median",newdata)
```

```

posterioroverall <- myMCMCpoisson(crash ~ I(aadt/maxaad) + ba +
offset(log(nmil)) - 1 , data=newdata, burnin=10000,mcmc=50000, b0=0,
B0=precision )
plotposterior(posterioroverall,titlename='Crash',newdata,overall=TRUE)
posterioroverallfatal <- myMCMCpoisson(fatal ~ I(aadt/maxaad) + ba +
offset(log(nmil)) - 1, data=newdata, burnin=10000,mcmc=50000, b0=0,
B0=precision )
plotposterior(posterioroverallfatal,titlename='Severe',newdata,overall=
TRUE)
posterioroverallheadon<- myMCMCpoisson(headon ~ I(aadt/maxaad) + ba +
offset(log(nmil)) - 1, data=newdata, burnin=10000,mcmc=50000, b0=0,
B0=precision )
plotposterior(posterioroverallheadon,titlename='Crossed-
Median',newdata,overall=TRUE)

```