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Use of Roadway Attributes in Hot Spot Identification and Analysis

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ABSTRACT

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The Utah Department of Transportation (UDOT) Traffic and Safety Division continues to advance the safety of roadway sections throughout the state. In an effort to aid UDOT in meeting their goal, the Department of Civil and Environmental Engineering at Brigham Young University (BYU) has worked with the Statistics Department in developing analysis tools for safety. The most recent of these tools has been the development of a hierarchical Bayesian Poisson Mixture Model (PMM) of traffic crashes known as the Utah Crash Prediction Model (UCPM), a hierarchical Bayesian Binomial statistical model known as the Utah Crash Severity Model (UCSM), and a Bayesian Horseshoe selection method. The UCPM and UCSM models helped with the analysis of safety on UDOT roadways statewide and the integration of the results of these models was applied to Geographic Information System (GIS) framework.

This research focuses on the addition of roadway attributes in the selection and analysis of "hot spots." This is in conjunction with the framework for highway safety mitigation migration in Utah with its six primary steps: network screening, diagnosis, countermeasure selection, economic appraisal, project prioritization, and effectiveness evaluation. The addition of roadway attributes was included as part of the network screening, diagnosis, and countermeasure selection, which are included in the methodology titled "Hot Spot Identification and Analysis." Included in this research was the documentation of the steps and process for data preparation and model use for the step of network screening and the creation of one of the report forms for the steps of diagnosis and countermeasure selection.

The addition of roadway attributes is required at numerous points in the process. Methods were developed to locate and evaluate the usefulness of available data. Procedures and systemization were created to convert raw data into new roadway attributes, such as grade and sag/crest curve location. For the roadway attributes to be useful in selection and analysis, methods were developed to combine and associate the attributes to crashes on problem segments and problem spots. The methodology for "Hot Spot Identification and Analysis" was enhanced to include steps for the inclusion and defining of the roadway attributes. These methods and procedures were used to help in the identification of safety hot spots so that they can be analyzed and countermeasures selected. Examples of how the methods are to function are given with sites from Utah's state roadway network.

Keywords: Poisson Mixture Model, crash analysis, hot spots, safety, roadway attributes

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1 INTRODUCTION

The Utah Department of Transportation (UDOT) Traffic & Safety Division continues to advance the safety of roadway sections throughout the state. UDOT has continually placed safety at the forefront of their priorities and continues to develop and publicize the "Zero Fatalities: A Goal We Can All Live With™" campaign to increase awareness of the importance of highway safety. UDOT has also strived to be at the forefront of research and education through their active participation and membership in the Transportation Research Board (TRB) Highway Safety Performance Committee and their willingness to invest in safety research. The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) are also continually working to aid states in safety analysis, primarily with the release of the AASHTO *Highway Safety Manual* (HSM) to aid in the analysis of transportation safety data (AASHTO 2010). This chapter serves to provide background and objective information for this thesis and a general overview of the organization of the thesis.

1.1 Background

To aid UDOT in meeting their goal of advancing the safety of roadway sections throughout the state, Brigham Young University (BYU) has worked consistently with the Department in developing analysis tools for safety. The most recent of these tools has been the development of the Utah Crash Prediction Model (UCPM), which is a statistical model of traffic crashes that includes variables such as functional classification, vehicle miles traveled (VMT), speed limit, and other factors on UDOT roadways statewide, and the integration of the results of this model in a Geographic Information System (GIS) framework. The development of these tools, combined with previous research focused around evaluating effectiveness of safety improvements, calibration of HSM models, and development of a basic framework for safety mitigation shown in Figure 1-1, have helped to set the stage for this, the next phase of the research (Saito et al. 2011, Schultz et al. 2010, Schultz et al. 2011, Schultz et al. 2012, Schultz et al. 2013).

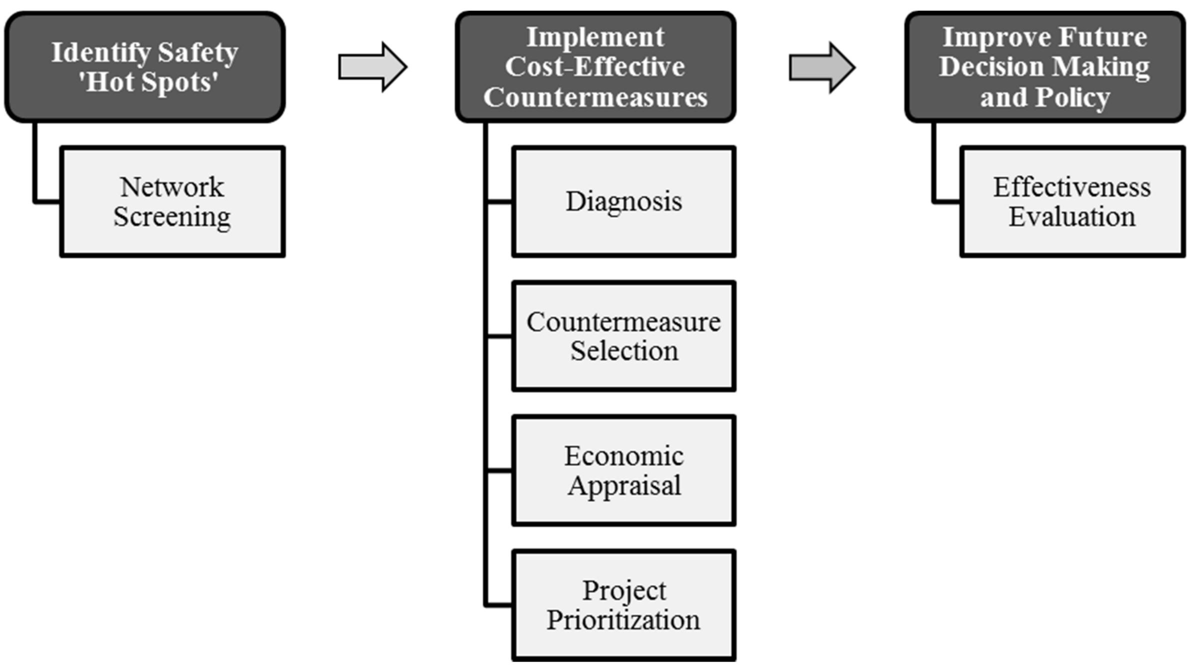

Figure 1-1: Framework for highway safety mitigation (adapted from AASHT0 2010).

1.2 Objectives

The primary objective of this research is to update and improve the predictive crash model developed by BYU in previous research, which is used to identify safety hot spots. This research will apply the addition of roadway characteristics and attributes to the model to increase flexibility and functionality. The objective is to evaluate roadway data, including attributes obtained through Light Detection and Ranging (LiDAR) roadway surveys, through calibration and sensitivity analysis to identify key roadway attributes that contribute to crashes. These key attributes are used to identify and prioritize locations for statewide safety projects These attributes are also used in reviewing methods of selecting countermeasures for the locations that are identified.

1.3 Organization

This thesis is organized into the following chapters: 1) Introduction, 2) Literature Review, 3) Data, 4) Statistical Model, 5) Roadway Attributes Identification and Analysis 6) Examples and Results, and 7) Conclusions. A list of references, list of acronyms, and appendices follow the indicated chapters.

Chapter 1 presents an overview including background and objectives of this research.

Chapter 2 is a literature review outlining safety, analysis techniques, and the use of roadway attributes.

Chapter 3 discusses the data used in this study and analysis. General considerations are given as well as a discussion of data systemization and standardization for use in the model. A review of how the data are processed is also included.

Chapter 4 discusses the theoretical aspects of the hierarchical Bayesian model used for the identification of the segments and statistical methods used in sensitivity analysis of the roadway attributes. This chapter also includes statistical outputs and a discussion on the results.

Chapter 5 is a discussion of the process used in determining the problem segments and key roadway attributes that contribute to crashes. A discussion of selection and use of data during the process is included.

Chapter 6 is a discussion and review of the processes using examples with a detailed discussion of the steps used, including specific data.

Chapter 7 provides conclusions of the research presented in this thesis along with recommendations for future research to be considered.

2 LITERATURE REVIEW

A literature review was performed on traffic safety and possible roadway attributes that can be analyzed and identified as corresponding to roadway safety. This chapter gives the reader a background into safety, crash analysis techniques, purpose of crash analysis, and model variables and attributes. The roadway attributes literature review primarily focuses on the HSM with a review of attributes used in other models and methods. For more detail on the safety and crash analysis techniques, the reader should refer to previous research related to this topic (Saito et al. 2011, Schultz et al. 2010, Schultz et al. 2011, Schultz et al. 2012, Schultz et al. 2013).

2.1 **Safety**

Traffic and roadway safety definitions can typically be grouped into two categories: subjective and objective. The subjective definitions are based on the perception or observations of the user on how safe a traffic or roadway system is. These observations are typically associated with a feeling or opinion of the level of safety. Qualitative definitions are typically associated with measureable data points such as crash frequency, crash severity, and other crash attributes (Schultz et al. 2011). The HSM defines safety as "the crash frequency or crash severity, or both, and collision type for a specific time period, a given location, and a given set of geometric and operational conditions" (AASHTO 2010, p. 3-1). In most definitions, safety is related to crashes in some form. Thus, in order to fully understand and define safety, it is necessary to understand and define crashes. The HSM defines a crash as "a set of events not under human control that results in injury or property damage due to a collision of at least one motorized vehicle and may involve collision with another motorized vehicle, a bicyclist, a pedestrian, or an object" (AASHTO 2010, p. 3-3).

Roadway safety has long been a focus of UDOT. This focus can be seen by the implementation of a statewide safety campaign in 2003 by UDOT and other safety stakeholders in the state, including the Utah Department of Public Safety (UDPS), Utah Department of Health (UDOH), and the Utah Transit Authority (UTA). The primary goal of the campaign is to reduce the number of serious injuries and fatalities throughout the state with the end goal of zero fatalities. "Zero Fatalities: A Goal We Can All Live With™" is the title of this safety campaign (Zero Fatalities 2013). With greater understanding and focus given to safety, assets can be employed to improve and create more efficient safety mitigations, which then can be implemented to reduce the number of fatal and serious injuries observed on the roadways (Schultz et al. 2013).

2.2 Crash Analysis Techniques

Crash analysis techniques are crucial to continuous improvement of roadways when dealing with traffic safety. Over the years many models and methods have been developed and employed to review and analysis the safety of the roadway systems. Each model or method comes with its own set of advantages and disadvantages, depending on the purpose and goals of the analysis and the quality and quantity of data available (Herbel et al. 2010, Schultz et al. 2012). These models and methods can be categorized in two ways: traditional descriptive analysis and predictive analysis (Schultz et al. 2013). Recent research wherein both previous and new models were reviewed provides additional predictive models.

2.2.1 Traditional Descriptive Analysis

As discussed in previous research, traditional descriptive analysis is designed to use historical data alone. The methods focus on summarizing, quantifying, and analyzing these data. The traditional analysis methods include before and after studies, crash rates or frequencies for defined segments, and equivalent property damage only (PDO) analysis. These methods have a number of strengths, including being useful in locating and prioritizing sites that need improvements and in the evaluation of effectiveness. However, crashes are events that are both random and rare, which indicates that a combination of factors may cause a crash. The randomness of crashes will cause the frequency to naturally fluctuate about an average, known as the regression to mean (RTM) bias. The traditional analysis methods generally do not consider RTM, which may result in focusing on locations that may not be critical, causing an inefficient use of safety improvement funds (AASHTO 2010, Schultz et al. 2011). Further information on traditional descriptive analysis methods and RTM bias can be found in the literature (Hauer 1997, Hauer et al. 2002, Qin et al. 2004, Saito et al. 2011, Schultz et al. 2010, Schultz et al. 2011, Schultz et al. 2012, Schultz et al. 2013).

2.2.2 Predictive Analysis

As the need for more advanced safety analysis has increased, there has been a shift from the traditional descriptive analysis to quantitative predictive analysis. Quantitative predictive models are statistically-based models that use variables to calculate an expected number of crashes and severities at a specific site or roadway segment. These models address the issue of RTM bias and use regression analysis to predict the crash count based on the input variables used. Typically the models make use of historical data for the selected site and data from additional sites that share similar characteristics (Schultz et al. 2011). Predictive analysis methods discussed in previous research include crash modification factors (CMFs), crash reduction factors (CRFs), safety performance functions (SPFs), ordinary least square regression and Poisson estimations, negative binomial (NB) models, Empirical Bayesian (EB) methods, and hierarchical Bayesian methods. The variables used differ between the models and the user of the models and can cause varying results from the models (Schultz et al. 2011). Further information on these predictive analysis methods can be found in the literature (AASHTO 2010, Gross et al. 2010, Hadi et al. 1995, Hauer 1997, Olsen et al. 2011, Qin et al. 2005, Saito et al. 2011, Schultz et al. 2010, Schultz et al. 2011, Schultz et al. 2012, Schultz et al. 2013, Strathman et al. 2001).

2.2.3 Recent Predictive Models

Recent models aid the continuing effort to improve and advance crash analysis. Two recent methods are the Quantile Regression Method (Wu et al. 2014) and the Bayesian Spatial Joint (BSJ) method (Zeng and Huang 2014). Both methods apply statistical models using a variation of crash and roadway attributes for analysis. The Quantile Regression Method analyzes the crash data and the effect of the covariates through the quantiles versus the mean. This is done to account for the large number of zero crash counts, causing the right skewed distribution. It is claimed that this technique also allows for relaxed restrictions of the response variable by the researcher (Wu et al. 2014). This statistical model is used in predicting crashes in two ways, one by location and the other by probability. Further information on the Quantile Regression Method can be found in the literature (Wu et al. 2014).

The BSJ method is a zonal crash prediction model (CPM) rather than a site CPM. Many of the CPMs that exist analyze at the site level, or more specifically, a single type segment of roadway or an intersection (Zeng and Huang 2014). The BSJ method attempts to analyze and make crash predictions at a zonal level or road network level by looking at intersections and their connected road segments simultaneously. This is done using spatial correlation based on the idea that roadway attributes are in close proximity and may share confounding factors. In this method, the statistical model used a conditionally autoregressive (CAR) Bayesian spatial model. Whereas most applications of the CAR are limited to a sole type of road entity or traffic zone, the BSJ modifies the CAR base with a spatial correlation solely between intersections and segments. The model also employs indicator variables to distinguish whether it is a segment or an intersection. Further information on the BSJ method can be found in the literature (Zeng and Huang 2014).

2.3 Purpose of Crash Analysis

The primary purpose of crash analysis is to locate and identify possible areas that could be considered unsafe. The crash analysis methods and models used in the traditional descriptive analysis and predictive analysis are designed to help engineers determine where these locations are that may be unsafe and prioritize them. Once locations are identified, further analysis is required to determine what roadway attributes might be factors in the increased number of crashes. Countermeasures can then be evaluated and selected for implementation. Further discussion on possible countermeasures based on the National Cooperative Highway Research Program (NCHRP) Report 500 series can be found in the literature (Antonucci et al. 2004, Goodwin et al. 2005, Neuman et al. 2003a, Neuman et al. 2003b, Neuman et al. 2003c, Neuman et al. 2003d, Neuman et al. 2008, Neuman et al. 2009, Schultz et al. 2013).

2.4 Model Variables and Attributes

Crash analysis techniques use a number of different variables or attributes to analyze a site for safety. Traditional descriptive analyses are generally designed around specific attributes as in the case of before and after studies, which use crash count and frequency related to a specific roadway treatment (Schultz et al. 2011). Predictive models are generally more flexible and allow for multiple attributes to be reviewed during the analysis. The variables are chosen through a number of methods. The HSM methods based on the EB and NB use predefined CMFs giving a weighting to different roadway attributes that have been determined to have an effect on the number of crashes. Other models allow for more flexibility in the variable selection, thus eliminating the need to create CMFs and SPFs (Schultz et al. 2010). Regardless of the method in which the attributes are used, every model uses variables. These variables can be grouped into two different categories: crash attributes and roadway attributes. Most crash attributes are linked to human factors such as age, sex, intoxication, distracted, etc. Roadway attributes include items such as annual average daily traffic (AADT), lane width, functional class, curvature, shoulder width, barriers, grade, and medians. The following sections review fundamental attributes used as a foundation for many models, roadway attribute applications in crash analysis, and the utilization of LiDAR data in identifying attributes to be analyzed.

2.4.1 Fundamental Model Attributes

There are some attributes used across most of the predictive models. These attributes create a baseline description of the segments being analyzed, which allows the segments to be compared. Two of the most important and basic attributes for roadway analysis are traffic flow (typically provided in the form of AADT) and segment length. These attributes are used separately and in various combinations (e.g. VMT) (Zou et al. 2013). A fundamental attribute needed in predictive models is the crash count for each roadway segment. The HSM defines a roadway segment as “a continuous portion of roadway with similar geometric, operational, and vehicular characteristics” (AASHTO 2010, p. 13-2). Methods for determining crash counts on segments can be accomplished mathematically from a larger count (Hauer et al. 2002) or with GIS tools (Schultz et al. 2012). An additional attribute that is employed in a number of models is crash severity. The two main methods to apply severity levels to a model are to average the severity levels of the crashes over the segment or to select specific levels to narrow the crashes used in the model (AASHTO 2010, Gross et al. 2010, Hadi et al. 1995, Hauer 1997, Olsen et al. 2011, Qin et al. 2005, Saito et al. 2011, Schultz et al. 2010, Schultz et al. 2011, Schultz et al. 2012, Schultz et al. 2013, Strathman et al. 2001).

2.4.2 Roadway Attributes

Roadway attributes have long been a focus with regard to traffic and roadway safety. The traditional descriptive analysis used roadway attributes in before and after studies to determine the effect a change of roadway characteristics had on the number of crashes at that location. As advances have been made in the predictive quantified analysis, roadway attributes are generally employed in two different ways depending on the model. One, as used in the HSM and others, is as a statistical weighting used to predict crash counts. The other is to use the attributes in the process of creating homogenous roadways segments (AASHTO 2010, Hauer 1997, Olsen et al. 2011, Qin et al. 2005, Saito et al. 2011, Schultz et al. 2010, Schultz et al. 2011, Schultz et al. 2012, Schultz et al. 2013). Some common roadway attributes used are speed limit, number of lanes, and lane widths. The most comprehensive list of possible attributes can be found in the HSM. The HSM provide a list of CMFs that incorporate “the effects of geometric design and traffic control features” (AASHTO 2010, pp. 10-14). A review of the significant roadway attributes selected for use in few of the predictive analysis models can be found in the following subsections.

2.4.2.1 HSM Model Attributes. The HSM predictive model uses selected roadway attributes that are then analyzed to create a CMF to be used in the model as a weighted effect on the crash count. One main goal of the HSM is the use of different roadway attributes to predict the effect of possible countermeasures to reduce the crash frequency at a given location. The CMFs are also used in a straight predictive method based on the presence of the roadway attributes at a given location.

The selection method employed by the HSM to determine which attributes could be used to create CMFs has three steps: literature review, inclusion process, and expert panel review. The literature review performed on safety research pertaining to transportation “mostly dated from the 1960s to June 2008” (AASHTO 2010, p. D-7). The literature review consisted of a 5-step process to create a CMF can be found on page D-7 of the HSM. This process includes a statistical analysis of the effects of RTM and standard error. The expert panels “reviewed and assessed the relevant research literature related to the effects on crash frequency of a particular geometric design and traffic control feature” (AASHTO 2010, p. D-7). The inclusion process is based on the standard errors. The HSM determined that standard errors of 0.10 should generally be used in evaluating CMFs, although standard errors of 0.20 and 0.30 are also acceptable under certain circumstances.

The following is a list of the primary attributes selected as part of the HSM. It is not an all-inclusive list and additional information on attributes and CMFs can be found in the HSM (AASHTO 2010).

- Lanes, including width and number of lanes
- Shoulders, including width, type, and material
- Roadside hazard rating
- Horizontal alignment, including curvature and length
- Vertical alignment, including curvature and length

- Centerline rumble strips
- Auxiliary lanes, including passing lanes and two-way left-turn lanes
- Lighting
- Grade level
- Median, including type and width

2.4.2.2 Other Predictive Model Attributes. Other predictive analysis models generally use an abbreviated list of attributes based on the list above. The main limitation of attributes selected for use in other models is the availability. A study done by the University of Texas at Austin using the quantile regression (QR) to determine the influence of roadway attributes on crash counts excluded lighting, auxiliary lanes, hazard rating, and others because the dataset from the Highway Safety Information System (HSIS) for the state of Washington did not have the data available (Wu et al. 2014). Similarly, other studies are limited by available GIS data from different states and, in some cases, the need to acquire the data manually to provide a more complete list of attributes (Schultz et al. 2011, Schultz et al. 2012, Schultz et al. 2013, Zeng and Huang 2014).

2.4.3 LiDAR Data

Technological advances provide tools for improving roadway attribute data accuracy and availability for use in crash analysis. Two such technologies are LiDAR and GIS. For more detail on GIS use in safety research, the reader should refer to previous research related to this topic (Pradhan and Rasdorf 2009, Schultz et al. 2012).

The National Oceanic and Atmospheric Administration (NOAA) defines LiDAR as "a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth" (NOAA 2014). This technology is used to collect three dimensional (3D) data that can be used to generate accurate maps and models that can be used in GIS. LiDAR technology has been employed in scientific research for decades, but has only recently found its way into transportation safety research. LiDAR equipment, which was traditionally used by means of aircraft, has been adapted for and mounted to street vehicles, which has facilitated an increase in efficiency for use in documenting roadway attributes (UDOT 2014).

LiDAR is being used to collect "roadway distress data, surface areas, lane miles, number of signs, right-of-way (ROW), vertical clearances, and more, with each of those categories broken down even further into subcategories ranging from condition data to Global Positioning Systems (GPS) data, etc." (UDOT 2014). A primary benefit to collecting roadway attributes using LiDAR technology is that all the attributes can be collected at the same time as part of the same dataset. This increases the accuracy of attribute locations, not only to the road segment, but also the relationship between the different attributes. These data are then being used in conjunction with analysis tools to determine possible hazardous road segments by comparing site attributes with attributes known to increase the likelihood of a crash (Pradhan and Rasdorf 2009).

2.5 Chapter Summary

Safety can be defined by both subjective and objective means, with subjective based on a user's perception of safety and objective generally based on the quantitative measure of crash frequency. There are two basic categories of objective analysis that employ the use of crash frequency: traditional descriptive and predictive analysis. Traditional descriptive analysis uses techniques of summation and quantification to areas of concern, whereas predictive analyses are based on advanced statistical models. These methods and techniques are used to locate problematic segments of roadway and intersections where improvements through countermeasures can be implemented.

The statistical models used in the various predictive analyses generally make use of variables or attributes. These attributes can be classified as crash or roadway attributes. Crashes are typically associated with human factors, whereas roadway attributes are characteristics of a roadway segment that might affect the number of crashes at that location. These roadway attributes are used in a number of ways to help predict the number of crashes. These predicted counts are compared to historical data to determine the problem locations. The HSM, through extensive research, has compiled the most comprehensive list of roadway attributes that could be used in crash analysis. These attributes are used by the HSM to create CMFs to be used as weighting factors. Other models use similar, but shorter, lists of attributes based on their functionality and the availability of data for the roadway attributes. A new method for acquiring that data is the use of LiDAR systems. LiDAR technology has advanced the accuracy and availability of the roadway attributes. Knowing the location and type of roadway attribute is crucial in determining the form of countermeasures which are best suited to reduce the number of crashes at a problematic location. The next chapter reviews and discusses the data needs for this project.

3 DATA

Data are a primary portion of any model. Data can affect which models are used, as well as the effectiveness of the model. Two major factors to consider in when choosing the type and method of crash analysis are availability and quality. The availability and quality might limit the level of analysis or even the type of analysis that can be done for a specific dataset. Availability restricts the methods, as models must have data to be used, while quality or lack of quality may require certain data to be removed from the model, thus making it essentially not available. Accuracy is important, as it is a determining factor to the level of validity and accuracy of the results. This chapter reviews and discusses general data considerations (e.g., accuracy, availability, coverage, and usability), data management and systemization, what datasets were used in this project and how they were used, and the project tasks associated with the data. For additional information not provided in this chapter about data, the reader is referred to the report titled "Traffic and Safety Statewide Model and GIS Modeling" in the literature (Schultz et al. 2012).

3.1 General Data Considerations

There are several general considerations that need to be employed when reviewing data for any model. These considerations will affect what model is selected, as well as if and how the data are used as part of the model. Accuracy, availability, coverage, and usability are a number of the general considerations of any dataset that might be used in analysis. These four considerations are discussed further in the following subsections.

3.1.1 Accuracy

Accuracy relates to the correctness and precision of the data and the ability of the data to provide valid results. "Accuracy is important in order for the analysis to be valid and lead to real safety improvements" (Schultz et al. 2012). This is especially important in automated data preparation. Many tools such as GIS, computer scripts, and database systems are currently used in automating the preparation of data. There are many benefits of automating data preparation including speed, efficiency, and, in most cases, increased accuracy. However, with automation, a simple error can propagate through many iterations and layers to cause significant inaccuracy. Quality checks should be implemented at various levels to ensure that minor errors are found and corrected. Examples of quality checks include peer review, spot-checks, and comparing the prepared data to the original. When possible, quality control checks should be automated for repeatability. However, some may need to be specific due to analysis needs (Schultz et al. 2012).

3.1.2 Availability

Availability of data can potentially limit the methods (i.e., the tools used to analyze the data) and depth of analysis. Availability and access to the data will be one of first steps in determining whether the data are viable as an input. When data are widely available, it encourages analysis and sharing of results. Protected and/or non-accessible data restricts general availability, which can prove to be of little to no value depending on the data's difficulty to acquire (Schultz et al. 2012). The implementation and expansion of web-based tools such as the UDOT Open Data website (now part of the UDOT Data Portal and the Utah Automated

Geographic Reference Center (AGRC) (Utah AGRC 2014)) are becoming essential to data availability, as these tools provide single point access for the sharing of data and are increasing in number at both the state and federal levels.

Availability is an important consideration for both long and short terms. Data collection plans need to be reviewed for long-term collection methods to ensure the availability of data for future analysis. Data that become unavailable due to a lack of updating or collection will affect the accuracy in the future. Although unique one-time collection and use of datasets is sometimes necessary, there is little value after the initial use (Schultz et al. 2012).

3.1.3 Coverage

Coverage relates to the extent of information to which the data refer, and could limit the scope of analysis. The consideration of coverage is based on the completeness of the data as well as the overall range of the data. Completeness refers to data that are missing that should be included, whereas range refers to the geographic area of the data and the date or the time period from which the data were collected. The constraints for the coverage may vary depending on the statistical model being used. For this research, data covering the entire state of Utah were used. For each dataset used, a review of the coverage should be completed to determine the range and completeness of the dataset. It is important to note that the dataset with the least coverage will be the limiting factor on the level of the analysis for both time and geographic area. With the implementation of roadway attributes, certain attributes will not exist at every segment or intersection, so the preference would be that none or zero is an appropriate option for the attributes. As with availability, long term and short term access should be reviewed. Any limitation to the coverage will decrease the output of the analysis (Schultz et al. 2012).

3.1.4 Usability

Usability or usefulness of the data in the analysis should be considered to reduce unneeded effort. Usability generally refers to type, format, and usefulness. Data can meet all the other requirements and still not provide much worth to the analysis. It is good to determine if the data are or could be useful, before spending time and effort in data collection and preparation. Data are now available in many types and formats. Depending on the tools used in gathering and preparation, some formats might not be useful or compatible. The benefit of using advanced tools such as ArcGIS, database and scripting is that most of the programs come with a number of built-in conversion processes. These tools, when used properly, can typically produce a dataset in a useable format (Schultz et al. 2012).

3.2 Data Management and Systemization

One objective of this research was to improve upon the data management systems from previous research found in the literature (Saito et al. 2011, Schultz et al. 2010, Schultz et al. 2011, Schultz et al. 2012, Schultz et al. 2013) through the process of systematization. The systemization of data and model processes focused on the implementation of automation and documentation. The systemization of methods and processes is important when the desire is for more than a one-time analysis. Systemization provides a level of repeatability and consistency, allowing for similar or the same analysis to be performed on multiple datasets. The following subsections will describe data uniformity and uniformity methods applied to the utilized datasets, the improvements in systemization with a focus on automation of data preparation, and documentation of the processes in a user manual.

3.2.1 Data Uniformity

Generally, all required data will not come in a single dataset; this makes uniformity important in order to ensure accuracy and compatibility between the different datasets. An important consideration when using multiple datasets with tools such as ArcGIS is relational data. Verification that the datasets can be spatially or linearly related should be done to confirm the data's usability. The following list was created in previous studies (Schultz et al. 2012, Schultz et al. 2013). It contains five data fields that are recommended for use in all datasets.

1. "ROUTE_ID": Contains four numeric digits with the route number and leading zeroes
2. "DIRECTION": Contains P, N, or X corresponding to the route direction
3. "LABEL": Five-digit code with the ROUTE_ID and DIRECTION fields joined
4. "BEG_MILEPOINT": Beginning milepoint of the segment
5. "END_MILEPOINT": Ending milepoint of the segment

These fields correspond with the State Routes Linear Referencing System (LRS) dataset that is required for use in the model that was developed for this research project. Use of ArcGIS for linear and spatial referencing of two or more datasets requires a consistent "Identifier" field. This field must be present in each dataset with data presented in the same format (Esri 2014). For this and previous research, Field 3 of the list (LABEL) was used for this identifying field. The "LABEL" field consists of a string type format, which includes a combination of the four-digit route ID and the single letter direction ID (e.g., 0006P). Typically, roadway milepost convention has the mileage on the mileposts increasing from west to east and south to north; for this research positive travel direction is the direction following the direction of increasing mileposts. The "P" direction code indicates that route milepoint measures are increasing with the positive direction of vehicle travel. The “N” direction code indicates that milepoints are increasing in the negative of the direction of vehicle travel. Finally, the “X” direction is used as a surrogate measure for the “N” direction. The “X” direction follows the same geometry as the “N” direction, but has milepoints that match the “P” direction, meaning the milepoints are decreasing in the negative travel direction. For this research, only divided roadways have both a “P” and “X” segment; all other segments are noted only by the “P” direction. The other fields in the list are used for ease in creation of automation tools. Additional information about data uniformity can be found in the literature (Schultz et al. 2012).

3.2.2 Automation

Automation is an important aspect of systemization; it typically uses computers and computer software to complete tasks independent of additional inputs. Automation can increase efficiency by reducing time and effort needed to perform redundant and tedious tasks. More importantly, if properly done, automation can reduce human error and increase accuracy and consistency. A list of processes and flow was generally laid out in previous research. The previous research also provided some automation, mostly in the creation of tools used in ArcGIS. These tools are used to segment roadways and perform crash counts (Schultz et al. 2012). The automation, as part of this research, included creating scripting for speed and ease of data preparation and presentation of results. Additional automation was required due to changes in collection and management of required datasets.

3.2.3 Documentation

Documentation is a critical aspect for reproducing consistent and repeatable analyses. The process of documentation included descriptions and notations as part of the scripts used for automation and step-by-step instructions from data collection to result presentation in the form of a user's guide. Scripts designed for repeated use with different datasets should include both an initial description of what the function of the script is and a general discussion of the variables being used. Comments should also be placed at various steps to allow the future user to understand and adjust the script for future variations in the datasets. A user's guide or manual should be created to provide overall instructions on the various actions to be taken to complete the analysis.

Previously created scripts were reviewed for function and completeness. During the review, it was discovered that a few of the scripts were designed with one-time analysis as the primary function. Updating scripts included adding flexibility and function to the code and written comments and descriptions to help facilitate future review and modification. The comments included descriptions of the variables used in the script with details on the data type and format needed for the proper functionality. A detailed overview was added to the start of each script that included a discussion of the needs, the function, and brief explanation of the purpose behind the script.

The majority of the work on documentation resulted in a complete user's guide for future analysis using the statistical model described in Chapter 4. The guide includes a brief discussion on the three primary programs that are employed during the process: Excel, ArcGIS, and R. The discussion explains where and how each tool is used in the process. A section on data collection and preparation lists all the required datasets, including where to acquire data, how to configure the information, and examples of the data once preparation is complete. The guide provides a detailed step-by-step tutorial that provides an overview and details that help the user take the data from the source through the segmentation process then to the model analysis, ending with an optional presentation method completed with ArcGIS. Previous research provided basic process flow to create a general outline and methodology for the user's guide. Additional information and hints were found in the research notes and other sources available from past researchers. Other data needed for the guide were gathered from personal discussion with researchers and statisticians who had used many of the processes and methods. The final process, flow, and techniques were developed by working through each step and documenting the successful methods. These methods were documented in the UCPM User's Guide (Bassett et al. 2015).

3.3 Utilized Datasets

This section provides an overview of the datasets utilized for this project. Table 3-1 is a summary of the datasets and their source, format, and future availability. This table only shows the datasets that were used in this project and is not a comprehensive list of all possible datasets that could be used in crash analysis. There were two main sources for the data used in this research: the UDOT Traffic and Safety Division and the web-based UDOT Open Data Portal. "The UDOT Open Data is a central clearinghouse of all public UDOT data" (UDOT 2015a). This tool provides "easy, transparent access" (UDOT 2015a) to roadway datasets for the state of Utah, including most of the datasets listed in Table 3-1. The second source of data was the Traffic and Safety Division of UDOT. The curvature dataset was in beta form and not cleared for public access, so it was provided directly from UDOT. The crash data, which are of a sensitive nature and also are not available for public access, were also provided directly from UDOT.

The data from UDOT Open Portal were downloaded in shapefile format. This was to facilitate the data being used in the ArcGIS program. The comma separated variable (CSV) format was chosen for the crash data, based on the format needed by the program selected for the data preparation and clean-up. The curvature data were only available in the shapefile format. Many of the datasets in shapefile format were acquired through LiDAR technology. UDOT currently plans to update the LiDAR datasets every two years. UDOT has permanent traffic counters, placed throughout the state, that are used to produce AADT on an annual basis. The crash data collected and compiled by UDOT are also updated annually. The other data will be updated as noted in Table 3-1. Refer to Section 3.4 for more information on the how the datasets were implemented and applied.

Table 3-1: Data Source Summary

Dataset	Source	Format	Future Availability
State Routes LRS	UDOT Open Data	Shapefile	Updated Regularly
Crash Data	Traffic and Safety (UDOT)	CSV Tables (Excel)	Updated at least Annually
AADT	UDOT Open Data	Shapefile	Updated Annually
Truck AADT	UDOT Open Data	Shapefile	Updated Annually
Speed Limit	UDOT Open Data	Shapefile	TBD
Functional Class	UDOT Open Data	Shapefile	TBD
Through Lanes	UDOT Open Data	Shapefile	TBD
Urban Code	UDOT Open Data	Shapefile	TBD
Curvature	Traffic and Safety (UDOT)	Shapefile	Updated Biennially
Shoulder	UDOT Open Data	Shapefile	Updated Biennially
Medians	UDOT Open Data	Shapefile	Updated Biennially
Rumble Strips	UDOT Open Data	Shapefile	Updated Biennially
Walls	UDOT Open Data	Shapefile	Updated Biennially
Barriers	UDOT Open Data	Shapefile	Updated Biennially
Auxiliary Lanes	UDOT Open Data	Shapefile	Updated Biennially
Intersections	UDOT Open Data	Shapefile	Updated Biennially
Signs	UDOT Open Data	Shapefile	Updated Biennially

3.4 **Project Data Tasks**

There are five distinct tasks for which the datasets mentioned in Table 3-1 are used as part of this project. These tasks are: data preparation, the roadway segmentation process, use and calibration as a variable in the model, for microanalysis of hot spots, and for analysis of the roadway attributes at the hot spot location. The following sections will describe these tasks and how the data are used in each one.

3.4.1 Data Preparation

Three general data groups are prepared for use in the model in this project: segmentation data, crash data and roadway attributes. The data all require similar preparation methods, even though they are used in very different methods. Modifications were made in formatting, organization, and filtering. Table 3-1 contains a complete list of the datasets used for this analysis and each had to undergo some modification to create the uniformity discussed in Section 3.3. The data were readily available and downloaded from UDOT Open Data as a shapefile (UDOT 2015a). A critical dataset in the facilitation of this analysis was the State Route LRS data. This was used as the required base route for all linear referencing. This research was only conducted on state route segments excluding ramp systems. All data for segments with a route number higher than 491 and ramp segments were removed and stored in additional datasets. This procedure was performed on all the datasets except the referencing data found in the State Route LRS. All data preparation was completed in Excel with Visual Basic for Applications (VBA) macros to complete the work. The data were then spot checked and reviewed for correctness through physical and macro methods. Once reviewed, ArcGIS was used to create layers for each dataset using the State Routes LRS as the base route for consistency.

The crash data were received from UDOT directly and were separated by year and data type. The data types included crash, location, people, vehicle, and rollup data including crash attributes. These data share a common link through a unique crash ID. Each dataset provides a different set of attributes focusing on a specific category relating to crashes. The crash data are general attributes of the crash, including manner of collision and contributing factors. The location data include milepost, routes, county, city, and GPS coordinates. The people dataset includes specific data about the driver and passengers of the vehicles involved, whereas the vehicle data include items, such as sequence of events, vehicle make and models, and impact information. These data required the most preparation. The preparation included combining the data into one complete dataset inclusive of the years from 2008 to 2012 that could be used for this analysis and the different data types. The redundant data between the different datasets were removed to provide clarity of column requirements and selections. As with the roadway data, additional data were added and column headers updated to meet the uniformity requirements. These data were used to create an ArcGIS layer for analysis with the segments. For additional information and details on the data preparation processes, refer to the literature (Schultz et al. 2012, Schultz et al. 2013).

3.4.2 Segmentation Process

The purpose of the segmentation process is to generate and identify homogenous roadway segments based on roadway data and roadway characteristics. These roadway segments are used in the UCPM and the Utah Crash Severity Model (UCSM). This process is necessary so that every segment created has consistent attributes and characteristics along the entire length of the segment. For this project the state route system was segmented using five datasets: functional class, AADT, speed limit, number of through lanes, and urban code. As discussed, these data were prepared to include the five fields listed in the Section 3.2.1. The process was completed using an ArcGIS tool called "Overlay." This tool, using the base layer of the State Route LRS, segmented each roadway into smaller segments by sequentially overlaying each of the five datasets. Although the order is not critical, it is important to be consistent to produce the best results. This method provides varying lengths of roadway segments. For this and previous research, it is assumed that the segments generated are of sufficient length. For more information of the concerns and considerations about the segmenting process and a more in-depth description, refer to the literature (Schultz et al. 2012, Schultz et al. 2013).

3.4.3 Model Variables Calibration and Use

The UCPM and the UCSM require input variables for execution. For this project, those potential variables come from the datasets listed in Table 3-1. The flexibility of the UCPM and the UCSM allow the input variables to be changed based on the data available or desired in the crash analysis. The variables can also be manipulated in the model based on how the code is written to provide additional variables to use in the analysis. It is important to note that as the model is analyzing segments, each segment must have the variable associated with it for the segment to be considered valid.

A critical aspect of the function of the model is selecting the crash severity to be used when running the model. The use of different severity combinations has been found to produce different hot spot locations. These hot spots are the segments determined by the model to have the highest probability of having a high crash rate based on the parameters used in the model. This variation based on severity combinations is because of the tendency that some segments have to experience one severity more than another (Schultz et al. 2013). Another consideration when reviewing which severity combination to use is the amount of crash data that are available for the different combinations. Limiting the severity selection potentially limits the number of crashes or the number of segments with crashes used in the model. Limited data can reduce the accuracy and consistency of model output. This project is focused on using severities K, A, and B in the KABCO system of ranking crash severity or high severity crashes. KABCO is a traditional scale of crash severity classification. The KABCO system has the following definitions of crash severity types: (K) Fatal, (A) Incapacitating Injury, (B) Non-Incapacitating Injury, (C) Possible Injury, and (O) PDO. As part of the Centralized Accident Records System (CARS), a collaboration of Utah agencies created and has updated the Utah Investigators Vehicle Crash Report Instruction Manual (DI-9 manual) (Utah TRCC 2012). This manual outlines a crash severity scale used across all Utah law enforcement and safety agencies. The DI-9 manual provides guidance to the law enforcement officer on how to fill out a crash report. The manual uses a crash severity numeric scale of 5 through 1, with "5" equivalent to a K and "1" equivalent to an O in the KABCO scale. For this report the Utah scale has been converted to the KABCO for ease of common convention. Excel and ArcMap can be used to narrow the crash severity types to those that are wanted for a specific model run from the dataset.

Given the flexibility of the UCPM, a variety of covariates can be used in the prediction and analysis processes. Calibration of the potential covariates is required to determine which covariates have the possibility of being important in explaining the number of crashes. The covariates found in the datasets listed in Table 3-1 are initially run through a Bayesian horseshoe selection method to determine which of the potential covariates have a high probability of not being zero. The covariates run through the Bayesian horseshoe selection method include variables from the crash data and roadway attributes. For a full list of variables reviewed and additional information on the analysis, refer to Chapter 4. Once a subset of covariates has been identified using the Bayesian horseshoe selection method, additional calibration is completed to find the ‘best fit’ model for the data. This is accomplished by running the statistical model using varying combinations of subsets of covariates and finding the deviance information criterion (DIC). The DIC is used with Bayesian model selection, and uses calculations for deviance, likelihood, and expectations to provide a single number to compare models (Ramsey and Schafer 2002). Determining the covariate combination with the lowest DIC is deemed to be the ‘best fit’ model for the given dataset. Finally, a sensitivity analysis is completed on a number of the top ranking models. This sensitivity analysis is completed on the outputs of the models in relation to the other datasets to determine if the different models produce results that have statistically significant differences. This analysis is also performed to determine the validity of the results based on the data used. Additional information on the datasets, how they are used in this analysis, and the methodology associated with the sensitivity analysis of model outputs can be found in Chapters 5 and 6.

The processes reviewed in this section and Section 3.4.2 can be used to change the roadway type or characteristics for analysis or create new subsets of data based on a variety of inputs that the model can use. Even though it was not done on this project, a subset of ramp segments, or a subset of urban or rural roadways could be created and analyzed to determine hot spots. Also, if additional crash or roadway characteristics are available, these data could also be incorporated and calibrated for use in the model. For more information about data preparation for use in the model, refer to the literature (Schultz et al. 2012).

3.4.4 Hot Spot Microanalysis

The UCPM and UCSM statistical models are used to determine which of the roadway segments have a statistically higher number of crashes. These segments are considered to be problematic or “hot spots” and require additional analysis. Once a list of problematic segments has been created, the data can be used to perform microanalysis on each hot spot segment. This analysis is done to determine if each segment as a whole is problematic or if there are specific locations along the segment (problem spots) where the majority of the crashes occur. The analysis also includes a review of the possible characteristics that can be addressed through countermeasures. For this level of microanalysis, the primary dataset used is the crash data to determine the crash counts along the segments. Additional analysis was conducted on the crash subsets of the people involved in the crash, the vehicles involved in the crash, and possible contributing factors based on the officer’s report. Additional information on the datasets, how they are used in the analysis, and methodology associated with the analysis of hot spots is described in greater detail in Chapters 5 and 6.

3.4.5 Roadway Attributes Analysis

The initial hot spot analysis provides a list of locations along the hot spot segments that have been determined to meet the requirements of minimum number of crashes per segment. The analysis also provides a list of the crashes and their characteristics to be used in additional microanalysis to determine which roadway attributes are present at the subset of problematic locations. The data will be used to determine which roadway attributes might contribute to the crashes through their proximity or absence and can be addressed through countermeasures. The main data used in this microanalysis are the roadway attributes listed in Table 3-1 collected though LiDAR: curvature, shoulders, medians, rumble strips, walls, barriers, auxiliary lanes, intersections, and signs. Additional datasets were created from the intersection and sign data. Using the intersections data, a dataset was created for intersections per mile (IPM). The sign data were used to create a dataset for signs per mile (SPM). Both of these datasets were based on the total count of each along the segments. The elevation data from each sign were also used to create datasets for grade and location of crest and sag curves. This was completed by stepping through each data point and comparing the change in elevation to determine what values for the grade were. As the elevations were not of the roadway the grades are approximate and are used for general location. These data will be used in conjunction with the subset of the crash data discussed in Section 3.4.4. More information on the roadway attributes datasets can be found in Chapters 5 and 6. Other datasets should also be considered in the microanalysis of roadway attributes such as additional lane widths and speed limits.

3.5 Chapter Summary

Data provide two primary limiting factors on the type and level of crash analysis that can be performed, as well as the validity and accuracy of the analysis. These limitations are quality and availability. Other considerations concerning the data are accuracy, availability, coverage, and usability. This chapter reviews the need and also methods for data uniformity and systemization and discusses the data to be used in this project. There are five distinct data tasks as part of this project. These tasks are data preparation for use in additional tasks, segmenting the roadway into sections with similar characteristics for use in the statistical model for the determination of hot spots, for microanalysis for the selected hot spots, and for analysis of common roadway attributes at the hot spot locations.

4 STATISTICAL MODEL

A hierarchical Bayesian model was developed to analyze crashes on all state roads in Utah. This chapter discusses the theoretical basis for the covariate calibration using the Bayesian horseshoe selection method, hierarchical Bayesian model, model development including a summary of the components used to develop the model, and the resulting output of the models. A comparison of the two models is also included in this section. The crash data in this chapter is protected under 23 USC 409.

4.1 Covariate Calibration – Bayesian Horseshoe Selection Method

A Bayesian horseshoe selection method is a technique that can be used for variable selection. Variable selection can be defined as a method that identifies a subset of relevant variables from a large number of possible predictor variables that can be used in a statistical model. The effect of the variables not included in the model is essentially assumed to be 0. Therefore, if the vector of coefficients for all of the variables is $\boldsymbol{\theta}$, only a subset of the coefficients is not equal to 0, these are the variables the model wants to identify. There are a few different approaches in Bayesian literature that can be used to estimate a sparse vector $\boldsymbol{\theta} = (\theta_1, \dots, \theta_n)$, (i.e., a vector comprised mostly of zeroes.), among the most common being lasso and ridge. Carvalho et al. (2008) showed that although the Bayesian horseshoe selection method is similar to both of these techniques, it outperforms both in handling and sparsity.

The Bayesian horseshoe selection method gets its name from the horseshoe prior that is placed on the coefficients. The horseshoe prior is symmetric about 0, has an infinitely tall spike at 0, and has heavy tails. These features make it a useful prior because it will essentially force the coefficient to be 0 for a variable that is not important, but its tails are heavy enough to allow for the coefficients to be large if that is what the data dictates (Carvalho et al. 2008). Figure 4-1 shows the results after running the Bayesian horseshoe selection method with all of the potential variables in the crash dataset. The variables in red are the variables that have a high probability of not being zero.

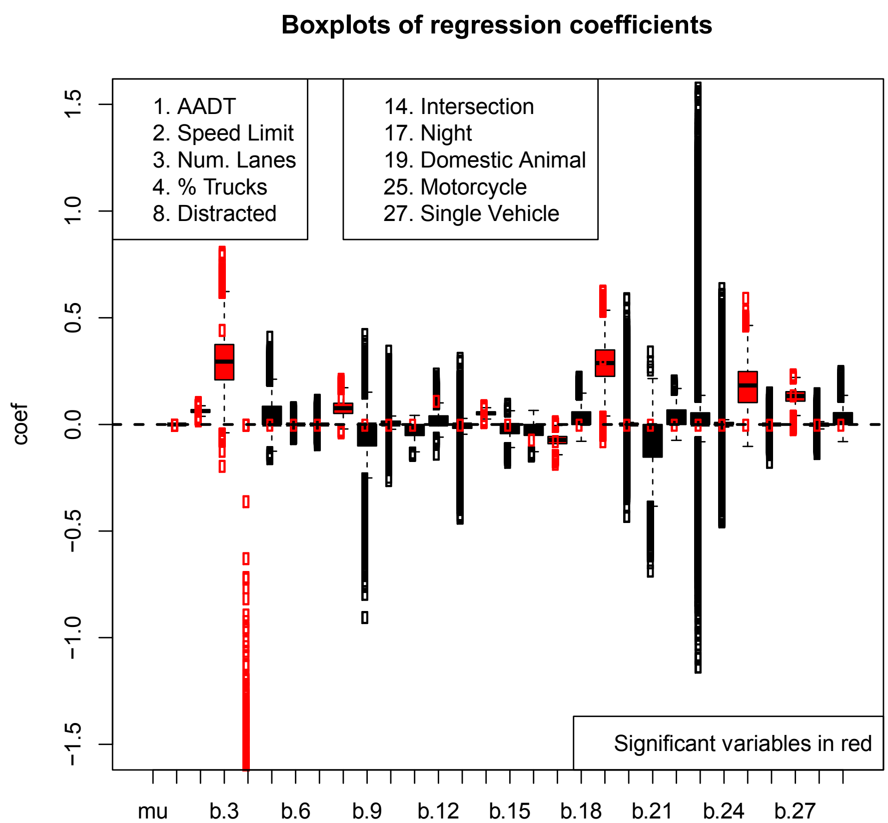

Figure 4-1: Results after running Bayesian horseshoe selection method.

Another advantage of the Bayesian horseshoe selection method is that it could be used to determine a probability that the coefficient for each potential variable is not equal to zero. This is shown in Figure 4-2. As can be seen in Figure 4-2, there is a distinguished gap that separates the potential covariates. The variables whose probabilities were greater than 0.85 were those that were determined to be significant and those are the variables that are highlighted red in Figure 4-1. The Bayesian horseshoe selection method is used as a step in the model process and allows for simultaneous parameter selection and model evaluation. This simultaneous selection and evaluation allows for comparative analysis between models with close results.

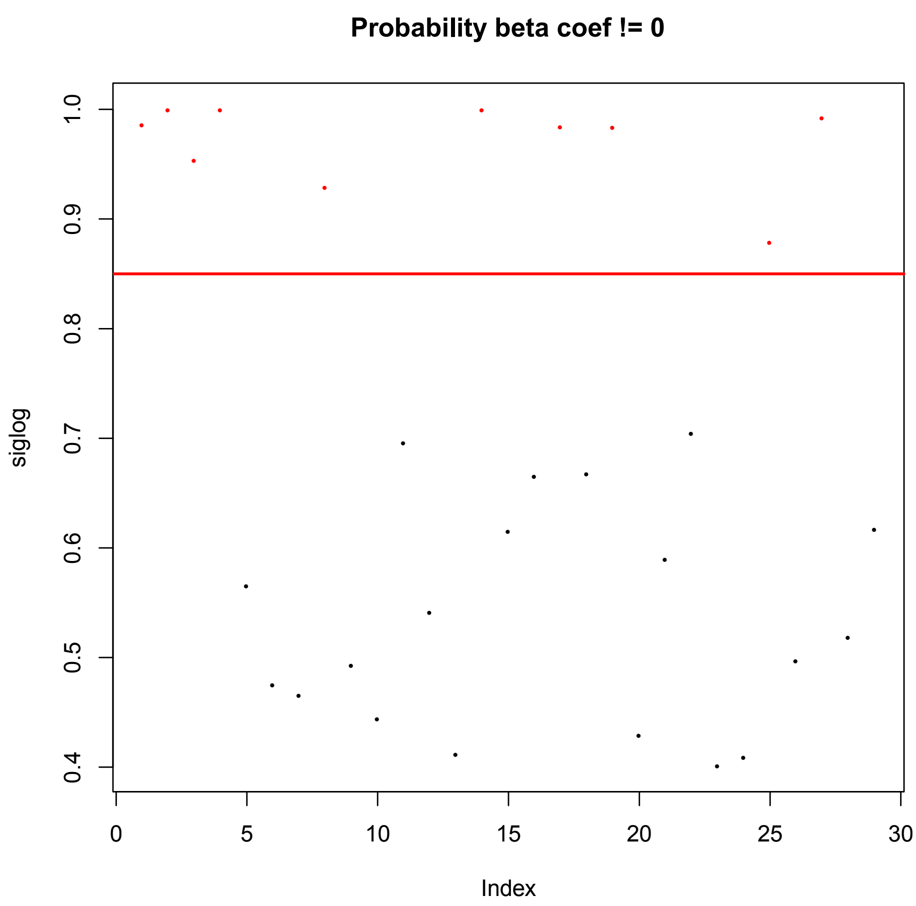

Figure 4-2: Probability that the respective coefficient is not equal to zero.

4.2 Hierarchical Bayesian Model

A full specification of a Bayesian model includes a distribution for the data, called a likelihood, and a prior distribution for the unknown parameters in the likelihood. Because the response variable is the number of crashes on a segment of a state road in Utah, the data are modeled using the Poisson distribution, a model commonly used for count data. One assumption of the Poisson distribution is that the mean and variance of the data are equal. A disproportionately large number of road segments being analyzed in this study have zero crashes, making the basic assumption of the Poisson distribution false. This high number of zero crash segments causes the variance to exceed the mean resulting in overdispersion of the data.

Given the discrepancy between actual crashes and predicted crashes (especially at 0), a modified Poisson distribution that preserves the ability to model count data while also allowing for excess segments with zero crashes is recommended and utilized. In particular, a Poisson Mixture Model (PMM) is selected in order to account for the overabundance of zeros while maintaining a good fit for the count data.

To develop the PMM, the variable Y_{ijk} is used to denote the number of crashes on the i^{th} road segment on the j^{th} route with the k^{th} functional classification, where Y_{ijk} is an outcome from a mixture distribution whose probability density function is illustrated in Equation 4-1.

$$f\left(Y_{ijk}\middle|\lambda_{ijk}\right) = \{p_{ijk} + (1 - p_{ijk})e^{-\lambda_{ijk}}\}I_{y_{ijk}=0} + \left\{(1 - p_{ijk})\frac{\lambda_{ijk}^{Y_{ijk}}e^{-\lambda_{ijk}}}{Y_{ijk}!}\right\}I_{y_{ijk}>0} \tag{4-1}$$

where: Y_{ijk} = number of crashes,

λ_{ijk} = the mean and variance of the crash count for segment *i*, route *j*, and functional class *k,*

p_{ijk} = the probability that the crash count is zero,

$I_{y_{ijk}=0}$ = indicator function that takes value of 1 if the crash count for segment *i,* route *j,* and functional class *k* is 0, and 0 otherwise, and

$I_{y_{ijk}>0}$ = indicator function that takes value of 1 if the crash count for segment *i,* route *j,* and functional class *k* is greater than 0, and 0 otherwise.

Using the canonical log link function, which is standard for Poisson regression, Equations 4-2a and 4-2b show the models for λ_{ijk} and p_{ijk}.

$$\log(\lambda_{ijk}) = \beta_{0j} + \beta_{1j}VMT_{ijk} + \beta_{2j}SpeedLim_{ijk} + \beta_{3j}NumLanes_{ijk} + \beta_{4j}\%Trucks_{ijk} + \beta_{5j}Distracted_{ijk} + \beta_{6j}Intersection_{ijk} + \beta_{7j}Night_{ijk} + \beta_{8j}Domestic\_Animal_{ijk} + \beta_{9j}Motorcycle_{ijk} + \beta_{10j}Single\_Vehicle_{ijk} \quad (4\text{-}2a)$$

$$\log(\frac{p_{ijk}}{1-p_{ijk}}) = \gamma_{0j} + \gamma_{1j}VMT_{ijk} + \gamma_{2j}SpeedLim_{ijk} + \gamma_{3j}NumLanes_{ijk} + \gamma_{4j}\%Trucks_{ijk} + \gamma_{5j}Distrated_{ijk} + \gamma_{6j}Intersection_{ijk} + \beta_{6jk}Night_{ijk} + \beta_{6jk}Domestic\_Animal_{ijk} + \beta_{6jk}Motorcycle_{ijk} + \beta_{6jk}Single\_Vehicle_{ijk} \quad (4\text{-}2b)$$

The variables; VMT, speed limit (*SpeedLim*), number of lanes (*NumLanes*), percentage of trucks (*%Trucks*), whether the driver was distracted (*Distracted*), if crash was intersection related (*Intersection)*, if the crash occurred at night (*Night*), if a domestic animal was involved (*Domestic_Animal*), if a motorcycle was involved (*Motorcycle*), and if there was only one vehicle involved in the crash (*Single_Vehicle*), shown in Equations 4-2a and 4-2b were selected based on the Bayesian horseshoe selection method described in Section 4.1. In order to assess the effects of these 10 variables on λ_{ijk}, the variables β_{0j}, β_{1j}, β_{2j}, β_{3j}, β_{4j}, β_{5j}, β_{6j}, β_{7j}, β_{8j}, β_{9j}, and β_{10j} are introduced and similarly for p_{ijk}, the variables γ_{0j}, $\gamma_{1j}, \gamma_{2j}, \gamma_{3j}, \gamma_{4j}, \gamma_{5j}, \gamma_{6j}, \gamma_{7j}, \gamma_{8j}, \gamma_{9j}$, and γ_{10j}.

Non-informative multivariate normal (MVN) prior distributions are utilized in the model as outlined in Equations 4-3 through 4-6. In these equations the matrix **I** represents an identity matrix of appropriate dimension, which dimension has the same number of rows and columns as the number of predictor variables, plus one for the intercept. The identity matrix is multiplied by 100 to ensure that the priors are diffuse, with a variance of each parameter being 100.

$$\vec{\beta}_{jk} \sim MVN(\vec{\mu}_k, 100\mathbf{I}), \tag{4-3}$$

$$\vec{\gamma}_{jk} \sim MVN(\vec{\Gamma}_k, 100\mathbf{I}), \tag{4-4}$$

$$\vec{\mu}_k \sim MVN(\vec{0}, 100\mathbf{I}), \text{ and} \tag{4-5}$$

$$\vec{\Gamma}_k \sim MVN(\vec{0}, 100\mathbf{I}). \tag{4-6}$$

The parameters $\vec{\beta}_{jk}$ and $\vec{\gamma}_{jk}$ have prior distributions depending on other parameters, $\vec{\mu}_k$ and $\vec{\Gamma}_k$, called hyperparameters. These can be interpreted as parameters in the linear model for the k^{th} functional classification, or average parameters for the routes in the k^{th} functional classification. For example, the average effect of VMT on $\log(\lambda_{ijk})$ is given by β_{1j}, which is specific to the j^{th} route and Γ_{1k} gives the average effect of VMT on the entire k^{th} functional classification.

Hierarchical Bayesian methods were utilized to obtain posterior distributions for each parameter in the model and for every combination of route and functional classification. In the statewide data, there were 11 parameters in the linear models, 11 hyperparameters, and 304 routes nested within seven functional classifications, yielding a total of 6,842 parameters. The joint posterior distribution of the parameters is proportional to the product of the mixture distribution for each crash count multiplied by each of the priors. Samples from each conditional posterior were obtained using Markov Chain Monte Carlo (MCMC) and Gibbs sampling methods (Qin et al. 2005). This resulted in posterior distributions of $\vec{\beta}_j$ and $\vec{\gamma}_j$ for each route and posterior distributions of $\vec{\mu}_k$ and $\vec{\Gamma}_k$ for each functional classification. This process is called hierarchical Bayesian regression.

4.3 **Model Development**

The model was developed using the R programming language because of its versatility and abundance of statistical functions and packages. R is also available as a free download and runs on a variety of computer platforms (RPSC 2012). Hierarchical Bayesian modeling using MCMC methods, especially with the number of parameters used in this analysis requires heavy computation. Running the desired number of iterations could take hours or even days, depending on the amount of data being analyzed and the capabilities of the computer hardware running the computations.

As part of the computation, a candidate generating distribution was used from which MCMC draws were determined to be probable and accepted as samples from the posterior distribution (Gelfand and Smith 1990). Determining the variance of the candidate generating distribution can be challenging. The process of trying a candidate generating distribution variance, analyzing the results, and changing the variance accordingly is called tuning. Though most tuning in the model was done automatically, it can take up to a full day. Further, the automatic tuning is not a guarantee that the choice of candidate variance is good. Before using the results of an MCMC run, the trace plots or the plot of value against iteration number, and output by the R function should be analyzed to ensure that they are acceptable.

4.4 Model Output

Using the posterior distributions obtained for all of the parameters described above, posterior predictive distributions were constructed for each segment. Posterior predictive distributions give a distribution of the number of crashes that would be expected on a segment given its VMT and other variables. The analyst can then determine where the actual number of crashes falls in the posterior predictive distribution by observing the area to the left of the actual number of crashes in the posterior predictive distribution, or the percentile of the actual number of crashes (between 0 and 1). A high percentile (near 1) would indicate that the actual number of crashes is larger than predicted on that segment, while a percentile near 0 would indicate that the segment had less crashes than predicted.

An example posterior predictive distribution produced by the model is shown in Figure 4-3. The bars represent the distribution of the number of crashes that would be expected on this segment based on analysis of all segments in the same functional classification and route, having the same covariate characteristics; such as the same VMT, speed limit, functional class, and number of lanes. The solid vertical line represents the actual number of crashes for this segment. The proportion of the area of the distribution to the left of the solid vertical line is the percentile. In the case shown in Figure 4-3, the percentile is equal to 0.965, thus indicating that the actual number of crashes on this road segment was higher than predicted.

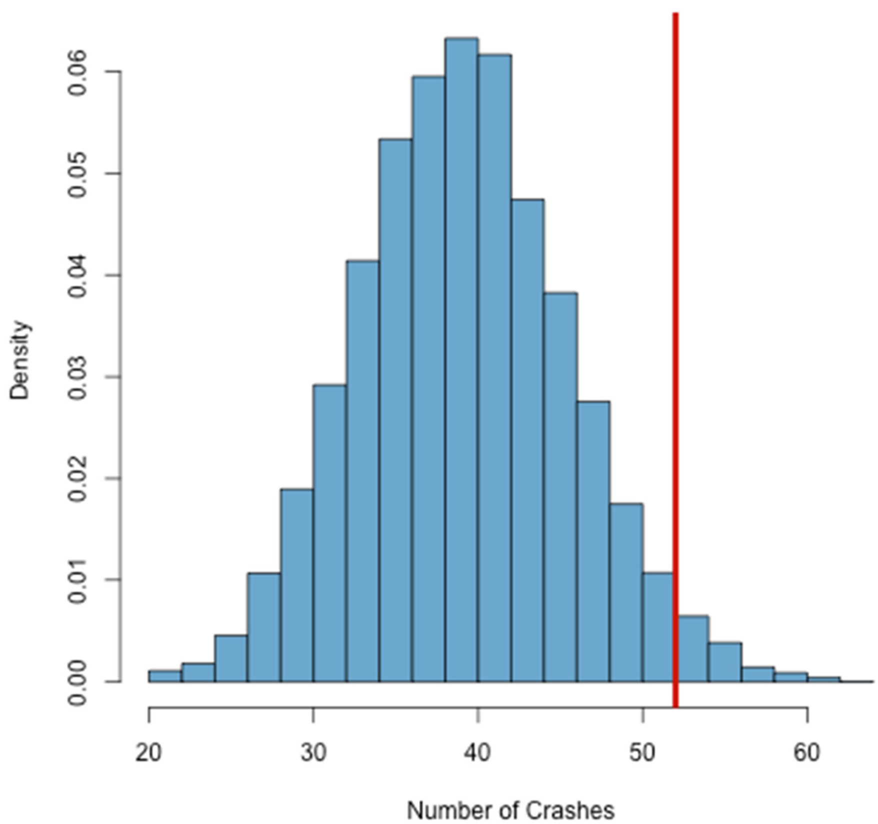

Figure 4-3: Example of a posterior predictive distribution for a single road segment.

In some cases, the number of crashes predicted is low but the actual number of crashes is only slightly larger (e.g., if the median of the posterior predictive distribution is 1 and the actual number of crashes is 2). The percentile for this segment would likely be very high but the difference between the predicted and actual values is very low. If only the percentile were considered when identifying a hot spot this segment would be identified since the number of crashes is statistically significant, but it may not necessarily be practically significant. Thus the median of the posterior predictive distribution is included in the model output as well. The median of the posterior predictive distribution can then be compared to the actual crash value and the difference can also be analyzed. The combination of the percentile and the difference between the predicted median and actual number of crashes will indicate how dangerous a segment may be expected to be. This process will be illustrated in the methodology presented in Chapters 5 and 6.

4.5 **Model Comparison**

The two models that have been developed to provide a view of crashes on roadway segments each have strengths and limitations. The UCPM and the UCSM were each designed for a specific purpose and should be used in conjunction with each other as neither replaces the other. This section will discuss and review the uses, data, and brief review of results for each model. More discussion of the results can be found in Chapter 6.

4.5.1 Utah Crash Prediction Model

The UCPM is to create a distribution of the number of crashes that could occur. The mean of the distribution is used as the expected number of crashes that might occur on a specific segment based on the given characteristics of that segment. The distribution of crashes for the segment and provides the percentile for the segment based on the number of crashes that did occur on the segment. The model is designed to allow a variety of parameters to be used in creating the distribution. A pre-selection process using the Bayesian horseshoe selection method is applied to the dataset being used. This allows for the use of characteristics associated with the crashes and drivers or roadway attributes to be used as possible influencers on the predicted crashes and distribution. The Bayesian horseshoe selection method takes all possible parameters in the dataset and produces a list of the significant ones that then should be used. The selected parameter set can be used to predict the number of crashes for a given severity group. The prediction value will be tied to that same severity group. This allows flexibility in both the inputs and the level of crash prediction modeling. The crash prediction model used with the crash data from 2008 to 2012 and using all rollup parameters as possible variables produced a model using the following input parameters. The model was run with severity group B (Non-Incapacitating Injury), level A (Incapacitating Injury) and level K (Fatal)., however the numeric representation is required for the model. The results of the model execution will be presented in Section 6.1.

- VMT
- Speed limit
- Number of lanes
- Total percent trucks
- Distracted
- Intersection
- Night
- Domestic animal
- Motorcycle
- Single vehicle

4.5.2 Utah Crash Severity Model

The UCSM is used to determine the probability of a severe crash occurring. Using a Binomial link, the model produces three main outputs: the probability that a severe crash occurs given that a crash has occurred on a selected segment, the predicted number of severe crashes, and the probability that the respective number of severe crashes occurred. With these outputs each segment can be assigned a ranking based on a low probability of the predicted crashes occurring and the difference between the actual and predicted numbers of crashes. This ranking produces both "hot spots" and "safe spots." These segments can then be analyzed further. This model can be run with the same dataset as the crash prediction model with one exception. The crash safety model must have a count of every crash that occurred on that segment in the time period given, as well as the count of crashes occurring in the severity group. As with the crash prediction model, the probabilities will be for the same severity group as used in for the inputs. The crash safety model has flexibility of parameter used in the model. Based on the data used for this analysis following variables were included in the model. The results of the model execution will be presented in Section 6.1.

- VMT
- Speed limit
- Number of lanes
- Total percent trucks
- AADT

4.6 **Chapter Summary**

To analyze crashes on Utah roadways, a hierarchical Bayesian PMM model was developed using the R programming language. The PMM is necessary because there are a high number of segments in the data with zero crashes, causing the data to be over-dispersed. Posterior predictive distributions for each roadway segment are developed using MCMC and Gibbs sampling methods. By comparing the posterior predictive distribution with the actual number of crashes for a given segment it can be determined if more crashes have occurred on that segment than would normally be expected. These can be used in post analysis to determine rank each segment to determine which segments should be the focus of further analysis. Two models have been development which can be used. The UCPM using the Bayesian horseshoe selection method is used to predict the number of crashes that are expected and the UCSM includes a binomial flag to allow for fewer data points. Each model produces a list that can be ranked.

5 ROADWAY ATTRIBUTES IDENTIFICATION AND ANALYSIS

A methodology for hot spot identification and analysis was developed as part of previous research on the UCPM (Schultz et al. 2013). The methodology outlines the process to identify, analyze, and define problematic segments. The process continues to evaluate and select countermeasures that are feasible to implement at the given segments. This chapter reviews the steps in the hot spot analysis methodology. These steps are: identifying problematic segments with safety concerns, identifying problem spots within the segments, identifying common roadway attributes within the segments, microanalysis of problematic segments and spots, defining the segment, defining the roadway attributes, defining the problem, evaluation of possible countermeasures, selection and recommendation of feasible countermeasures, and complete the analysis reports. These steps and flow are illustrated in Figure 5-1. This chapter discusses how to identify and define roadway attributes within the segments and how roadway attributes fit as part of the methodology step of analysis. An application of the methodology with examples is provided in Chapter 6.

5.1 Identifying Problematic Segments for Review

The primary method for identification of problematic segments is by the statistical procedure of the UCPM or the UCSM. The process is defined and discussed in Chapter 4. In this application, two models produced different output variables, which required varied methods in the ranking process. The models each used the same data with the severity group for the UCPM including level B (Non-Incapacitating Injury), level A (Incapacitating Injury) and level K (Fatal) and the severity group for the UCSM including level A (Incapacitating Injury) and level K (Fatal). The output from the UCPM is a probability ranking for each segment defined through the segmentation process. Because each segment received its own probability, there are occurrences where two segments have the same probability. To facilitate a hierarchal ranking of the UCPM, a combination of the difference between the actual number of crashes and the predicted number of crashes and the model probability are used. The output from the UCSM has three components: the probability that the crash was severe, the expected number of crashes, and the probability that the expected number of severe crashes occurred. To facilitate a hierarchal ranking for the UCSM, a combination of the difference between the actual number of severe crashes and the predicted number of severe crashes and the probability that the number of expected crashes occurred are used. Based on the combination for either model, two levels of ranking are assigned to each roadway segment. The first is a hierarchal ranking starting at "1" and going through the total number of segments. The second is a categorical ranking from 5 to 1, "5" being the most problematic and with "1" being the least problematic. Table 5-1 lists the percent of the total segments that are allocated to each rank. Using the results from these rankings, the analyst is able to determine the quantity of segments to use as part of the continued analysis

Table 5-1: Ranking Percentile

Rank	Percentile
5	5%
4	15%
3	60%
2	15%
1	5%

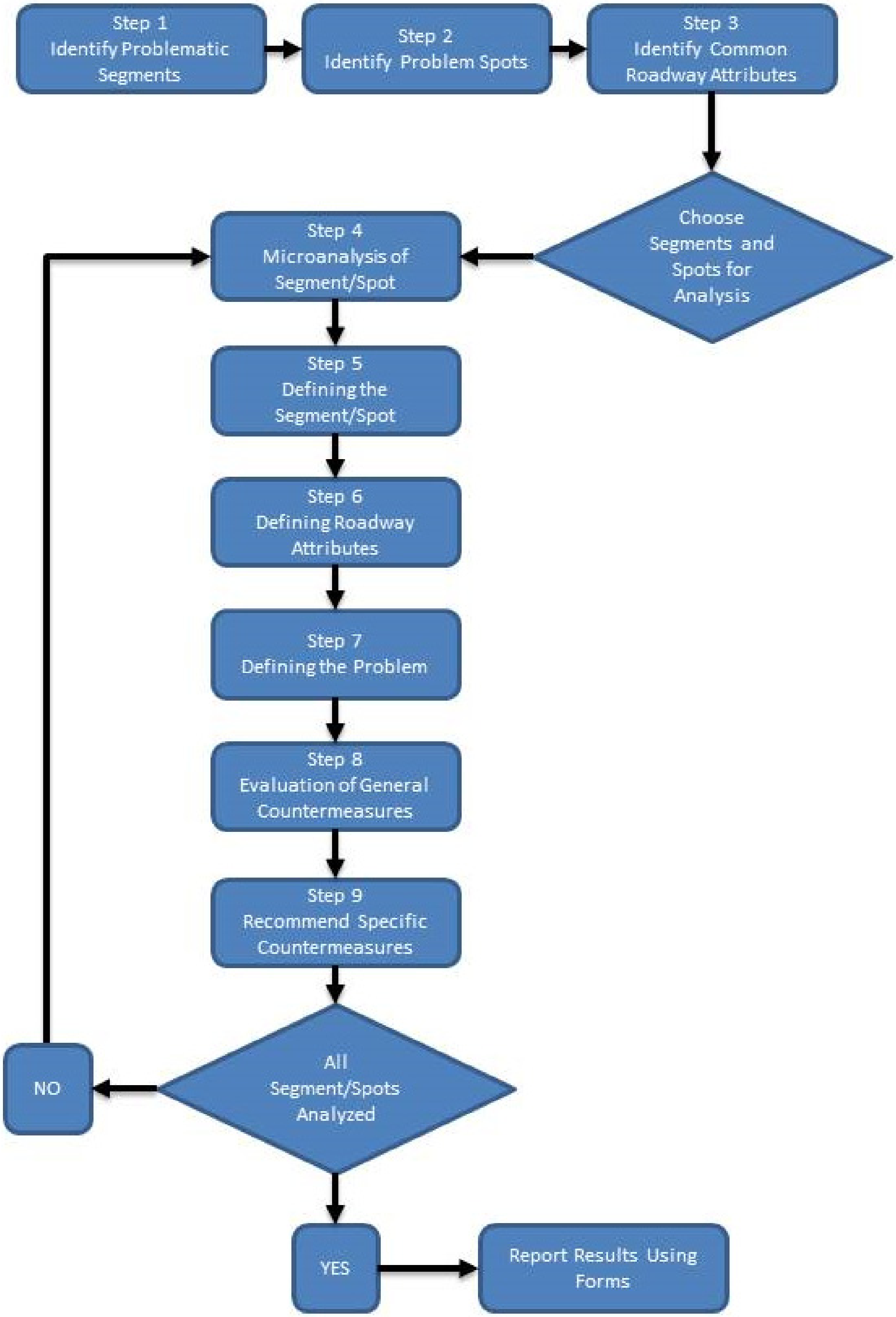

Figure 5-1: Methodology flowchart.

5.2 Identifying Problem Spots within the Segments

Once the ranking is completed, it is necessary to do further analysis to determine whether there are problem spots within the each segment that may be the cause of the segment's ranking. These problem spots are identified primarily with the use of ArcGIS crash analysis. The crashes located on the ranked segments may or may not be distributed evenly along the length of the segment. The model looks at the segment as a whole with total crashes accounted for along the entire length of the segment. The segments produced by the methodology described in Section 3.4.2, can have a wide range of lengths (Schultz et al. 2013). An analysis needs to be completed to determine if the problem is along the entire length or at specific locations.

This analysis classifies the hot spot as a problem segment or a problem spot. A problem segment requires further analysis to be completed along the entire length of the segment and should include all crashes the occurred on the segment within the crash severity group. If it is determined that there is a problem spot, the further analysis should only include the reduced length section and the crashes occurring on the reduced section of the segment.

ArcGIS has a number of tools to use in determining locations of any problem spots along the length of the segment. The two main tools "Strip Analysis" and "Sliding Scale Analysis" (Esri 2014) were both used and evaluated as part of the research (Schultz et al. 2012, Schultz et al. 2013). It was determined that there was not a significant difference between the outputs, and that the Sliding Scale Analysis had a few benefits of the Strip Analysis. Based on these findings, the Sliding Scale Analysis was used for this research. The tool produces an output file called "High Accident Locations" or HALs (Esri 2014). The tool allows the user to adjust for crash count and analysis length. This flexibility allows the user to individualize the analysis for specific needs and situations (Schultz et al. 2013). Using the output of the tool, the user can create a list of possible spots that along the segments that need further analysis

5.3 Identifying Common Roadway Attributes within the Segments

Roadway attributes typically exist in varying types along a roadway. As the length of a segment increases, the likelihood of variation in the roadway attributes increases. The segments produced by the segmentation process are generally long enough for variation of the roadway attributes. The micro-segments created from the Sliding Scale Analysis tool will vary in length based on the inputs used; however, the lengths are more consistent than the lengths of the primary segments and can be significantly shorter. With the shortened length of analysis area, an accurate association can be made between the problem spots and the existence and single type of each roadway attribute.

The association of roadway attributes to the micro-segments is accomplished with the linear referencing tool found in ArcGIS. The linear referencing tools used are "Spatial Join" and "Overlay Route Event" (Esri 2014). The HAL output is a simple shape layer that only includes the start and stop points of the micro-segment and basic polyline attributes. The micro-segments need to be associated with the data from the primary segments. This is accomplished with the use of the Spatial Join tool. The tool uses the spatial location of the micro-segments and combines the segment entity and the primary segment at that location. Figure 5-2 is a screenshot of the Spatial Join tool showing a number of the inputs required. With the joining of the data, the roadway attributes can by associated with the micro-segments by the methods of either the Spatial Join tool or the Overlay Route Event tool. Each function provides the same end result of roadway attributes at the given micro-segment location; however, the methods used and the presentation of the results differ. Each method is reviewed in the following sections.

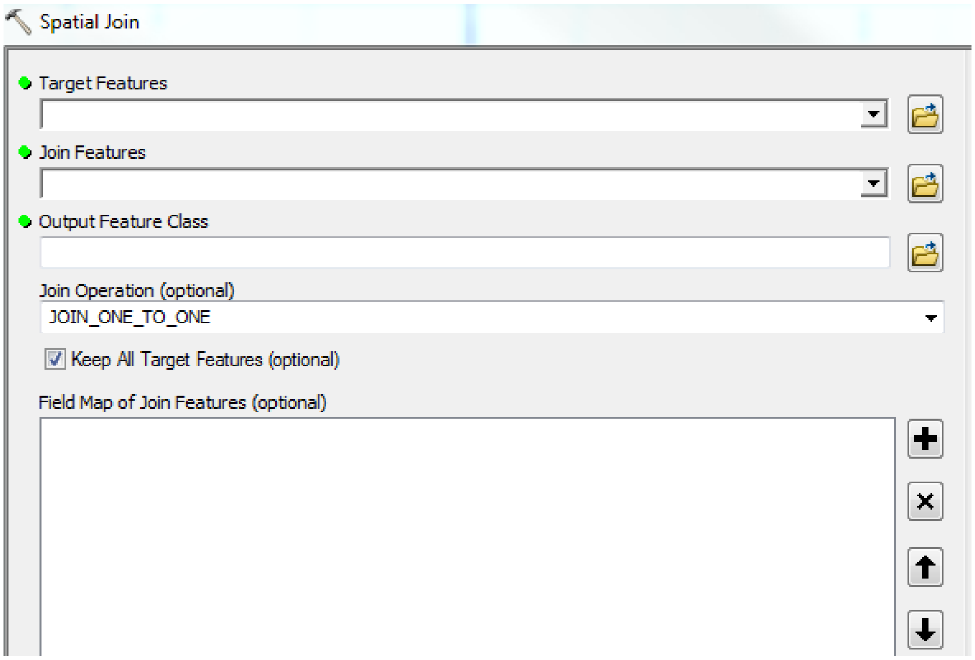

Figure 5-2: Spatial Join (Esri 2014).

5.3.1 Spatial Join Tool

The Spatial Join tool is used to combine any two sets of data based on their spatial interaction. Just as with the micro-segment and primary data, the Spatial Join tool can be used to join the various roadway attributes data to the full micro-segment data (Esri 2014). The user has the option to limit the data that is combined by selecting only the attribute columns wanted in the new dataset. Using this method, a new dataset can be created that combines the segment information. The data can be combined into a large single dataset including all roadway attributes, or individual datasets per attribute. Additional data evaluation is needed upon completion based on the preference and application of the analyst.

5.3.2 Overlay Route Event Tool

The Overlay Route Event tool is designed to take two tables and create a single output based on the intersection or union of the inputs (Esri 2014). Using the Overlay Route Event tool allows the user to create segments of roadway based on single or multiple roadway attributes. The function combines the data for the base file from the segmentation process with the data of the selected attributes, creating a single file including all data. The new dataset includes the starting and ending points of the new segments based on the intersection points of the segments being overlaid. The tool is designed to overlay two layers at one time; however, using the Model Builder, a series of overlay functions can be used to apply the overlay function to multiple datasets (Esri 2014). Figure 5-3 shows the user interface for the Overlay Route Event tool. Caution should be used when overlaying more than two datasets, as the length of the segment may become too short for practical purposes. For this research, only one attribute layer was overlaid with the segment data, producing a combined single dataset that included all of the data for the segment and the data for a single roadway attribute. Additional data evaluation is needed upon completion on the joining of the segment and roadway attributes, based on the user's preference and application.

5.4 Microanalysis of Problematic Segments and Spots

Completing the steps of hot spot identification using the statistical model and GIS, and determining what road attributes exist at those locations, provides the user with the necessary data to perform microanalysis on each of the individual problem segments or problem spots. "The purpose of the microanalysis is to determine the cause of the problem, location of the problem, and any factors that may be contributing to the problem" (Schultz et al. 2013). This section discusses many of the tools that can be used in the microanalysis process. These tools include the crash data, LiDAR/roadway attribute data, Internet tools, site visits, and communicating with the experts.

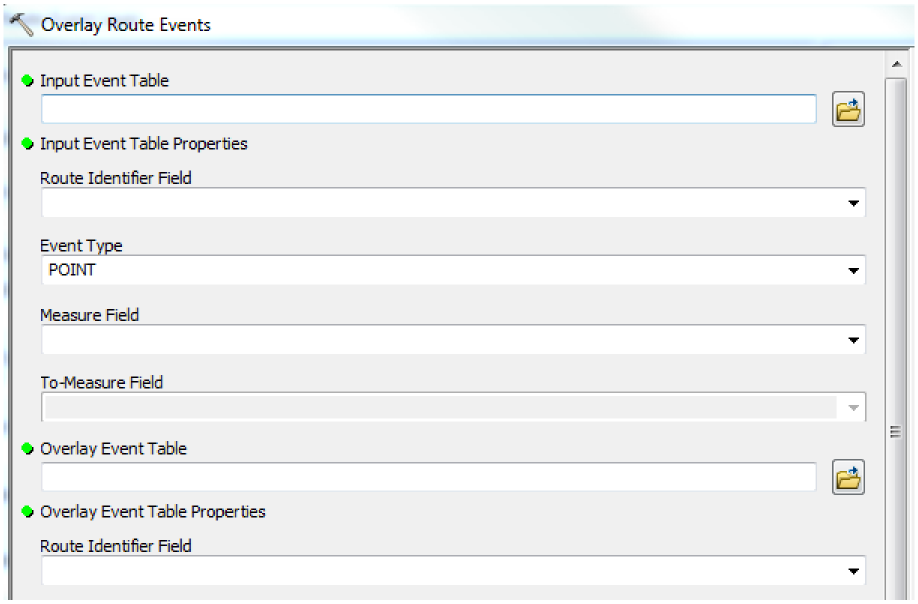

Figure 5-3: Overlay Event Table (Esri 2014).

5.4.1 Crash Data

The crash data include information about the crashes that occurred on the segments and at the location reviewed as part of the analysis. The purpose of reviewing the crash data is to help identify what common characteristics are, if any, of the crashes at a specific location (Schultz et al. 2013). The size of the files containing the crash data are typically large and include the information on all the crashes in the study area, not just the crashes occurring at the microanalysis locations. With the datasets for the problem segments and problem locations, the crash dataset can be filtered to only the crashes needed for the analysis with the use of ArcGIS tools. Select by Location, Spatial Join, and other tools can be used to select the crashes needed for review (Esri 2014).

As discussed in Section 3.4.4, the crash data also comes in multiple files based on the information type. It is also beneficial to the user to have all the crash datasets compiled into a single file for ease of analysis. Combining the crash data into a single dataset makes it easier to look for common traits and characteristics that could be contributing to the safety problems (Schultz et al. 2013). Consideration of data for compilation and review are: crash sequence of events, vehicle maneuvers, manner of collision, speed related, roadway geometry related, and intersection-related. However, selection of important crash data to include is dependent on the availability and access of the data and the analysis being performed (Schultz et al. 2013). Chapter 6 discusses specific crash data used for this research for the state of Utah.

5.4.2 LiDAR/Roadway Attributes Data

The roadway attributes data include data about the types and location of the different roadway attributes that exist at or along the area of analysis. The purpose of reviewing these data is to determine if there are any commonalities between the types of roadway attributes at the different problematic locations. The data files of the roadway attributes vary in size and these datasets can be large and include data that may not be helpful in the analysis of the segments. Each roadway attribute has different fields that are useful for analysis. The data should be filtered to include only the fields of interest in an effort to reduce the size of the files and increase the speed of the review. For ease of analysis, the various attributes should be combined into a single dataset with all attributes listed for each problem spot and problem segment. Table 5-2 is a list of the fields (i.e., characteristics) for each roadway attribute considered for compilation and review. However, selection of important roadway attributes data to include is dependent on the availability and access of the data and the analysis being performed. Chapter 6 discusses specific roadway attribute data used for this research for the state of Utah.

Table 5-2: Roadway Attribute Data Fields

Dataset	Field	Description
Grade	Maximum grade	Use the maximum grade that is found along the segment
Crest/Sag	Number of changes	The number of vertical curves along the segment
	Greatest % Change	The greatest change in grade along the segment
Rumble Strip	Exist	Does a rumble strip exist at any point on the segment
Wall	Exist	Does a wall existed at any point along the segment
Shoulder	Material	The material at the shoulder location
	Edge Type	The type of edge i.e., curb and gutter, none, etc.
	Width	Width of the shoulder
Median	Type	Type of median
	Island	Is there and island
	Width	Width of the median at location
Intersection	Intersection per Mile (IPM)	Number of intersection divided by length
	Count	Total number of signs along the segment
Lanes	Left Turn (LT)	Number of LT lanes at location
	Right Turn (RT)	Number of RT lanes at location
	Acceleration/Deceleration	Number of acceleration and deceleration lanes at location
	Two-Way-Left-Turn-Lane (TWLTL)	Does a TWLTL exist as the location
Signs	Signs per Mile (SPM)	Updated Biennially
	Count	Updated Biennially consist of only UDOT Signs
Curvature	Class	FHWA classification of curves on the segment
	Degree of curvature	The degree of curvature for the curves on the segment
	Radius	Radius of the curves on the segment
	Length	Length of the curves on the segment
Barrier	Center Type	The type of barrier in the center of roadway at location
	Outside Type	The type of barrier at outside of roadway at location

5.4.3 Internet Tools

There are a few tools that are Internet-based that can assist with the microanalysis of the problem spot locations and problematic segments, by providing the user visual aids of the locations being analyzed. The primary tools that can be used for this purpose for the Utah locations are Google Earth (Google, Inc. 2015a), Google Maps (Google, Inc. 2015b), and UDOT's Roadview Explorer (UDOT 2015b). Additional tools, if available, could also be considered as resources in analyzing the hot spots. These tools can allow the user to become more familiar with the segments and locations before performing a site visit. These tools can also provide information pertaining to the history and future of the site that a site visit will not. This is done by looking at past years' data available for the site. Future construction projects by UDOT for the state can be overlaid in the mapping tools to determine what, if any, changes are planned for the site. These tools can also help with preparing for the actual site visit and providing perspectives that are not available on site, such as a bird's eye view. All data provided by the Internet sources should be reviewed for accuracy and quality (Schultz et al. 2013). Chapter 6 discusses specific use of Internet tools and data used for this research for the state of Utah.

5.4.4 Site Visits

Visiting the site of interest is a critical part of the microanalysis process. After the analyst has gathered the information provided through the statistical model and Internet tools, the site visit should be conducted. The site visit provides firsthand knowledge of the existing conditions of the area. Many of the items needed for a full analysis can only be learned by being on-site and evaluating the locations from the perspective of the user. "A site visit allows the analyst to verify or dismiss conclusions drawn from other analysis methods" (Schultz et al. 2013). Once a site visit is completed, the analyst will have gained the knowledge and understanding of the site that will allow for a more complete view of the problems associated with the safety concerns. The site visit can also provide the analyst with insight on possible countermeasures that can be used to minimize or mitigate the issues at the site (Schultz et al. 2013). Chapter 6 discusses specific data gathered from sites for this research for the state of Utah.

5.4.5 Communicating with Experts

Communicating with the experts familiar with the site and area can provide a unique perspective. Experts, such as law enforcement agencies, local and state government officials, traffic engineers in the area, and local DOT employees, have a specific understanding of the area, which includes a view from the past, present, and future. This view may also include public opinion and possible stakeholders to contact for additional information. "Stakeholders are able to provide opinions, observations, and concerns that could aid in defining the problem and evaluating possible countermeasures" (Schultz et al. 2013). The information gained through communicating with experts and stakeholders provides greater understanding of the site, helps ensure that no information is overlooked, can help with the selection of feasible countermeasures, and provides support for those countermeasures once selected (Schultz et al. 2013). Chapter 6 discusses specific data gathered from experts for this research for the state of Utah.

5.5 **Defining the Segment**

Once a thorough and detailed microanalysis has been completed on the hot spot location, the analyst should use the data gathered to define the area of the segment. The definition process provides an opportunity to increase understanding of the characteristics found at the location of the segment. It is important that the definition process includes the location of the hot spot based on the mileposts. These mileposts can be for the start and end of the problem segments of problem spots if the issues are localized. In addition to the location, the definition should include the roadway attributes found at the location. Additional information on defining the segment is discussed in the literature (Schultz et al. 2013).

5.6 Defining the Roadway Attributes

There are a few roadway attributes that should be included for all analyzed segments; these will be pulled from the variables used for the statistical model. The roadway attributes of number of through lanes and speed limit were used in the model for this research and are included as part of the definition of the segments. Additional roadway attributes for consideration are intersection types, if present, roadway geometry, median, and any other characteristics that are deemed necessary to fully understand the segment (Schultz et al. 2013). These attributes will typically be pulled from the roadway attributes dataset created as part of the microanalysis. The segment definition should only include the attributes of significance at location of analysis. Chapter 6 discusses definitions or roadway attributes along specific segments for this research for the state of Utah.

5.7 Defining the Problem

After the analysis of the problem segments or problem spots has been completed and the segment or location has been properly defined, it is possible to define the problem associated with the cause for hot spot classification. The clear definition increases the ease for the selection of possible countermeasures. This step should define the cause of the problem and any contributing factors. Once the segment and the problem are defined, it is possible to make a list of the possible countermeasures and perform the evaluation based on feasibility. If these steps have been performed and a clear problem was not defined, the steps should be reviewed to determine if any information was missed or overlooked. “Without a clearly defined problem it becomes difficult, if not impossible, to find a solution” (Schultz et al. 2013).

5.8 Evaluation of Possible Countermeasures

The output of the analysis, in defining the segment and safety problems, is the information needed to create a comprehensive list of possible countermeasures that might be used to improve the conditions at the hot spot locations. This list should include all the known countermeasures and is used as the basis for the evaluation process. “This list of countermeasures is to be evaluated based on effectiveness, cost, implementation time, feasibility, and other considerations that are important to the specific segment or spot location” (Schultz et al. 2013). The evaluation process includes answering questions about the countermeasures that include topics such as speed of implementation, cost of single versus multiple countermeasures, existing implementations, and others. For a more complete list of questions, refer to the previous research (Schultz et al. 2013).

5.9 Selection and Recommendation of Feasible Countermeasures

Once the evaluation is completed and the appropriate questions have been asked and answered, the process of elimination can be applied. The elimination process reviews the countermeasures against the responses to the question of feasibility. The full list of possible countermeasures will be reduced to only those options that are both viable and feasible, and help mitigate the issue found at the hot spot location (Schultz et al. 2013).

With the reduced list from the evaluation process, the final step is to select the countermeasure that will have the greatest impact on improving safety for each specific location.

The selection can be a single countermeasure or a combination of multiple countermeasures. Once selected, the countermeasure(s) should be recommended for implementation. At this point it is possible that no countermeasure(s) can be recommended; if this occurs, the user may want to review the previous steps to determine if any information was missed or overlooked that could support the user in determining suitable countermeasures for the location. "Recommendations should only be made if countermeasures can be shown to improve the safety at a site with a known problem" (Schultz et al. 2013).

5.10 **Completing Analysis Reports**

To support the methodology discussed in this chapter and previous research (Schultz et al. 2013), formal reports were created to document the results of the analysis. Two report forms were created to meet the needs of both documenting the full analysis and reporting the findings. The form for the full report includes sections for each of the steps of the analysis methodology. The form includes data on the problem segments and any problem spots within the hot spot segments. Models used for selection and ranking are also included. Tables are provided to include all crash and roadway geometry characteristics determined in the analysis to be part of the problem definition. Additional sections were included for problem definition, countermeasures, and recommendations.

The second form is the deliverable report to the Department of Transportation (DOT). Based on requirements provided, the report is designed to provide a synopsis of the analysis, and not the complete results. The form includes segment information, problem definition and countermeasure recommendation, and a narrative of the crash and roadway data. The report form is to be completed after the analysis is concluded and all information documented. Both forms include written descriptions of the data to be included and helpful information on where to find them and how to process them. A copy of both forms is provided in Appendix A.

5.11 **Chapter Summary**

The hot spot identification and analysis methodology has a number of processes that step the user through: identification and selection of location, identification of common roadway attributes with in the segment, microanalysis, definition of the segment, roadway attributes, and safety problem, the evaluation and selection of countermeasures and the completion of the analysis reports. The process of microanalysis consists of reviewing the data on the crashes and infrastructure found at the locations of interest. Site visits to gain firsthand knowledge and communicating with the experts on those locations are also very important steps in gathering the necessary information required to fully evaluate and select the countermeasures. These countermeasures are the output of the process and should be recommended for implementation to improve the safety of the location. Throughout the processes, road attributes play a part in analysis, definition, and countermeasure selection. These processes include the use of a number of software programs, including tools in ArcGIS, Excel spreadsheets, and Internet tools such as Google Maps, Google Earth, and Roadview Explorer, to locate, categorize, associate, and analysis roadway attributes and segments.

6 EXAMPLES AND RESULTS

This chapter is designed to demonstrate the methodology of the analysis process outlined in Chapter 5. The process will be illustrated through the use of examples, to provide the reader with an improved understanding of the process and steps. This chapter follows the steps that are included in the hot spot analysis methodology. Selections from the results for the two models are used in the steps of the process which are: identifying problematic segments with safety concerns, identifying problem spots within the segments, identifying common roadway attributes within the segments, microanalysis of problematic segments and spots, defining the segment, defining the roadway attributes, defining the problem, evaluation of possible countermeasures, selection and recommendation of feasible countermeasures, and complete the analysis reports. The chapter discusses, through examples, how to identify and define roadway attributes within the segments and how roadway attributes fit as part of the methodology step of analysis. The crash data in this chapter is protected under 23 USC 409.

6.1 Identifying Problematic Segments for Review

To begin the process, a statistical model must be chosen to provide the base dataset in the analysis and identification of the problem segments or “hot spots.” For the analysis completed in this research, data used in the statistical model included all crashes from the years 2008 to 2012. Each model required a different subset of the crash data. For the UCPM, the crash data were filtered to include only severity level B (Non-Incapacitating Injury), level A (Incapacitating Injury), and level K (Fatal). The data for this model include total crash counts for each segment and the count of crashes for each attribute selected by the Bayesian horseshoe selection method.

The modeling of the UCPM required 100,000 iterations for each segment to obtain posterior predictive distributions on the number of crashes expected to occur. For the UCSM, the crash data were filtered to include only severity level A (Incapacitating Injury) and level K (Fatal) to focus the model on the most severe types of crashes. The data for this model include total crash counts for both all severity levels and the severity group of level A (Incapacitating Injury) and level K (Fatal). The modeling of the UCSM required 10,000 iterations for each segment to obtain the probabilities and number of severe crashes expected to occur.

For the UCPM the actual number of crashes was compared to the posterior predictive distribution to determine the percentile for each segment as a number between 0 and 1. The percentile was used in the ranking of the segments such that the higher the percentile the higher the ranking. For the UCSM the relationship between total crashes and the number of crashes in the severity group was used to create a data point for each crash with a binomial flag on whether it was severe or not. Using these data, the model was used to determine that if a crash were to occur, what the probability is that it would be severe. The model was then used to determine the expected number of severe crashes using the total crashes and the probability that the crash was severe. In addition to these outputs the data inputted into the model were used to determine the probability that the expected number of crashes actually occurred. The probability was used in the ranking process. A low probability, that the expected number of severe crashes occurred, was used to coincide with a higher ranking. Both models required the use of the difference between the actual crashes and the expected crashes in the overall ranking.

The UCPM gave priority first to the higher percentile and then to higher difference in actual and expected crashes, whereas the UCSM gave priority first to the low probability that the expected number of severe crashes occurred and then to the higher difference between actual and expected. For the UCSM a low probability that the expected number of severe crashes occurred is an indicator that the actual number of severe crashes is significantly higher or lower than the expected crashes. The ranking used the difference between the actual and expected number of severe crashes with a larger positive number indicating the highest ranking. Combining the ranking from each variable provides an overall ranking for probable hot spots. The higher the overall calculated ranking, the greater the chance the segment is a hot spot and that the segment needs to be analyzed for safety improvements. Tables 6-1 and 6-2 show the top 20 segments from each model based on the ranking calculated. These segments are ordered from highest ranking downward to the 20th ranking.

In Table 6-1, the column labeled "Post Med" represents the median of the posterior predictive distribution. The table also includes the total actual crashes, the number of crashes representing the difference between the actual and the "Post Med," and the percentile of the actual crashes based on the distribution. In Table 6-2, the column labeled "Prob S" refers to the probability that a crash was severe, given that a crash occurred. The column labeled "Prob NS" refers to the probability that the respective number of severe crashes actually occurred on the segment. The table also includes the total number of actual crashes, the total number of severe crashes including level A (Incapacitating Injury) and level K (Fatal), and the number of crashes representing the difference between actual and expected. Given that different severity groups were used for the UCPM and the UCSM, no comparison between results can be made. More information on the statistical models can be found in Chapter 4.

Table 6-1: Top 20 UCPM Hot Spots

Route	Beginning Mile point	Ending Mile point	Functional Class	Total Crashes	Post Med	Difference	Percentile
89	388.438	389.123	Other Principal Arterial	37	14	23	1.00000
15	250.923	253.557	Interstate	28	11	17	0.99999
89	415.425	415.994	Other Principal Arterial	35	16	19	0.99991
15	292.596	293.634	Interstate	25	11	14	0.99973
89	369.036	369.532	Other Principal Arterial	31	16	15	0.99931
89	267.346	276.21	Other Principal Arterial	17	6	11	0.99914
89	386.955	388.438	Other Principal Arterial	44	26	18	0.99868
89	345.017	346.455	Other Principal Arterial	34	18	16	0.99862
89	431.317	433.164	Other Principal Arterial	16	6	10	0.99859
68	48.314	49.312	Other Principal Arterial	39	22	17	0.99857
15	296.093	297.314	Interstate	41	24	17	0.99839
15	303.414	304.427	Interstate	30	16	14	0.99799
89	335.59	336.03	Other Principal Arterial	28	15	13	0.99794
15	357.554	361.92	Interstate	23	11	12	0.99760
89	347.36	347.664	Other Principal Arterial	21	11	10	0.99650
15	275.279	276.064	Interstate	26	14	12	0.99628
89	349.471	350.056	Other Principal Arterial	32	18	14	0.99626
15	248.845	250.923	Interstate	13	5	8	0.99580
89	386.346	386.801	Other Principal Arterial	21	11	10	0.99560
89	413.927	414.22	Other Principal Arterial	17	8	9	0.99521

Table 6-2: Top 20 UCSM Hot Spots

Route	Beginning Mile point	Ending Mile point	Functional Class	Total Crashes	Severe Crashes	Difference	Prob S	Prob NS
80	3.993	41.278	Interstate	83	16	10.758	0.063	0.000
68	11.638	23.934	Minor Arterial	62	11	7.835	0.051	0.000
6	290.894	300.359	Other Principal Arterial	16	5	4.209	0.049	0.001
134	13.451	14.067	Minor Arterial	6	3	2.761	0.040	0.001
80	41.278	48.94	Interstate	15	5	4.053	0.063	0.002
173	8.516	8.775	Minor Arterial	46	6	4.691	0.028	0.002
15	82.253	94.453	Interstate	84	12	7.253	0.057	0.002
191	128.89	129.26	Other Principal Arterial	2	2	1.913	0.044	0.002
39	38.173	42.336	Major Collector	15	5	3.960	0.069	0.002
6	25.25	27.1	Other Principal Arterial	8	3	2.703	0.037	0.002
89	303.16	305.53	Other Principal Arterial	26	5	4.004	0.038	0.002
48	7	7.4	Minor Arterial	71	6	4.576	0.020	0.003
71	8.843	9.212	Other Principal Arterial	49	6	4.547	0.030	0.003
89	24.91	28.62	Other Principal Arterial	13	4	3.226	0.060	0.005
89	328.55	328.847	Other Principal Arterial	52	6	4.274	0.033	0.006
92	13.23	22.6	Major Collector	43	4	3.246	0.018	0.006
89	351.984	352.71	Minor Arterial	20	4	3.176	0.041	0.007
89	376.77	377.324	Minor Arterial	94	8	4.962	0.032	0.008
80	3.993	41.278	Interstate	83	11	5.758	0.063	0.009
111	2.811	4.9	Minor Arterial	75	7	4.472	0.034	0.010

6.2 Identify Problem Spots within the Segments

Once the model results were analyzed and ranked, the next step was to analyze each of the top segments to identify possible problems spots within the problem segments. Section 5.2 discussed the various methods and tools that can be used to identify problem segments within the problem segments. For this research the Sliding Scale analysis tool was used to select possible problem spots. The selection was based on the similar results produced by the Strip analysis tool and the Sliding Scale analysis tool and the possible issues with the splitting of HALs as discussed in Section 5.2 and previous research (Schultz et al. 2013).

The Sliding Scale analysis tool was run on the top 20 segments from both models. Three parameters were required to run the analysis and to determine if problem spots exist: length of the window, length each step would take, and the number of crashes per window. For the analysis of the UCSM top 20 segments, the window length on 1/20 of a mile was used with 1/40 of a mile used for each step. For analysis on the results from the UCSM a minimum of 5 crashes per window was used as the threshold to be considered a HAL. Five crashes were selected based on the use of 5 years of crash data, which would provide an average of one severe crash per year on the micro segment of severity level A (Incapacitating Injury) and level K (Fatal), based on the same reasoning used for the UCSM results. For the analysis of the UCPM top 20 segments, the window length on 1/20 of a mile was used with 1/40 of a mile used for each step. The crash count threshold for the UCPM needed to be determined to allow for the larger severity group used in the model. Two minimum crashes thresholds were used to run a sensitivity analysis on the number of crashes to use as a threshold when the dataset includes severity level B (Non-Incapacitating Injury), level A (Incapacitating Injury), and level K (Fatal). The first was the same as the UCSM using five crashes of severity level A (Incapacitating Injury) and level K (Fatal).

The second threshold was 25 crashes per window when using level B (Non-Incapacitating Injury), level A (Incapacitating Injury), and level K (Fatal); 25 crashes was calculated based on the sensitivity analysis to provide the same ratio of crashes per window to total crashes in the dataset. The sensitivity indicated that when adding level B (Non-Incapacitating Injury) to the severity group, the total crashes used in the model are five times as many crashes than when only using severity level A (Incapacitating Injury) and level K (Fatal).

After the analysis was complete using the sliding scale tools, it was determined that from the top 20 segments in the UCSM, a total of two problem spots existed within the segments. From the analysis on the top 20 segments from the UCPM, neither minimum crash threshold identified problem spots. The sensitivity analysis showed that the 5 crashes per year including level B (Non-Incapacitating injury) produced similar results as the one high severity crash per year of data, and is recommended to be used for future research for ease and convenience of using a single dataset throughout the analysis. Table 6-3 shows where these problem spots are located, along with the number of crashes for each severity.

Table 6-3: UCSM Segment Problem Spots

Route	Segment Mile point	Total Crashes	Problem Spot	Severe Crashes	Severity 5	Severity 4	Segment Rank
173	8.516-8.775	46	8.741-8.775	6	1	5	6
48	7-7.4	71	7.025-7.1	6	1	5	12

For the purpose of this study, only the top three problem segments from each model and the two problems spots from the UCSM were chosen for further analysis. The analysis will continue following the steps as prescribed in Chapter 5 and from previous research (Schultz et al. 2013). This report will document the results of the analysis from the highest ranked problem segment from UCSM and the problem spot located along the 6th highest problem segment. The analysis follows the prescribed methodology. These examples from the UCSM results are the problem segment on I-80 from milepoint 3.993 to milepoint 41.278 and the problem spot on SR-173 between milepoint 8.516 to milepoint 8.775. These segments are selected to represent the both a segment and spot and were both selected from the UCSM for consistency in severity group. The analysis results for the 2nd and 3rd ranked problem segments from the UCSM and problem spot located on the 12th ranked problem segment of the UCSM results, which was the highest ranked hot spot with a problem spot, and the top three ranked problem segments from the UCPM results completed as part of this research can be found in Appendix B. Appendix B includes two documents for each on the 8 segments analyzed; the analysis results and the report documents.

6.3 Identifying Common Roadway Attributes within the Segments

The next step in the methodology is to associate the problem segments and problem spots with the roadway attribute data. Section 5.3 discussed two tools in ArcGIS that could be used to accomplish associating the data for each roadway dataset to the segment data. For this research the Spatial Join tool was selected. The selection was based on similar outputs from both Spatial Join tool and the Overlay Route Event tool and the issue related to point data and the Overlay Route Event tool and the possible splitting of the original segment.

The Spatial Join tool was applied to the top 20 segments for both models, including the two problem areas identified from Sliding Scale analysis tool. The segment data was joined with 11 roadway attribute datasets: barriers, walls, lanes, shoulders, medians, intersection, signs, grade, sag and crest curves, curvature, and rumble strips. The spatial join was run 11 times, once for each roadway attribute dataset. The process produced 11 combined datasets. Three primary parameters were used to run the spatial join tool: target feature class, join feature class, and join operation. For all 11 dataset segments, data were selected for the target feature class. The join features class was used to add each roadway attribute at one attribute per run. The "join one to many" (Esri 2014) was selected as join operation parameter to collected every variation of roadway attribute. The length of the problem segment and the roadway attribute segments are not consistent and the attributes can change over the length of the segment. Joining all of the variations of an attribute to the problem segment ensures that all possible data were collected. The number of attributes along the problem segment depends on the roadway attribute and the length and type of the segment. The number of variations of a specific attribute along the analyzed hot spots ranged from 1 to 15. Each dataset was exported to an Excel format for further analysis and evaluation.

This step in the process was completed on data for all 20 segments from both models. For the purpose of this study, the remaining steps were only completed on the top three problem segments from each model and the two problem spots from the UCSM were chosen for further analysis. The analysis and evaluation of these data and changes along the segments was completed as described in Section 5.4.2 and the results can be found in Section 6.4.2.

6.4 Microanalysis of Problematic Segments and Spots

The description of the microanalysis step can be found in Section 5.4 and previous research (Schultz et al. 2013). This description includes an overview of the tools that can be used as part of a microanalysis of the problem spot, including crash data, LiDAR and roadway attributes, Internet tools, site visits, and communicating with experts. This section will focus on how these tools are used and the results from applying these tools to the example segments.

6.4.1 Crash Data

Part of the microanalysis process is to identify common traits and characteristics within the crash data for the segment. The crash data used in this step were used previously with the model and ArcGIS analysis. The primary use was the number of crashes that occurred on the segment, and with the introduction of the Bayesian horseshoe selection method, the number of crashes with specific characteristics. This step includes a more in-depth and proactive approach to using the crash data to help in the safety analysis process.

The crash data were provided in six separate datasets for the years 2008 to 2012. Of these six datasets, four were used in the analysis; crash, location, rollup, and vehicle. The four crash datasets provided in the CSV files were not modified from the original data; however, the data were compiled and organized to allow for ease in analysis. The datasets were provided in separate CSV files for each dataset per year. The data were first complied for all five years by dataset. Once the data were compiled by dataset, the data for location, crashes, rollup, and event data from vehicles were compiled into a single dataset. The files were compiled using the unique identifier of CRASH_ID used by all crash datasets. The crash data originated from the DI-9 forms used by the law enforcement officers when documenting the incident at the scene.

The crash dataset was used to pull general information about the crash. The crash dataset includes data about the crash conditions, road conditions, light conditions, horizontal alignment, weather conditions, and harmful events. Data pertaining to the first harmful event, collision type, and manner of collision were used for this study. The data were organized by crash ID and include a single dataset per crash ID.

The crash rollup data are quick reference datasets complied by UDOT to help determine the contributing factors in a crash. For every crash ID, there is a single list of possible contributing factors that could have led to the crash, including factors associated with people, the vehicle, and site specific data. If the possible contributing factor was involved in the crash, then it is marked with a "Y" for "yes," but if it is not involved then it is marked with an "N" for "no." For this study only factors that were marked "Y" on 40 percent or more of all the crashes were included in this analysis. When only a few or none of the factors exceeded 40 percent, data pertaining to driving under the influence (DUI), aggressive driving, speed related, intersection-related, roadway geometry related, and teenage driver were used in the analysis regardless of the number of "Y" responses. When all of the data were compiled into one file for the problem segment that is being analyzed, it becomes easy to see common traits and characteristics that could be contributing to the safety problem.

The crash vehicle data were also used to determine information on the progression of the crash. The crash vehicle dataset includes data about the sequence of events, vehicle maneuvers, number of vehicles, and harmful events. Data pertaining to the sequence of events and the vehicle maneuver were used for this study. The data were organized by crash ID and vehicle ID; each crash ID will include a dataset for each vehicle involved in the crash. For multiple vehicle crashes, the data for each vehicle was analyzed.

The crash comments dataset contains narrative information from the law enforcement officer about the crash. There is only one set of comments for every crash ID. Many of the crash IDs do not have officer comments because that section in the DI-9 form is not required. When the data are available, it is important and should be considered. The data were reviewed if there were comments, but this information will not be added to this report. It is suggested that the compiled crash comments file be referred to when defining the problem at the segment and also when evaluating possible countermeasures (Schultz et al. 2013).

“There are many different types of information that can be pulled from the crash data files. Not all of the data were considered relevant or important for this step in the microanalysis. It is important for the analyst to pull all data that are relevant to the segment for analysis” (Schultz et al. 2013). As noted previously, one problem segment and one problem spot will be presented in this chapter as examples of how to follow the methodology, while results of the of all eight analysis segments completed including both the analysis results and the report document are provided in Appendix B. These locations, I-80 and SR-173, are presented in the following subsections and as subsections in the remaining sections of this chapter.

6.4.1.1 Crash Data for Hot Spot on Interstate 80. A compilation of the crash data from the crash, vehicle, and rollup datasets for I-80, mile point 3.993 to mile point 41.278, can be found in Tables 6-4 through 6-6. Table 6-4 provides the crash file data, Table 6-5 provides the vehicle file data, and Table 6-6 provides the crash rollup file data (all information not available is represented with an NA in the table). The events data that are available as part of the vehicle dataset includes run-off-road (ROR), overturn, collision with motor vehicle, crash involving fixed objects, and others.

Table 6-4: Crash File - I-80 (Mile point 3.993-41.278)

Crash ID	First Harmful Event	Manner of Collision
10189905	Overturn/Rollover	NA
10161354	Unknown	NA
10189196	Unknown	NA
10202756	Overturn/Rollover	NA
10351160	Overturn/Rollover	NA
10230515	Overturn/Rollover	NA
10230509	Motor Vehicle	Sideswipe Same
10286112	Unknown	NA
10297616	Delineator Post	NA
10340083	Overturn/Rollover	NA
10362050	Motor Vehicle	Front to Rear
10387448	Overturn/Rollover	NA
10414963	Overturn/Rollover	NA
10442316	Overturn/Rollover	NA
10448632	Overturn/Rollover	NA
10455345	Overturn/Rollover	NA

Table 6-5: Vehicle File - I-80 (Mile point 3.993-41.278)

Crash ID	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
10189905	ROR, Median, ROR, Rollover	Rollover	Straight Ahead
10161354	ROR, Median, ROR, Rollover	Rollover	Straight Ahead
10189196	Median, ROR, Rollover	Rollover	Straight Ahead
10202756	ROR, Rollover	Rollover	Straight Ahead
10351160	ROR, Rollover	Rollover	Straight Ahead
10230515	Rollover	Rollover	Straight Ahead
10230509	Median, Crash Cushion	Crash Cushion	Overtaking/Passing
10286112	ROR, Median, ROR, Rollover	Rollover	Straight Ahead
10297616	ROR, Delineator, ROR, Rollover	Rollover	Straight Ahead
10340083	ROR, Post, Rollover	Rollover	Straight Ahead
10362050	Motor Vehicle, ROR	Motor Vehicle	Turning Left
10387448	ROR, Rollover	Rollover	Straight Ahead
10414963	ROR, Equipment, Rollover	Rollover	Straight Ahead
10442316	ROR, Rollover	Rollover	Straight Ahead
10448632	ROR, Rollover	Rollover	Straight Ahead
10455345	ROR, Rollover	Rollover	Straight Ahead

Table 6-6: Rollup File - I-80 (Mile point 3.993-41.278)

Crash ID	Speed Related	Overturn/ Rollover	Roadway Departure	Night Conditions	Single Vehicle	Improper Restraint	DUI	Drowsy Driving
10189905	N	Y	Y	Y	Y	Y	N	Y
10161354	N	Y	Y	N	Y	N	N	N
10189196	N	Y	Y	Y	Y	Y	N	N
10202756	Y	Y	Y	N	Y	N	N	N
10351160	Y	Y	Y	N	Y	N	Y	N
10230515	Y	Y	N	N	Y	N	N	N
10230509	N	N	Y	Y	N	N	N	N
10286112	N	Y	Y	N	Y	Y	N	N
10297616	N	Y	Y	Y	Y	Y	Y	N
10340083	N	Y	Y	Y	Y	Y	Y	N
10362050	N	N	N	N	N	Y	N	N
10387448	N	Y	Y	Y	Y	Y	N	N
10414963	N	Y	N	N	Y	N	N	N
10442316	N	Y	Y	Y	Y	N	Y	N
10448632	N	Y	Y	Y	Y	Y	Y	N
10455345	Y	Y	N	N	Y	Y	Y	N
Total	4/16	14/16	12/14	8/16	14/16	9/16	6/16	1/16

Upon review of the crash data tables for the hot spot located along I-80, it was determined that the common trend was an excess of rollover and ROR collisions. These types of collisions happened while the vehicle was traveling straight or passing. The possible contributing factors are speeding, night conditions, and DUI.

6.4.1.2 Crash Data for Problem Spot on State Route 173. A compilation of the crash data from the crash, vehicle, and rollup datasets for SR-173, mile point 8.741 to mile point 8.775, can be found in Tables 6-7 through 6-9. Table 6-7 provides the crash file data, Table 6-8 provides the vehicle file data, and Table 6-9 provides the crash rollup file data (all information not available is represented with an NA in the table).

Table 6-7: Crash File – SR-173 (Mile point 8.741 - 8.775)

Crash ID	First Harmful Event	Manner of Collision
10364447	Motor Vehicle	Front to Rear
10362518	Pedestrian	Unknown
10393002	Motor Vehicle	Angle
10416558	Motor Vehicle	Angle
10424833	Motor Vehicle	Angle
10453787	Motor Vehicle	Angle

Table 6-8: Vehicle File – SR-173 (Mile point 8.741 - 8.775)

Crash ID	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
10364447	Motor Vehicle, Motor Vehicle	Motor Vehicle	Straight Ahead, Stopped in Lane
10362518	Pedestrian	Pedestrian	Turning Left
10393002	Motor Vehicle	Motor Vehicle	Straight Ahead, Turning Left
10416558	Motor Vehicle	Motor Vehicle	Straight Ahead, Turning Left
10424833	Motor Vehicle	Motor Vehicle	Straight Ahead, Straight Ahead
10453787	Motor Vehicle	Motor Vehicle	Straight Ahead, Straight Ahead

Table 6-9: Rollup File – SR-173 (Mile point 8.741 - 8.775)

Crash ID	Speed Related	Intersection Related	Roadway Geometry	Teenage Driver	Older Diver	Aggressive Driving	DUI	Drowsy Driving
10364447	N	Y	N	N	N	N	N	N
10362518	N	Y	N	N	N	N	N	N
10393002	N	Y	Y	N	N	N	N	N
10416558	N	Y	N	N	N	N	N	N
10424833	N	Y	N	N	N	N	N	N
10453787	N	Y	N	N	N	N	N	N
Total	0/6	6/6	1/6	0/6	0/6	0/6	0/6	0/6

Upon review of the crash data tables for the problem spot on SR-173, it was determined that the common trend was an excess of angle collisions at a signalized intersection. These types of collisions happened while the vehicle was traveling straight and turning left. The possible contributing factor is roadway geometry.

6.4.2 LiDAR Data/Roadway Attributes Data

The description of the microanalysis step can be found in Section 5.4.2. This description includes an overview of the LiDAR and roadway attributes. This section will focus on how these tools are used and the results from applying these tools to the example segments.

6.4.2.1 Roadway Attributes for Hot Spot on Interstate 80. This segment of I-80 has very little variation on grade with the measured grade ranging from a minimum of 0 percent to a maximum grade of -0.88 percent. The absence of a crest or sag curves was expected, due to the lack of change in grade. No horizontal curves were associated with this segment of I-80. The segment consists of two lanes in each direction with no turn lanes, ramps, or auxiliary lanes. The shoulders average 5 feet in width on both the left and right side of the roadway with a maximum of 30 feet and a minimum of 3 feet. The directions of travel are separated with a wide flat depressed median that is on average about 300 feet wide except for the beginning quarter mile which is 37 to 38 feet wide with an installed cable barrier. There are rumble strips on both the right and center of the roadway for most of the length of the segment. There are four intersections as part of a single interchange at the beginning of the segment and a rest stop located at approximately milepoint 9.8, producing an IPM of only 0.107 intersections per mile. There are 110 signs located along the length of segment that are distributed fairly evenly over the entire segment and producing a SPM of 2.95 signs per mile. Table 6-10 includes the compiled roadway attributes for this segment. Table 6-10 includes data for all roadway attributes. The data for SPM and IPM include both the total count along the segment and the rate per mile.

Table 6-10: Roadway Attributes - I-80 (Mile point 3.993-41.278)

Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
300 ft Flat	4/0.107	110/2.95	5 ft /Asphalt	Flat	None	4 Thru	None	Yes

6.4.2.2 Roadway Attributes for Hot Spot on State Route 173. SR-173 included variation in grade along the segment. The variation ranged by about 2 percent ranging from maximum positive grade of 1.1 percent to a maximum negative grade of -1 percent. These changes in grade resulted in two sag curves each of approximately 1 percent change. The segment is located at an intersection and includes two through lanes in each direction and dedicated left turn (LT) and right turn (RT) lanes for both major approaches. The roadway includes paved shoulders that terminate in a curb and gutter treatment. The width of the shoulders is on average 11 feet wide and varies from a maximum of 16 feet to a minimum of 0 feet as the segment approaches the intersection. There is a raised median on the east side of the intersection separating the eastbound traffic from the westbound LT lane. The segment includes one curve situated on the beginning half of the full segment. The curve, which is a Class A curve of about 450 feet in length with a radius of 2,631 feet, ends prior to the problem area of the segment. There are no rumble strips, barriers or walls at this location. There was one intersection located at the problem area of the segment, producing an IPM of only 3.86 intersections per mile. There are 11 signs located along the length of full segment and were located primarily at the intersection and problem area. These signs produced a SPM of 42.5 signs per mile based on the short length of the segment. Table 6-11 includes the compiled roadway attributes for this segment.

Table 6-11: Roadway Attributes – SR-173 (Mile point 8.741-8.775)

Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/ Barrier	Rumble
4ft Raised	1/3.861	11/42.5	11ft / Curb and Gutter	1.1%	Class A, L=450, R=2631	4 Thru, LT and RT Lanes	No	No

6.4.3 Internet Tools

The description of the microanalysis step can be found in Section 5.4.3. This description includes an overview of the internet tools. This section will focus on how these tools are used and the results from applying these tools to the example segments.

6.4.3.1 Internet Tools for Hot Spot on Interstate 80. It was observed that I-80 from milepoint 3.993 to milepoint 41.278 is an interstate highway that begins just outside of Wendover and continues to the first bend in the freeway. This section of interstate has two lanes of travel in each direction with a center median. For the entire section there are no barriers in the median or at the shoulders. The shoulders are all paved with rumble strips along most of the length of the roadway section. Figure 6-1 from Google Earth shows the I-80 segment.

Figure 6-1: Birds eye view of Interstate 80 (Google, Inc. 2015a).

Roadview Explorer was used to analyze the I-80 segment to determine if there were any changes made to the roadway in the past 5 years. The analysis showed that very few changes were made on this segment of I-80 from 2009 to 2014. The changes that were made included restriping and the addition of rumble strips near the rest stop. At locations where the median was narrower, the addition of cable barriers was also noted sometime between 2009 and 2011. Deterioration of the road surface can also be seen. Figure 6-2 shows a portion of the segment in 2009, while Figure 6-3 shows the same portion of the segment in 2014.

Figure 6-2: Interstate 80 in 2009 (UDOT 2015b).

Figure 6-3: Interstate 80 in 2014 (UDOT 2015b).

6.4.3.2 Internet Tools for Hot Spot on State Route 173. It was observed that SR-173 (5300 South) from mile point 8.741 to mile point 8.775 is a Minor Arterial at the intersection with Murray Boulevard (700 West). This section of roadway has two lanes of travel in each direction with a center median. The median to the east is a raised median and the median to the west is a center LT lane. At the intersection, each direction has a dedicated LT lane with approximately 200 feet of storage. Both approaches include a dedicated RT lane at the intersection. The intersection is signal controlled with LT phasing on the cross street and on the SR-173 approaches. Figure 6-4 shows the intersection in the problem spot.

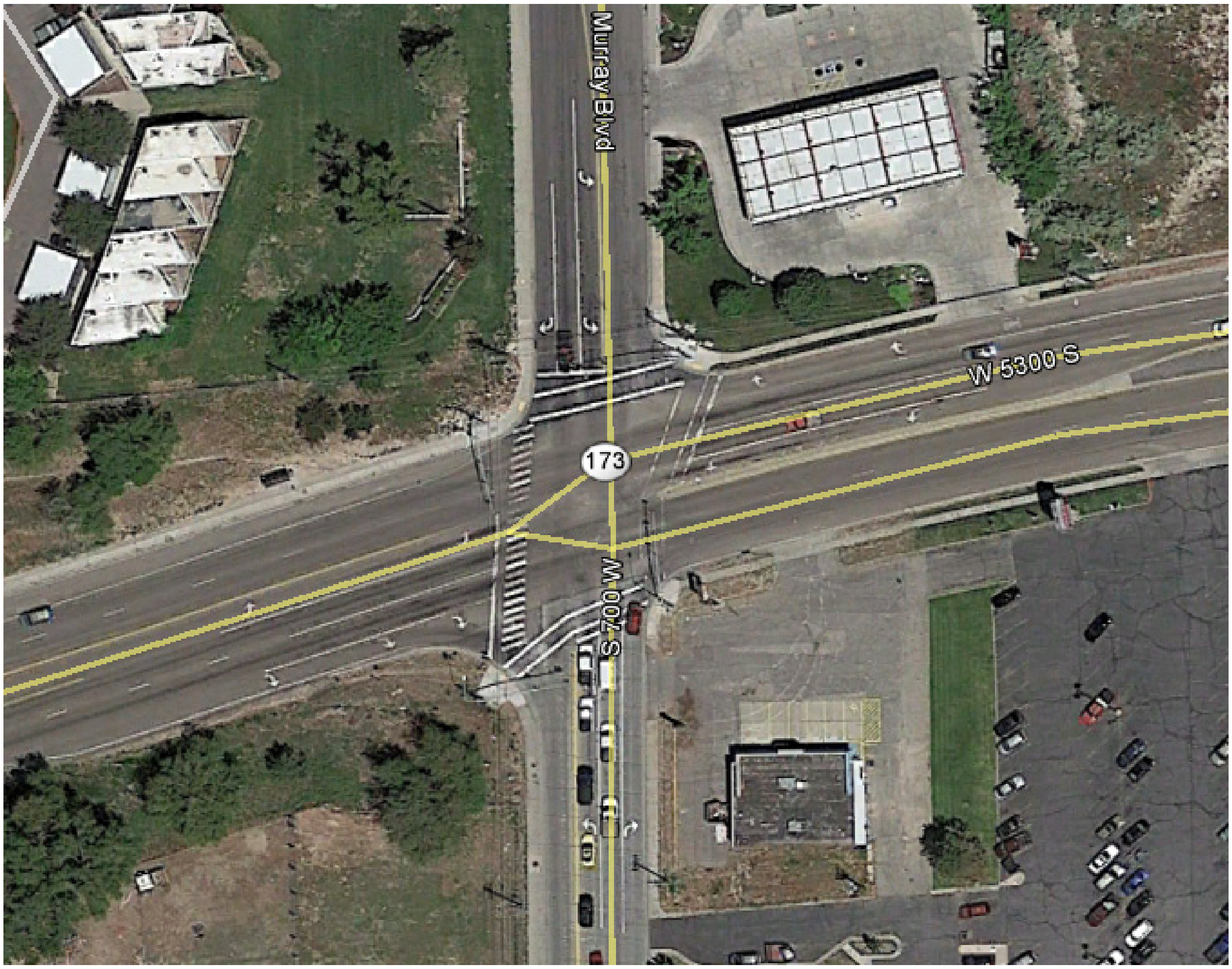

Figure 6-4: Birds eye view of State Route 173 (Google, Inc. 2015a).

Roadview Explorer was used to analyze SR-173 to determine if there were any changes made to the roadway in the past 5 years. The analysis showed that no changes can be seen for this segment of SR-173 from 2010 to 2014. Figure 6-5 shows a portion of the segment in 2010, while Figure 6-6 shows the same portion of the segment in 2014.

Figure 6-5: State Route 173 in 2010 (UDOT 2015b).

Figure 6-6: State Route 173 in 2014 (UDOT 2015b).

6.4.4 Site Visits

Following the methodology outlined in Chapter 5, the next step is to conduct a site visit. Visiting the site helps the analyst to see and understand the interactions at the hot spot location. "A site visit is critical to the analysis of a roadway when safety issues are of concern. The main purpose of a site visit is to get a firsthand feel or understanding of how the roadway segments function" (Schultz et al. 2013). The site visit also allows assumptions to be verified before the selection of countermeasures, including changes that may have been made that were not represented with the Internet tools.

The description of the microanalysis step can be found in Section 5.4.4. This description includes an overview of the site visit step. This section will focus on how this step is used and the results from applying these tools to the example segments.

6.4.4.1 Site Visit for Hot Spot on Interstate 80. A site visit was made to the hot spot on I-80 on April 23, 2015. The visit was made to take measurements and verify assumptions about median, barriers, shoulder, and grade. Figure 6-7 shows the typical lane and shoulder configuration along the hot spot. It was observed during the site visit that most of the segment was flat and absent of curvature. The average measured distance across the center median was 305 feet. A median barrier was found on the segment at the first portion, but ended after about 0.2 miles. One observation from the site visit was that after the shoulder, there was a relatively abrupt drop of a few feet to the center median. Another was the existence of two cable barriers along the median from milepoint 10.5 to milepoint 11.5 and from milepoint 32.5 to milepoint 38.5. Figure 6-8 shows the typical median found along the segment. There is, on average, 6 feet of paved shoulder.

Figure 6-7: Typical lane and shoulder configuration on Interstate 80.

Figure 6-8: Typical median and rumble strip on Interstate 80.

6.4.4.2 Site Visit for Hot Spot on State Route 173. A site visit was conducted at the problem spot on SR 173 on April 23, 2015 to take measurements. Along with taking measurements, the approach from each direction was driven to get a feel for sight distances and any obstructions that might exist to reduce visibility while approaching the intersection. After this was done, the traffic patterns at the intersection were observed for a time to help understand how it operates. It was observed that the signal at this intersection seems to be operating properly with no particular problems observed. Special attention was made to the eastbound approach as 4 out of the 6 crashes involved a vehicle from this approach. It was observed that at the intersection, the pedestrian crosswalks were hindered by a raised median on the northbound and westbound approach, which could be a concern, as this is a marked school crossing. It was also observed that the approach angle for the eastbound and westbound movements was 72 degrees. While driving the eastbound approach, the vertical and horizontal curvature as well as obstruction from vegetation on the south side of the road reduces visibility. Although the visibility was obstructed, the sight distance appeared to be sufficient. Figure 6-9 shows the eastbound approach to the intersection.

Figure 6-9: Eastbound approach to problem location on SR-173.

6.4.5 Communicating with Experts

For this research no experts familiar with these sites were contacted to get their opinion on the safety problems that may exist. “The purpose of communicating with an expert about the site would be to gain understanding and knowledge about the study area. An expert familiar with the site could help point out concerns that might be overlooked. It is recommended that this analysis tool be utilized before any countermeasure is implemented. It is also important to understand that this step can be done one time or at several different times throughout the methodology steps” (Schultz et al. 2013). This step is designed to improve the understanding of the site and gain addition perspective on the site; this analysis step is not required when using the analysis methodology. Based on a meeting with UDOT, the analyst was able to gain further insight into how use the U-Plan Internet tools. This Internet tool allows the analyst to be able to see future, current, and past construction projects at the site being analyzed.

6.5 **Defining the Segment**

The next step in the process, once careful microanalysis has been performed on the problem segment or problem spot, is to define the problem area of the segment. This step is to help gain a better understanding of the segment and the characteristics found within the segment. The following subsections provide the results of this step in the methodology for I-80 and SR-173, respectively.

6.5.1 Interstate 80

The problem segment on I-80 is located between the milepoint 3.993 and milepoint 41.278. The roadway segment is a divided interstate highway with two travel lanes in each direction. The posted speed limit for this stretch of roadway was 75 mph during the study period and has since been rasied to 80 MPH. There are rumble strips on both sides of the road for both travel directions. The center median separating opposing traffic is flat and unpaved with a wide ditch in the middle for most of the length with a cable barrier at the beginning of the segment. The width of the median and ditch is an average of 300 feet. The shoulder in the middle is 5 feet. The shoulder next to the outside lane is paved the length of the segment. The pavement of the shoulder is 10 feet wide. The lanes are 12 feet wide and seem adequate. The problem appears to be along the entire length of the segment.

6.5.2 State Route 173

The problem spot on SR-173 is located primarily at milepoint 8.77. This spot is part of a larger problem segment on SR-173 between milepoint 8.516 and milepoint 8.775. The problem spot is located at the signalized intersection of 5300 South and Murray Boulevard (700 West) in Murray, Utah. The posted speed limit on 700 West in the area is 40 mph, while the posted speed limit on 5300 South is 35 mph. The problem spot occurs for traffic traveling on 5300 South, which has two lanes in each direction. For the eastbound traffic there is a LT lane and RT lane with a storage length of approximately 200 feet. For the southbound traffic there is a LT lane and RT lane with a storage length of approximately 200 feet. At the intersection there is no shoulder, but there is a gutter, curb, and sidewalk. There is a raised median on the east side that separates opposing traffic at the intersection. Lane widths are slightly larger than 12 feet. There are pedestrian crosswalks on all legs of the intersection, including a school crossing on the west side of the intersection.

6.6 Defining the Roadway Attributes

Once the segment is defined, the roadway attributes located at the problem segment or problem spot can be defined. This step is to help gain a better understanding of the roadway configuration and the attributes at the location that might be contributing to the crashes. The following subsections provide the results of this step in the methodology for the segments on I-80 and SR-173, respectively.

6.6.1 Interstate 80

This segment of I-80 is very flat with no horizontal or vertical curvature. The lane configuration is constant throughout the segment with two through lanes in each direction. The shoulders are all about 5 feet in width on both the left and right side of the roadway. The directions of travel are separated with a wide flat median that is on average about 300 feet wide and is situated a few feet lower than the roadway. There are rumble strips on both the right and center of the roadway for most of the length of the segment.

6.6.2 State Route 173

This segment of SR-173 has a slight slope of 1.1 percent increasing in elevation in the eastbound direction. The lane configuration at the intersection includes through and turning lanes. The roadway includes a variable width paved shoulder that terminates in a curb and gutter treatment. There is a raised median on the east side of the intersection separating the eastbound traffic from the westbound LT lane. The intersection was built on a Class A curve of about 450 feet in length and a radius of 2,631 feet. There are no rumble strips, barriers or walls at this location.

6.7 **Defining the Problem**

After completion of a careful microanalysis performed on the problem segment or problem spot, the next step is to define the problem. “This step in the methodology is to help gain a better understanding of the segment and the characteristics found within the segment” (Schultz et al. 2013). The following subsections provide the results of this step for I-80 and SR-173, respectively.

6.7.1 Interstate 80

The safety problem along the segment of I-80 located between the milepoint 3.993 and milepoint 41.278 is an excess of ROR and rollover crashes resulting in high severity level A (Incapacitating Injury) and level K (Fatal). Based on the crash data in Table 6-4, Table 6-5, and Table 6-6, possible contributing factors to the problem are speeding, DUI, and light conditions (i.e., night time driving). The flat straight roadway geometry could also be a possible contributing factor.

6.7.2 State Route 173

The safety problem occurring at the problem spot on SR-173 at mile point 8.77 is an excessive number of right angle collisions between a vehicle turning left and a vehicle driving straight in the cross travel direction resulting in high severity collisions level A (Incapacitating Injury) and level K (Fatal). Based on the crash data in Table 6-7, Table 6-8, and Table 6-9, possible contributing factors to this problem are intersection geometry and layout.

6.8 **Evaluation of Possible Countermeasures**

The purpose of these safety analyses, defining of the segments, and the defining of the safety problems is to create a comprehensive list of all possible known countermeasures that can then be evaluated for possible improvement of safety. This list will be evaluated and all unfeasible countermeasures will be eliminated for the segment that is being analyzed. The following subsections provide the results of this step for I-80 and SR-173, respectively.

6.8.1 Interstate 80

The following is a list of possible countermeasures for implementation at the problem segment located on I-80. This list was evaluated based on the criteria and questions found in Section 5.6. The countermeasures listed are specific to the problem and not the site, and were compiled using the countermeasure matrices found in past research (Schultz et al. 2013). The list is based on ROR collisions, DUI, and speed collisions. Only countermeasures related to ROR, rollover, and DUI collisions were added to the list for evaluation.

- Install mid lane rumble strips
- Eliminate shoulder drop off
- Apply shoulder treatments such as eliminating shoulder drop off or widening shoulders

- Design safer slopes and ditches to prevent rollovers
- Install median and/or shoulder barriers
- Add or improve roadside hardware
- Widen left and right shoulders
- Conduct regular well-publicized driving while intoxicated (DWI) checkpoints

6.8.2 State Route 173

The following is a list of possible countermeasures for implementation at the problem spot located on SR-173. This list was evaluated based on the criteria and questions found in Section 5.6. The countermeasures listed are specific to the problem and not the site, and were compiled using the countermeasure matrices found in past research (Schultz et al. 2013). The list is based on signalized intersection collisions and includes countermeasures related to LTs for evaluation.

- Optimize clearance intervals
- Provide/improve LT channelization
- Improve visibility of signals and signs at intersection
- Provide targeted conventional enforcement of traffic laws
- Control speed on approaches
- Employ signal coordination along a corridor or route
- Install advance warning signs
- Improve signal coordination
- Restrict turning movements

6.9 **Selection and Recommendations of Feasible Countermeasures**

To finalize the analysis the final step in the methodology is to select countermeasures to be recommended for implementation at the hot spot. An evaluation considering the list of all possible countermeasures for implementation was completed including a review of the feasibility of each one. The following lists of possible countermeasures were considered as feasible solutions at each of the example sites (I-80 and SR-173). The countermeasures listed are specific to the site. No economic consideration was analyzed as this was beyond the scope of this project. The following subsections provide the results of this step in the methodology for I-80 and SR-173, respectively. All countermeasures were selected based on the proven status as per the NCHRP Report 500 series.

6.9.1 Interstate 80

The following provides a list of suggested countermeasures for implementation at the problem segment on I-80 based on the hot spot identification and analysis methodology.

- Eliminate shoulder drop off
- Design safer slopes and ditches – redesign center median
- Install median barriers
- Install shoulder barriers
- Widen the left and right shoulder
- Conduct regular well-publicized DWI checkpoints

6.9.2 State Route 173

The following provides a list of suggested countermeasures for implementation at the problem spot on SR-173 based on the hot spot identification and analysis methodology.

- Reduce approach speeds
- Optimize clearance intervals for LT movements
- Improve signal coordination along the corridor
- Install advance warning signs
- Improve visibility of signals and signs at intersection

6.10 **Chapter Summary**

A discussion of the hot spot identification and analysis methodology steps using examples was completed in this chapter. Two specific examples were used, including a problem segment and a problem spot from Utah's roadway network. A discussion of the locations and results for each of the individual steps was covered. The 1st ranked problem segment located on I-80 between mile points 3.993 and 41.278 and the highest crash count problem spot located on SR-173 at mile point 8.77 were the examples used to illustrate the methodology. The chapter includes the steps for analyzing and defining the roadway attributes for the locations analyzed. For both of these examples, a list of recommendations is provided on possible countermeasures for implementation. The main purpose of this chapter was to show how to follow the methodology in improving roadway safety by the selection of feasible countermeasures for implementation at known hot spots, including the additional steps related to roadway attributes. Appendix B includes two documents for each on the 8 segments analyzed; the analysis results and the report documents.

7 CONCLUSION

The purpose of this research was to advance the safety in the state of Utah by updating the safety analysis model to identify safety hot spots as a function of overall crashes and severity by using crash and roadway attributes. The update of the model included the addition of roadway asset data (including the LiDAR roadway inventory data) to allow the user to utilize the model to more closely examine the data and to identify key roadway characteristics that contribute to crashes and then search on these characteristics to identify and prioritize safety projects statewide. This included improving the methodology for accomplishing the first three steps in the framework for highway safety mitigation, illustrated in Figure 7-1, to address roadway attributes. The enhanced methodology covers the steps of network screening, diagnosis, and countermeasure selection. The crash data in this chapter is protected under 23 USC 409.

This chapter briefly summarizes the enhancements that were developed as part of this research project and provides recommendations for future research that should be considered to continue the advancement of safety research in Utah.

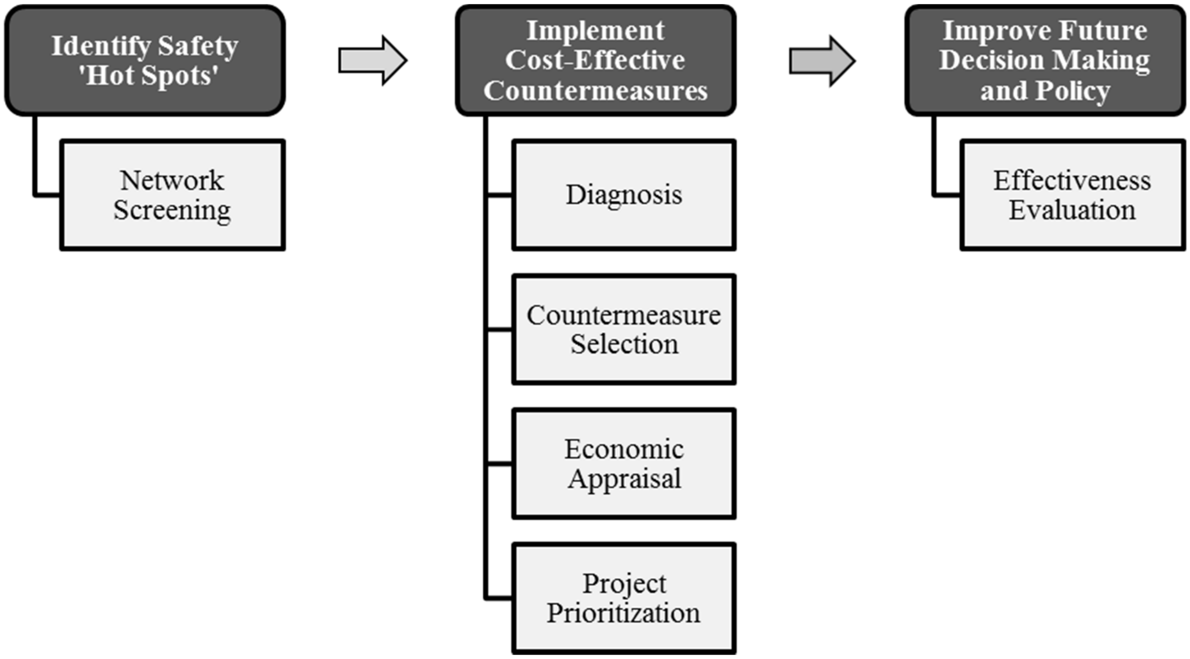

Figure 7-1: Framework for highway safety mitigation (adapted from AASHTO 2010).

7.1 Roadway Attributes Summary

Because of the improvement in available data through the use of LiDAR data collection methods, procedures were improved and created to associate these data to the segments and crash data for use with the models and analysis. These methods include the use of tools in ArcGIS, including Spatial Join and the Overlay Route Event tools, to combine the roadway attributes to the respective road segments. By associating the roadway data to the segment or crash, further analysis can be conducted to determine what the roadway characteristics are along the problem segment or at the problem location. The addition of roadway data is limited to the availability of the data in a spatially allocated format. Sub-steps were added to the methodology entitled, "Hot Spot Identification and Analysis" (Schultz et al. 2013). These sub-steps are associated with adding the roadway attributes to the analysis. A sub-step was added to Step 2 "Identify Problems Spots" to combine the characteristics that exist at the location. A sub-step was added to Step 4 “Defining the Segment,” which includes defining the roadway attributes for the segment of problem area.

7.2 Variable Selection Summary

The development of the process and methods used to associate the roadway attributes and crash characteristics required the development of a selection method to determine whether the added data could be used in the UCPM to help in determining locations for further analysis. The development of a Bayesian horseshoe selection method was developed for this purpose. The process for data preparation includes associating all desired roadway attributes to each crash to be used in the model. The Bayesian horseshoe selection method provides an output of the statistically significant parameters that were determined by evaluating and selecting the variables that are most likely not to be zero. These parameters can then be collected, combined, and used in the UCPM.

7.3 UCPM and UCSM Summary

With the improvement and implementation of safety measure over the years, Utah has seen decreases in severe crashes including level A (Incapacitating Injury) and level K (Fatal). This decrease also reduced the quantity of data that can be used in the UCPM. A limitation of the UCPM is that with limited data (i.e., a reduction in severe crashes), the results produced can have reduced accuracy. The addition of crash level B (Non-Incapacitating Injury) was used to overcome this limitation. The addition of level B (Non-Incapacitating Injury) severity crashes weighted the focus of the results of the UCPM to segments that had only a few or none of level A (Incapacitating Injury) and level K (Fatal) crashes. These are very useful, but require an additional method to focus solely on the high severity crashes. The development of the UCSM, using Bayesian statistics with a Binomial indicator for whether the crash was severe or not, was developed to focus on a specific severity level with limited severity data by including the data for all crash severities as well as data for only the desired crash severity. By developing and using this suite of models, potential locations with safety issues can be identified for further analysis. The results from the models that were chosen for further analysis are shown in Tables 7-1 and 7-2.

Table 7-1: Analyzed UCPM Hot Spots

Route	Beginning Mile point	Ending Mile point	Functional Class	Total Crashes	Post Med	Difference	Percentile
89	388.438	389.123	Other Principal Arterial	37	14	23	1.00000
15	250.923	253.557	Interstate	28	11	17	0.99999
89	415.425	415.994	Other Principal Arterial	35	16	19	0.99991

Table 7-2: Analyzed UCSM Hot Spots

Route	Beginning Mile point	Ending Mile point	Functional Class	Total Crashes	Severe Crashes	Difference	Prob S	Prob NS
80	3.993	41.278	Interstate	83	16	10.758	0.063	0.000
68	11.638	23.934	Minor Arterial	62	11	7.835	0.051	0.000
6	290.894	300.359	Other Principal Arterial	16	5	4.209	0.049	0.001
173	8.516	8.775	Minor Arterial	46	6	4.691	0.028	0.002
48	7	7.4	Minor Arterial	71	6	4.576	0.020	0.003

7.4 Future Research

In a continuation of research related to the analysis methodology and the framework for highway safety mitigation, four areas for future research were identified. These areas of future research would be consistent with past research and continue to aid UDOT in meeting their goal of advancing safety of throughout the state. These areas of research are: development of an intersection predictive crash model with the use of parameter selection; the development of a methodology on how to accomplish the next two steps of the framework for highway safety mitigation (i.e., economic appraisal and project prioritization); the implementation of the model at a national level using available data for other states; and the development of a graphical user interface (GUI) for all of the models.

7.4.1 Intersection Predictive Crash Model

The purpose of developing a methodology of using and selecting roadway and crash attributes to be implemented into the models is to increase the power and usefulness of the models to predict crashes. With this methodology, attributes and characteristics can be selected to focus on specific areas of analysis. Further research is recommended to develop a set of parameters that can be used in developing a model to focus on the prediction of crashes at and around intersections.

7.4.2 Continued Methodology Development

The purpose of the enhanced methodology is intended to provide a systematic approach for accomplishing the first three steps of the framework for highway safety mitigation, including the use of roadway attributes. For this framework to be fully utilized, a methodology would need to be developed for the remaining steps within the “Implement Cost Effective Countermeasures” subcategory (i.e., economic appraisal and project prioritization). Further research is recommended to develop a methodology for these steps.

7.4.3 Implementation on a National Level

The purpose of developing and improving the data preparation processes is intended to provide a step by step procedure that can take the data in various forms and produce a single dataset that can be used in the both the parameter selection model, as were the crash models. With the creation of these processes, additional crash data in other forms could be formatted into a dataset that could be used in the models. Further research is recommended to gather and evaluate the national crash data provided by other states for use in the crash models.

7.4.4 Development of a GUI for the Model Interface

The purpose in developing the parameter selection model and the predictive crashes model was to use statistical methods to determine and locate areas where further analysis could be performed to improve the safety of the roadway system. For these models to be fully utilized, they should incorporate user-friendly methods for adding data and running the models to produce the desired results. Further research is recommended to develop a user-friendly GUI for adding the crash data and running the models.

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LIST OF ACRONYMS

3D	Three-Dimensional
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AGRC	Automated Geographic Reference Center
BSJ	Bayesian Spatial Joint
BYU	Brigham Young University
CAR	Conditionally Autoregressive
CARS	Centralized Accident Records System
CMF	Crash Modification Factor
CPM	Crash Prediction Model
CRF	Crash Reduction Factor
CSV	Comma Separated Variable
DIC	Deviance Information Criterion
DOT	Department of Transportation
DUI	Driving Under the Influence
DWI	Driving While Intoxicated
EB	Empirical Bayesian
FHWA	Federal Highway Administration

GIS	Geographic Information System
GPS	Global Positioning Systems
GUI	Graphical User Interface
HAL	High Accident Location
HSIS	Highway Safety Information System
HSM	Highway Safety Manual
IPM	Intersections Per Mile
LiDAR	Light Detection and Ranging
LRS	Linear Referencing System
LT	Left-Turn
MCMC	Markov Chain Monte Carlo
MVN	Multivariate Normal
NB	Negative Binomial
NCHRP	National Cooperative Highway Research Program
NOAA	National Oceanic and Atmospheric Administration
PDO	Property Damage Only
PMM	Poisson Mixture Model
QR	Quantile Regression
ROR	Run-Off-Road
ROW	Right-of-Way
RT	Right-Turn
RTM	Regression to the Mean
SPF	Safety Performance Function

SPM	Signs Per Mile
TRB	Transportation Research Board
TWLTL	Two-Way Left-Turn Lanes
UCPM	Utah Crash Prediction Model
UCSM	Utah Crash Severity Model
UDOH	Utah Department of Health
UDOT	Utah Department of Transportation
UDPS	Utah Department of Public Safety
UTA	Utah Transit Authority
VBA	Visual Basic for Applications
VMT	Vehicle Miles Traveled

APPENDIX A: BLANK ANALYSIS REPORTS

A-1 Hot Spot Analysis

Safety Analysis on Hot Spot Segments

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

This section is for information on the hot spot segment and the sub-segments from the sliding scale analysis. Provide first the main segment data, and then use the table for the individual micro segments. If no micro segments are noted delete the table.

Table 1: Segment Metadata

Road Name:		**UCP Model Used:**	
Road Direction:		**Ranking from Model:**	
Beginning Mile Point:		**UDOT Region:**	
Ending Mile Point:		**County:**	
Dates of Data Source:		**Date of Analysis:**	

Table 2: Segment Characteristics

Function Class:		**AADT:**	
Number of Thru Lanes:		**Speed Limit (MPH):**	

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length

Micro Analysis

Crash Data

The crash data should be presented in the following tables. Each table has unique data requirements that need to be filled in from their respective datasets. The count and severity table needs the total counts for the segment as well as the sub-segments. The crash and vehicle table should contain the descriptive lists of the data requested in the table. Please do not use the codes found in the dataset, use the written description. For the roll-up table the headers are just examples please select and add the attributes that are of significance to the segment being analyzed. Input the "Y" or "N" and count/total.

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank

Table 5: Data from Crash and Vehicle Files

Crash ID	Sub-Segment	First Harmful Event	Manner of Collision	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver

Table 6: Data from Roll-Up File

Crash ID	Sub-Segment	Speed Related	Intersection Related	Roadway Geometry	Teenage Driver	Older Diver	Aggressive Driving	DUI	Drowsy Driving
Micro Total									
Micro Total									
Segment Total									

Current Conditions and Historical Perspective

This section is a written review of data that you have found on the area of analysis. This section should include a brief review of any changes made during the study period and general conditions of the area as they currently exist. Mention items that may have a relation to the crash analysis. Typically this information is gathered through internet tools such as, Google Earth and Roadview Explorer.

Site Visit

This section is a written description of items and characteristic of the roadway, surroundings and driver behavior that were observed during a site visit. Items should be listed that may have an effect on crashes.

Segment Definition

This section is to define the segment of concern. The segment of concern can be the entire segment or one or many micro segments. This includes a clear definition of location that can refer back to the metadata section and includes roadway characteristics and other data to fully understand the problem area. The table headers are examples. Add information of existing characteristics. Provide some written definition.

Table 7: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble

Problem Definition

This section includes the problem related to crashes at the segment. If the analysis is done correctly there should be clear evidence of the problem. This may include types of crashes and the sequence of events during the crash. Include in this section the possible causes; this will typically be crash attributes and road characteristics.

Countermeasures

Evaluation

This section includes a list of possible countermeasures that are problem specific that might be employed at the problem site.

Selection and Recommendation

This section includes a list of suggested countermeasures for implementation at the site. This list should be created as a subset of the Evaluation List, based on a feasibility review of each countermeasure.

A-2 Hot Spot Analysis Report

Safety Analysis on Hot Spots Report

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

This section is for information on the hot spot segment and the sub-segments from the sliding scale analysis. Provide first the main segment data, and then use the table for the individual micro segments. If no micro segments are noted delete the table.

Table 1: Segment Metadata

Road Name:	____________	**UCP Model Used:**	____________
Road Direction:	____________	**Ranking from Model:**	____________
Beginning Mile Point:	____________	**UDOT Region:**	____________
Ending Mile Point:	____________	**County:**	____________
Dates of Data Source:	____________	**Date of Analysis:**	____________

Table 2: Segment Characteristics

Functional Class:	____________	**AADT:**	____________
Number of Thru Lanes:	____________	**Speed Limit (MPH):**	____________

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length

Micro Analysis

Crash Data

The crash data should be presented in the following table. Each table has unique data requirements that need to be filled in from their respective datasets. The count and severity table needs the total counts for the segment as well as the sub-segments.

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank

Current Conditions and Historical Perspective

This section is a written review of data that you have found on the area of analysis. This section should include a brief review of any changes made during the study period and general conditions of the area as they currently exist. Mention items that may have a relation to the crash analysis. Typically this information is gathered through internet tools such as, Google Earth and Roadview Explorer and visits to the site.

Segment Definition

This section is to define the segment of concern. The segment of concern can be the entire segment or one or many micro segments. This includes a clear definition of location that can refer back to the metadata section and includes roadway characteristics and other data to fully understand the problem area. The table headers are examples. Add information of existing characteristics. Provide some written definition.

Table 5: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble

Problem Definition

This section includes the problem related to crashes at the segment. If the analysis is done correctly there should be clear evidence of the problem. This may include types of crashes and the sequence of events during the crash. Include in this section the possible causes; this will typically be crash attributes and road characteristics.

Countermeasures Recommendations

This section includes a list of suggested countermeasures for implementation at the site. This list should be created as a subset of the Evaluation List, based on a feasibility review of each countermeasure.

APPENDIX B: SUPPLEMENTAL HOT SPOT ANALYSIS REPORTS

B-1 US-89 from Milepost 388.438 to Milepost 389.123 Analysis

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spot Segments

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	US-89	**UCP Model Used:**	Prediction Model
Road Direction:	Positive	**Ranking from Model:**	1
Beginning Mile Point:	388.438	**UDOT Region:**	2
Ending Mile Point:	389.123	**County:**	Davis
Dates of Data Source:	2008-2012	**Date of Analysis:**	5/5/2015

Table 2: Segment Characteristics

Function Class:	Other Principal Arterial	**AADT:**	15,945
Number of Thru Lanes:	4	**Speed Limit (MPH):**	40

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	388.438	389.123	0.685

Micro Analysis

Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
388.438-389.123	37	0	3	34	1

Table 5: Data from Crash and Vehicle Files

Crash ID	Sub-Segment	First Harmful Event	Manner of Collision	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver

10203674	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Left, Straight Ahead
10212775	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead
10227297	1	N/A	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Left, Straight Ahead
10227406	1	Motor Vehicle in Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Stopped in Traff
10228952	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, ROR Right, Other Post/Pole/Support, Fence	Motor Vehicle in Transport	Turning Left, Straight Ahead
10232600	1	Motor Vehicle in Transport	Head On	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Left, Straight Ahead
10260276	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead
10260997	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Left, Straight Ahead
10261121	1	Pedestrian	N/A	Pedestrian, N/A, N/A, N/A	Pedestrian	Straight Ahead
10262856	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead
10303853	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Turning Left
10319620	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Left, Straight Ahead
10328368	1	Motor Vehicle in Transport	N/A	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Left, Straight Ahead
10331126	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Turning Left
10337782	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead
10370941	1	Motor Vehicle in Transport	Head On	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Left, Straight Ahead
10382436	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Left, Straight Ahead
10384790	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, Concrete Barrier, N/A, N/A	Motor Vehicle in Transport	Turning Left, Straight Ahead
10389925	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Turning Left
10389964	1	Motor Vehicle in Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Stopped in Traffic
10406198	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Left, Straight Ahead
10408956	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Left, Straight Ahead
10409204	1	Pedalcycle	N/A	Pedalcycle, N/A, N/A, N/A	Pedalcycle	Entering Traffic Lane
10410824	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Left, Straight Ahead
10410832	1	Motor Vehicle in Transport	Sideswipe Same Direction	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Left, Turning Left
10416536	1	Pedestrian	N/A	Operating Motor Vehicle, N/A, N/A, N/A	Pedestrian	Straight Ahead
10419827	1	Fell/Jumped from Motor Vehicle	Angle	Operating Motor Vehicle, Fell/Jumped from Motor Vehicle, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Other
10421647	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead
10423288	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Right, Straight Ahead

10426090	1	Motor Vehicle in Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Stopped in Traffic
10441308	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Turning Left, Straight Ahead
10494116	1	Motor Vehicle in Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Stopped in Traffic
10500495	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, Utility Pole/Light Support, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead
10500902	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead, Stopped in Traffic
10502198	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, Utility Pole/Light Support, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead
10515444	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, Other Non-Collision	Motor Vehicle in Transport	Straight Ahead, Stopped in Traffic, Turning Left
10517631	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead

Table 6: Data from Roll-Up File

Crash ID	Sub-Segment	Intersection Related	Teenage Driver	Older Driver	Light Conditions	DUI	Pedestrian Involved	Adverse Roadway Surface Condition	Adverse Weather
10203674	1	Y	N	N	N	N	N	Y	Y
10212775	1	Y	N	N	N	N	N	N	N
10227297	1	Y	N	N	N	Y	N	N	N
10227406	1	Y	Y	N	N	N	N	N	N
10228952	1	N	N	Y	N	N	N	N	N
10232600	1	Y	Y	N	Y	N	N	N	N
10260276	1	N	N	N	N	N	N	Y	Y
10260997	1	Y	N	Y	N	N	Y	N	N
10261121	1	Y	N	N	N	N	N	N	N
10262856	1	N	N	Y	N	N	N	Y	N
10303853	1	Y	N	N	N	N	N	N	N
10319620	1	Y	N	N	N	N	N	N	N
10328368	1	N	N	Y	N	N	N	N	N
10331126	1	N	Y	N	N	N	N	N	N
10337782	1	N	N	N	Y	Y	N	N	N
10370941	1	Y	Y	N	Y	N	N	N	N
10382436	1	N	N	Y	N	N	N	N	N
10384790	1	Y	N	Y	N	N	N	N	N
10389925	1	Y	N	N	N	N	N	N	N
10389964	1	N	N	N	N	N	N	N	N
10406198	1	Y	N	Y	N	N	N	N	N
10408956	1	N	Y	N	N	N	N	N	N
10409204	1	Y	N	N	N	N	N	N	N
10410824	1	N	N	N	N	N	N	N	N
10410832	1	N	N	N	N	N	Y	N	N
10416536	1	N	N	N	N	N	N	N	N
10419827	1	Y	N	Y	N	N	N	N	N
10421647	1	N	N	N	Y	N	N	N	N
10423288	1	N	Y	N	N	N	N	Y	Y
10426090	1	N	N	N	N	N	N	N	N
10441308	1	N	N	N	N	N	N	N	N
10494116	1	N	N	N	N	N	N	N	N
10500495	1	Y	N	N	N	N	N	N	N

10500902	1	Y	N	N	Y	N	N	N	N
10502198	1	Y	N	N	N	N	N	N	N
10515444	1	Y	Y	Y	N	N	N	N	N
10517631	1	Y	N	N	N	N	N	Y	Y
Segment Total		20/37	7/37	9/37	6/37	2/37	2/37	4/37	3/37

Current Conditions and Historical Perspective

This segment of US-89 (500 W) is located between Bountiful and West Bountiful in Utah. It was observed that between mile post 388.428 and 389.123 is an Other Principal Arterial through Bountiful. This section of roadway is two lanes of travel in each direction, with a two-way left turn lane (TWLTL) dividing the two lanes. This segment has curb and gutter, with no on-street parking offered. Figure 1 below is an aerial image from Google Earth, showing the problem segment. Roadview Explorer was used for the analysis of US-89 to determine if there were changes made. The analysis showed no changes between 2010 and 2012.

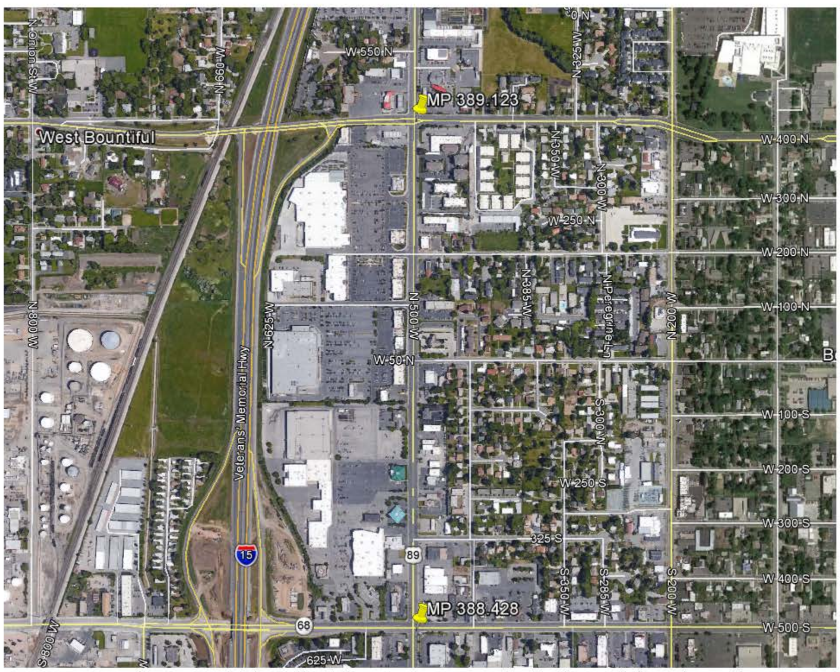


Figure 1: Aerial view of problem segment near Salt Lake City, Utah (Google Earth).

Site Visit

A visit was made in the hot spot on US-89. It was observed that there were many businesses along the area with multiple entrances to the commercial complexes. The segment has three signalized intersection (with traffic lights), two 4-leg and one 3-leg intersection. There are two lanes in each direction, a two-way left turn center lane, and no shoulder. There are sidewalks on both sides of the road and no medians. The speed limit is 40 mph. The intersection at 400 S with 500 W has yield on green left turn lights, and the intersection at 500 S 500 W has yellow flashing lights to turn left. Sometimes there are green left turn arrows for the approaches. Construction was happening at the time of the visit.

Segment Definition

This segment of US-89 is very flat with no horizontal or vertical curvature. The lane configuration is constant throughout the segment, with a two-way, left turn lane dividing the traffic flow for access to local businesses. There is no bike lane or on street parking along this segment. Although there aren't any major intersections between mile post 388.428 and 389.123, there are many access points for businesses located along this arterial. The sidewalk is set back about 3 feet from the top back of curb. There are few light poles along the segment. Table 7 provides a summary of the characteristics of the roadway.

Table 7: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	No	2/2.92	28/40.88	0', Curb and Gutter	No	No	4	No	No

Problem Definition

The safety problem along the segment of US 89 is an excess number of angles crashes at nearby intersections. While few were fatal, many of the crashes resulted in an injury to drivers and damage to vehicles. Based on the data provided in Table 6, possible contributing factors are conflicts at intersections, older drivers, younger drivers, and light conditions.

Countermeasures

Evaluation

The following is a list of possible countermeasures for implementation of the problem segment along US 89 in Bountiful, Utah. The countermeasures listed are specific to the problem and not the site, and were compiled using the countermeasure matrices found in the NCHRP 500 Reports. The list is based on crashes related to intersections and light conditions.

- Employ multiphase signal operation
- Optimize clearance intervals
- Restrict or eliminate turning maneuvers (including right turns on red)
- Employ signal coordination along a corridor or route
- Provide/improve left turn channelization
- Provide/improve right turn channelization
- Improve geometry of pedestrians and bicycle facilities
- Implement automated enforcement of red light running
- Restrict access to properties using driveways closures or turn restrictions
- Restrict cross median access near intersections
- Improve lighting near intersections and access points

Selection and Recommendation

The following provides a list of suggested countermeasures for implementation at the hot spot segment on US 89, based on the problem spot identification and analysis methodology.

- Employ multiphase signal operation
- Optimize clearance intervals
- Restrict or eliminate turning maneuvers (including right turns on red)
- Employ signal coordination along a corridor or route
- Implement automated enforcement of red light running
- Restrict access to properties using driveways closures or turn restrictions
- Restrict cross median access near intersections
- Improve lighting near intersections and access points

B-2 US-89 from Milepost 388.438 to Milepost 389.123 Report

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spots Report

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	US-89	**UCP Model Used:**	Prediction Model
Road Direction:	Positive	**Ranking from Model:**	1
Beginning Mile Point:	388.438	**UDOT Region:**	2
Ending Mile Point:	389.123	**County:**	Davis
Dates of Data Source:	2008-2012	**Date of Analysis:**	5/5/2015

Table 2: Segment Characteristics

Function Class:	Other Principal Arterial	**AADT:**	15,945
Number of Thru Lanes:	4	**Speed Limit (MPH):**	40

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	388.438	389.123	0.685

Micro Analysis

Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
388.438-389.123	37	0	3	34	1

Current Conditions and Historical Perspective

This segment of US-89 (500 W) is located between Bountiful and West Bountiful in Utah. It was observed that between mile post 388.428 and 389.123 is an Other Principal Arterial through Bountiful. This section of roadway is two lanes of travel in each direction, with a two-way left turn lane (TWLTL) dividing the two lanes. This segment has curb and gutter, with no on-street parking offered. The figure below is an aerial image from Google Earth, showing the problem segment. Roadview Explorer was used for the analysis of US-89 to determine if there were changes made. The analysis showed no changes between 2010 and 2012.

Segment Definition

This segment of US-89 is very flat with no horizontal or vertical curvature. The lane configuration is constant throughout the segment, with a two-way, left turn lane dividing the traffic flow for access to local businesses. There is no bike lane or on street parking along this segment. Although there aren't any major intersections between mile post 388.428 and 389.123, there are many access points for businesses located along this arterial. The sidewalk is set back about 3 feet from the top back of curb. There are few light poles along the segment. Table 5 provides a summary of the characteristics of the roadway.

Table 5: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	lanes	Wall/Barrier	Rumble
1	No	2/2.92	28/40.88	0', Curb and Gutter	No	No	4	No	No

Problem Definition

The safety problem along the segment of US 89 is an excess number of angles crashes at nearby intersections. While few were fatal, many of the crashes resulted in an injury to drivers and damage to vehicles. Based on the data provided in Error! Reference source not found., possible contributing factors are conflicts at intersections, older drivers, younger drivers, and light conditions.

Countermeasures Recommendations

The following provides a list of suggested countermeasures for implementation at the hot spot segment on US 89, based on the problem spot identification and analysis methodology.

- Employ multiphase signal operation
- Optimize clearance intervals
- Restrict or eliminate turning maneuvers (including right turns on red)
- Employ signal coordination along a corridor or route
- Implement automated enforcement of red light running
- Restrict access to properties using driveways closures or turn restrictions
- Restrict cross median access near intersections
- Improve lighting near intersections and access points

B-3 I-15 from Milepost 250.923 to Milepost 253.557 Analysis

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spot Segments

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	I-15	**UCP Model Used:**	Prediction Model
Road Direction:	Positive	**Ranking from Model:**	2
Beginning Mile Point:	250.923	**UDOT Region:**	3
Ending Mile Point:	253.557	**County:**	Utah
Dates of Data Source:	2008-2012	**Date of Analysis:**	5/5/2015

Table 2: Segment Characteristics

Function Class:	Interstate	**AADT:**	44,185
Number of Thru Lanes:	4	**Speed Limit (MPH):**	75

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	250.923	253.557	2.634

Micro Analysis

Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
250.923-253.557	28	1	6	21	2

Table 5: Data from Crash and Vehicle Files

Crash ID	Sub-Segment	First Harmful Event	Manner of Collision	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
10106912	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, Operating Motor Vehicle,	Motor Vehicle in Transport	Other, Straight Ahead, Straight Ahead, Straight

				Crossed Median/Centerline, Operating Motor Vehicle		Ahead
10205918	1	Overturn/Rollover	N/A	RAN Left, Crossed Median/Centerline, Overturn/Rollover, N/A	Overturn/Rollover	Straight Ahead
10206399	1	Motor Vehicle In Transport	Angle	Crossed Median/Centerline, Other Fixed Object, Crossed Median/Centerline, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead, Straight Ahead
10206760	1	Overturn/Rollover	N/A	ROR Left, ROR Right, Crossed Median/Centerline, Fence	Overturn/Rollover	Straight Ahead
10206793	1	Motor Vehicle In Transport	Angle	ROR Left, Operating Motor Vehicle, Guardrail, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead
10207001	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Slowing In Traffic Lane, Stopped in Traffic Lane
10260777	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Slowing In Traffic Lane, Stopped in Traffic Lane
10260783	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead
10266004	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Slowing in Traffic Lane
10266016	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Stopped in Traffic Lane
10284788	1	Other Fixed Object	Front to Rear	Other Fixed Object, Guardrail, N/A, N/A	Other Fixed Object	Straight Ahead, Straight Ahead
10286279	1	N/A	Front to Rear	ROR Left, Overturn/Rollover, N/A, N/A	Overturn/Rollover	Straight Ahead
10287051	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, Operating Motor Vehicle, N/A, N/A	Motor Vehicle in Transport	Slowing in Traffic Lane, Slowing in Traffic Lane, Stopped in Traffic Lane, Stopped in Traffic Lane
10289188	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, overturn/Rollover, Other Post/Pole/Support, Fence	Overturn/Rollover	Straight Ahead, Straight Ahead
10289345	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Slowing in Traffic Lane, Slowing in Traffic Lane
10289933	1	Other Fixed Object	Front to Rear	Other Fixed Object, N/A, N/A, N/A	Other Fixed Object	Straight Ahead, Stopped in Traffic Lane
10292820	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, Operating Motor Vehicle, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead, Slowing in Traffic Lane
10292860	1	Motor Vehicle In	Front to Rear	Operating Motor	Motor Vehicle in	Slowing in Traffic

		Transport		Vehicle, N/A, N/A, N/A	Transport	Lane, Slowing in Traffic Lane
10294725	1	Overturn/Rollover	N/A	Overturn/Rollover, N/A, N/A, N/A	Overturn/Rollover	Straight Ahead
10333273	1	Overturn/Rollover	N/A	ROR Right, Overturn, Rollover, N/A, N/A	Overturn/Rollover	Straight Ahead
10378033	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Slowing in Traffic Lane
10387375	1	Motor Vehicle In Transport	Sideswipe Same Direction	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Overtaking/Passing, Straight Ahead
10410515	1	Animal – Wild	N/A	Animal – Wild, N/A, N/A, N/A	Animal – Wild	Straight Ahead
10414180	1	Overturn/Rollover	N/A	ROR Left, ROR Right, Crossed Overturn/ Rollover, N/A	Overturn/Rollover	Straight Ahead
10428270	1	Overturn/Rollover	N/A	ROR Right, Overturn/Rollover, N/A, N/A	Overturn/Rollover	Straight Ahead
10451543	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Stopped in Traffic Lane
10460508	1	Cable Barrier	N/A	Operating Motor Vehicle, ROR Left, Crossed Median/Centerline, Access Control Cable	Cable Barrier	Straight Ahead, Straight Ahead
10488478	1	Traffic Sign Support	N/A	ROR Right, Traffic Sign Support, Delineator Post, Overturn/Rolover	Overturn/Rollover	N/A

Table 6: Data from Roll-Up File

Crash ID	Sub-Segment	Interstate Highway	Roadway Geometry	Roadway Departure	Overturn/Rollover	Speed Related	Adverse Road Surface Conditions	Adverse Weather	Single Vehicle
10106912	1	Y	N	N	N	N	N	N	N
10205918	1	Y	N	Y	Y	N	N	N	Y
10206399	1	Y	N	Y	Y	Y	Y	N	N
10206760	1	Y	N	Y	Y	N	N	N	Y
10206793	1	Y	N	Y	Y	Y	Y	Y	N
10207001	1	Y	Y	N	N	N	N	N	N
10260777	1	Y	Y	N	N	N	N	N	N
10260783	1	Y	Y	N	N	N	N	N	N
10266004	1	Y	N	N	N	N	N	N	N
10266016	1	Y	N	N	N	N	N	N	N
10284788	1	Y	Y	Y	Y	N	N	N	N
10286279	1	Y	Y	Y	Y	Y	Y	Y	Y
10287051	1	Y	N	N	N	N	N	N	N
10289188	1	Y	N	N	N	N	N	N	N
10289345	1	Y	N	N	N	N	N	N	N
10289933	1	Y	Y	Y	Y	N	N	N	N
10292820	1	Y	Y	N	N	N	N	N	N
10292860	1	Y	Y	N	N	N	N	N	N
10294725	1	Y	Y	N	N	Y	Y	Y	Y
10333273	1	Y	N	Y	Y	N	Y	Y	Y
10378033	1	Y	N	N	N	N	N	N	N
10387375	1	Y	N	N	N	Y	Y	Y	N

10410515	1	Y	N	N	N	N	N	N	Y
10414180	1	Y	Y	Y	Y	N	N	N	Y
10428270	1	Y	Y	Y	Y	Y	Y	Y	Y
10451543	1	Y	Y	N	N	Y	Y	Y	N
10460508	1	Y	Y	Y	Y	N	N	N	N
10488478	1	Y	N	Y	Y	Y	N	N	Y
Segment Total		28/28	13/28	12/28	9/28	8/28	8/28	7/28	9/28

Current Conditions and Historical Perspective

This segment of I-15 is located near Payson, Utah. It was observed that between mile post 250.921 and 253.557 is an Interstate Highway. Between 2008 and 2012, this section of roadway was 4 lanes, with two lanes in each direction, with a barrier separated median dividing the flow of traffic. As of 2012, this segment had about 10 feet of asphalt on the right shoulder. Roadview Explorer was used for the analysis of I-15 to determine if there changes made. The analysis showed that the lanes had been expanded from 4 lanes to 6 lanes between 2012 and 2014. Images from 2014 in Roadview Explorer show the extra lane being between the existing lanes, narrowing the width of the median. Figure 1 show an aerial view of the problem segment.

Figure 1: Aerial view of problem segment near Payson, Utah (Google Earth).

Site Visit

A site visit was made to the hot spot on I-15 (MP 250.9 – MP 253.6) in Payson. The purpose of this site visit was to examine the condition of the roadway and to determine the quality of the signage and barriers. This section is a 6-lane freeway, with 3 lanes in each direction. It seems that many of the accidents took place when this was a 4-lane freeway, with only 2 lanes in each direction. It was observed that it was a mostly straight section, with very gentle curves. For the first mile of the section (MP 250.9-252), there was a noise wall on the right side of the freeway. It appeared that the signage was clear and easy to read. The road markings were also very clear, and there was a rumble strip on the right and left sides. There was an 8 ft. shoulder on the right and the left. There was a cable barrier on the left side of the freeway. The last mile of the section (MP 252.5 – MP 253.6) had a steep drop-off on the right side of the freeway.

Segment Definition

This segment of I-15 is very flat, with no horizontal or vertical curvature. The Lane configuration is constant throughout the segment, with a cable barrier in the median, to divide the flow of traffic. There is adequate way finding signs along the corridor. There are rumble strips installed along the length of the segment. There are a few W-beams located near merge areas, rivers, and streams which the interstate passes over. Table 7 provides a summary of the characteristics of the roadway segment.

Table 7: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	Separate Grade	0/0.0	21/8.08	10', Asphalt	No	No	6	W-Beam Barrier	Yes

Problem Definition

The safety problem along this segment is I-15 is an excess number of roadway departures and overturn/rollover vehicles. Although only one crash was fatal, twenty one of the crashes resulted in some injury to the driver and/or passengers. Based on the data provided in Table 6, possible contributing factors are roadway geometry, speed, adverse road surface conditions, and adverse weather.

Countermeasures

Evaluation

The following is a list of possible countermeasures for implementation of the problem segment along I-15 near Payson, Utah. The countermeasures listed are specific to the problem and not the site, and were compiled using the countermeasure matrices found in the NCHRP 500 Reports. The list is based on crashes related to crashes related to speed and roadway departures.

- Provide enhanced pavement marking
- Apply shoulder treatments like eliminating shoulder drop off or widening shoulders
- Design safer slopes and ditches to prevent rollovers
- Improve design of roadway hardware

- Install variable message signs about adverse weather
- Implement active speed warning signs
- Strengthen the adjudication of speeding citations to enhance the deterrent effects of fines
- Use targeted conventional speed enforcement programs at locations known to have speeding related crashes
- Install lighting at high speed intersections

Selection and Recommendation

The following provides a list of suggested countermeasure for implementation at the problem segment of I-15, based on the problem spot identification and analysis methodology.

- Design safer slopes and ditches to prevent rollovers
- Improve design of roadway hardware
- Install variable message signs about adverse weather
- Implement active speed warning signs
- Install lighting at high speed interchanges

B-4 I-15 from Milepost 250.923 to Milepost 253.557 Report

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spots Report

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	I-15	**UCP Model Used:**	Prediction Model
Road Direction:	Positive	**Ranking from Model:**	2
Beginning Mile Point:	250.923	**UDOT Region:**	3
Ending Mile Point:	253.557	**County:**	Utah
Dates of Data Source:	2008-2012	**Date of Analysis:**	5/5/2015

Table 2: Segment Characteristics

Function Class:	Interstate	**AADT:**	44,185
Number of Thru Lanes:	4	**Speed Limit (MPH):**	75

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	250.923	253.557	2.634

Micro Analysis

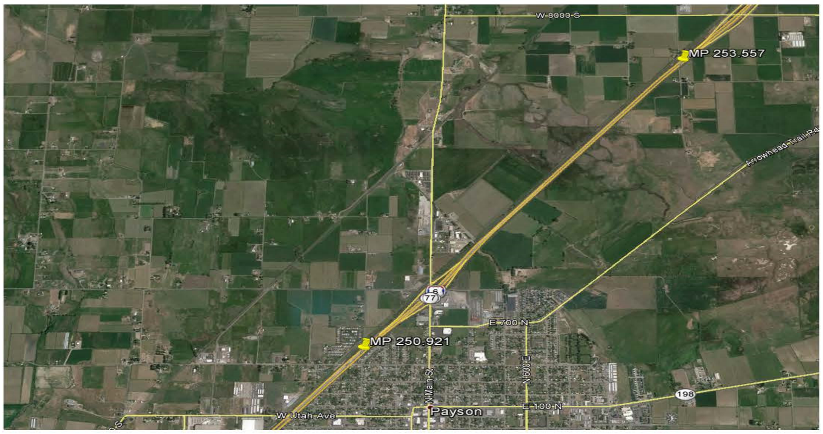
Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
250.923-253.557	28	1	6	21	2

Current Conditions and Historical Perspective

This segment of I-15 is located near Payson, Utah. It was observed that between mile post 250.921 and 253.557 is an Interstate Highway. Between 2008 and 2012, this section of roadway was 4 lanes, with two lanes in each direction, with a barrier separated median dividing the flow of traffic. As of 2012, this segment had about 10 feet of asphalt on the right shoulder. Roadview Explorer was used for the analysis of I-15 to determine if there changes made. The analysis showed that the lanes had been expanded from 4 lanes to 6 lanes between 2012 and 2014. Images from 2014 in Roadview Explorer show the extra lane being between the existing lanes, narrowing the width of the median. The figure shows an aerial view of the problem segment.



Segment Definition

This segment of I-15 is very flat, with no horizontal or vertical curvature. The Lane configuration is constant throughout the segment, with a cable barrier in the median, to divide the flow of traffic. There is adequate way finding signs along the corridor. There are rumble strips installed along the length of the segment. There are a few W-beams located near merge areas, rivers, and streams which the interstate passes over. Table 5 provides a summary of the characteristics of the roadway segment.

Table 5: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	Separate Grade	0/0.0	21/8.08	10', Asphalt	No	No	6	W-Beam Barrier	Yes

Problem Definition

The safety problem along this segment is I-15 is an excess number of roadway departures and overturn/rollover vehicles. Although only one crash was fatal, twenty one of the crashes resulted in some injury to the driver and/or passengers. Based on the data provided in **Error! Reference source not found.**, possible contributing factors are roadway geometry, speed, adverse road surface conditions, and adverse weather.

Countermeasures Recommendations

The following provides a list of suggested countermeasure for implementation at the problem segment of I-15, based on the problem spot identification and analysis methodology.

- Design safer slopes and ditches to prevent rollovers
- Improve design of roadway hardware
- Install variable message signs about adverse weather
- Implement active speed warning signs
- Install lighting at high speed interchanges

B-5 US-89 from Milepost 415.425 to Milepost 415.994 Analysis

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spot Segments

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	US-89	**UCP Model Used:**	Prediction Model
Road Direction:	Positive	**Ranking from Model:**	3
Beginning Mile Point:	415.524	**UDOT Region:**	1
Ending Mile Point:	415.994	**County:**	Weber
Dates of Data Source:	2008-2012	**Date of Analysis:**	5/5/2015

Table 2: Segment Characteristics

Function Class:	Other Principal Arterial	**AADT:**	27,640
Number of Thru Lanes:	6	**Speed Limit (MPH):**	35

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	415.524	415.994	0.569

Micro Analysis

Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
415.524-415.994	35	0	8	27	3

Table 5: Data from Crash and Vehicle Files

Crash ID	Sub-Segment	First Harmful Event	Manner of Collision	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
10200386	1	N/A	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Left, Straight Ahead
10200685	1	Motor Vehicle In	Angle	Operating Motor	Motor Vehicle In	Turning Left,

		Transport		Vehicle, N/A, N/A, N/A	Transport	Straight Ahead
10208110	1	Motor Vehicle In Transport	Head On	Operating Motor Vehicle, Crossed Median/Centerline, N/A, N/A	Motor Vehicle In Transport	Leaving Traffic Lane, Straight Ahead, Straight Ahead
10217463	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, No Damage to Vehicle, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Slowing in Traffic Lane, N/A
10221650	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Stopped in Traffic Lane, Stopped in Traffic Lane
10232450	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Stopped in Traffic Lane, Stopped in Traffic Lane
10237010	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, Operating Motor Vehicle, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Stopped in Traffic Lane, Stopped in Traffic Lane
10266839	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, Operating Motor Vehicle, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Stopped in Traffic Lane, Stopped in Traffic Lane, Stopped in Traffic Lane
10267817	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Turning Left
10268794	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Right, Straight Ahead
10305477	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Right, Stopped in Traffic Lane
10308020	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Left, Turning Right
10317131	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle , Operating Motor Vehicle, Operating Motor Vehicle, Operating Motor Vehicle	Motor Vehicle In Transport	Slowing in Traffic Lane, Stopped in Traffic Lane, Slowing in Traffic Lane, Slowing in Traffic Lane, Straight Ahead
10317378	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Stopped in Traffic Lane
10317581	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Stopped in Traffic Lane, Stopped in Traffic Lane
10321248	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Left, Straight Ahead
10331686	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Left, Turning Right
10332310	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Right, Straight Ahead
10339197	1	Tree/Shrubbery	N/A	ROR Right, Tree/Shrubbery, Utility Pole/Light/Support, Other Fixed Object	Other Fixed Object	Straight Ahead
10340260	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Straight Ahead
10363828	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Left, Straight Ahead
10401662	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Left, Straight Ahead

10404249	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Stopped in Traffic lane
10406035	1	Motor Vehicle In Transport	Head On	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Left, Turning Left
10440281	1	Pedalcycle	N/A	Pedalcycle, N/A, N/A, N/A	Pedalcycle	Straight Ahead
10447838	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Stopped in Traffic Lane
10503029	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Left, Straight Ahead
10509282	1	Tree/Shrubbery	N/A	Tree/Shrubbery, Operating Motor Vehicle, Operating Motor Vehicle, Operating Motor Vehicle	Motor Vehicle In Transport	Straight Ahead, Stopped in Traffic Lane, Stopped in Traffic Lane
10530082	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Left, Turning Left
10536766	1	Motor Vehicle In Transport	Head On	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Left, Straight Ahead
10537186	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Turning Left, Straight Ahead
10540698	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Straight Ahead
10541555	1	Pedalcycle	N/A	23 96 96 96	Pedalcycle	Straight Ahead
10548304	1	Motor Vehicle In Transport	Front to Rear	Operating Motor Vehicle, Operating Motor Vehicle, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Stopped in Traffic Lane, Stopped in Traffic Lane
10549354	1	Motor Vehicle In Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle In Transport	Straight Ahead, Straight Ahead

Table 6: Data from Roll-Up File

Crash ID	Sub-Segment	Intersection Related	Teenage Driver	Older Driver	Light Conditions	Adverse Roadway Surface Conditions	Adverse Weather	Improper Restraint	Speed Related
10200386	1	N	Y	N	N	N	N	Y	N
10200685	1	N	Y	N	N	N	N	Y	N
10208110	1	N	N	Y	N	N	N	Y	N
10217463	1	Y	N	Y	N	N	N	N	N
10221650	1	Y	N	N	N	Y	Y	N	Y
10232450	1	N	N	N	Y	Y	N	N	Y
10237010	1	Y	Y	N	Y	Y	N	N	Y
10266839	1	N	N	N	N	N	N	N	N
10267817	1	N	Y	Y	N	N	N	N	N
10268794	1	Y	N	N	Y	N	N	Y	N
10305477	1	N	Y	N	N	N	N	Y	N
10308020	1	Y	N	N	N	Y	Y	N	N
10317131	1	Y	N	Y	Y	N	N	N	N
10317378	1	Y	N	Y	N	N	N	N	N
10317581	1	N	Y	N	Y	N	Y	N	N
10321248	1	N	Y	N	Y	Y	Y	Y	Y
10331686	1	N	N	N	N	N	N	N	N
10332310	1	Y	N	N	N	N	N	N	N
10339197	1	Y	N	N	Y	N	N	N	N
10340260	1	Y	Y	N	Y	N	N	N	N
10363828	1	N	N	N	N	N	N	N	N
10401662	1	Y	Y	N	N	N	N	N	N
10404249	1	Y	N	Y	N	N	N	N	N
10406035	1	N	N	Y	N	N	N	N	N

10440281	1	Y	N	N	N	N	N	N	N
10447838	1	Y	N	N	N	N	N	N	N
10503029	1	Y	N	N	N	N	N	N	N
10509282	1	Y	Y	N	N	N	N	N	N
10530082	1	N	N	N	N	Y	Y	N	N
10536766	1	Y	Y	N	N	N	N	N	N
10537186	1	Y	N	Y	N	Y	N	N	N
10540698	1	N	Y	N	N	N	N	Y	N
10541555	1	N	Y	N	N	N	N	Y	N
10548304	1	N	N	Y	N	N	N	Y	N
10549354	1	Y	N	Y	N	N	N	N	N
Segment Total		20/31	12/31	9/31	9/31	8/31	6/31	6/31	**4**/31

Current Conditions and Historical Perspective

This segment of US89 (Washington Blvd) is located in Odgen, Utah. It was observed that between mile post 415.524 and 415.994 is an Other Principal Arterial through Ogden. This section of roadway is has three lanes of travel in each direction, with a two-way, left turn lane (TWLTL) diving the two directions of traffic. This segment has on-street parking and right turn lanes to business lots and neighborhood streets. There is curb and gutter along this corridor. Figure 1 below is an aerial image from Google Earth, showing the extents of the problem segment. Roadview Explorer was used for the analysis of US-89 to determine if there were changes made. The analysis showed no significant changes to the roadway. It's important to note that the posted speed limit is 40 mph, not 35mph as suggested from the crash data

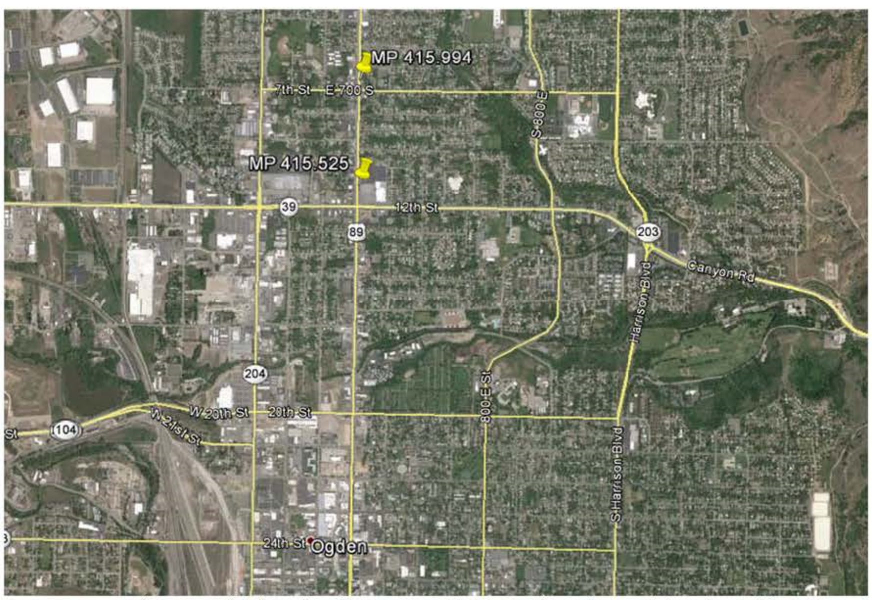


Figure 1: Aerial view of problem segment along US 89 in Ogden, Utah (Google Earth).

Site Visit

A site visit was made to the hot spot on US-89 in Ogden. The segment consists of 3 lanes in each direction with a two-way left turn center lane and parking spots of about 7 feet on both sides of the road. The segment is straight and flat. It was observed that the segment consists of commercial and residential areas with multiple entrances and driveways. The speed limit is 40 mph. There is only one traffic light intersection in the segment at 7th street and Washington Blvd. It was also observed that a low median exists from 7th street to the north of about 250 ft. separating the southbound left turn lane from the northbound lanes. This is the only median observed in the site.

Segment Definition

This segment of US-89 is very flat with no horizontal or vertical curvature. The lane configuration is constant throughout the segment, with a two-way, left turn lane dividing the traffic flow for access to local businesses. There is space for a right turn lane and on-street parking on the right shoulder of the road, although it switched between these functions frequently along the segment. Although there is on any major intersections in this segment, there are many access points for businesses located along this arterial, especially a large access point for a large shopping mall/complex. The sidewalk is set back about 4 feet from the top back of curb. There are a few light poles along the segment. Table 7 provides a summary of the characteristics of the roadway.

Table 7: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	No	1/1.76	14/24.61	0', Curb and Gutter	No	No	6	No	No

Problem Definition

The safety problem along the segment of US-89 is an excess number of angles crashes at nearby intersections. While there are no reported fatalities, the 31 crashes listed in this report resulted in injury to the driver or others. Based on the data provided in Table 6, possible contributing factors are conflicts at intersections, teenage drivers, older drivers, light conditions, adverse roadway surface conditions, and speeding.

Countermeasures

Evaluation

The following is a list of possible countermeasures for implementation of the problem segment along US-89 in Ogden, Utah. The countermeasures listed are specific to the problem and not the site, and were compiled using the countermeasure matrices found in the NCHRP 500 Reports. The list is based on crashes related to intersections and light conditions.

- Employ multiphase signal operation
- Optimize clearance intervals
- Restrict or eliminate turning maneuvers (including right turns on red)
- Employ signal coordination along a corridor or route

- Provide/improve left turn channelization
- Provide/improve right turn channelization
- Improve geometry of pedestrians and bicycle facilities
- Implement automated enforcement of red light running
- Restrict access to properties using driveways closures or turn restrictions
- Restrict cross median access near intersections
- Improve lighting near intersections and access points

Selection and Recommendation

The following provides a list of suggested countermeasures for implementation at the hot spot segment on US-89, based on the problem spot identification and analysis methodology.

- Employ multiphase signal operation
- Optimize clearance intervals
- Restrict or eliminate turning maneuvers (including right turns on red)
- Employ signal coordination along a corridor or route
- Implement automated enforcement of red light running
- Restrict access to properties using driveways closures or turn restrictions
- Restrict cross median access near intersections
- Improve lighting near intersections and access points

B-6 US-89 from Milepost 415.425 to Milepost 415.994 Report

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spots Report

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	US-89	**UCP Model Used:**	Prediction Model
Road Direction:	Positive	**Ranking from Model:**	3
Beginning Mile Point:	415.524	**UDOT Region:**	1
Ending Mile Point:	415.994	**County:**	Weber
Dates of Data Source:	2008-2012	**Date of Analysis:**	5/5/2015

Table 2: Segment Characteristics

Function Class:	Other Principal Arterial	**AADT:**	27,640
Number of Thru Lanes:	6	**Speed Limit (MPH):**	35

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	415.524	415.994	0.569

Micro Analysis

Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
415.524-415.994	35	0	8	27	3

Current Conditions and Historical Perspective

This segment of US89 (Washington Blvd) is located in Odgen, Utah. It was observed that between mile post 415.524 and 415.994 is an Other Principal Arterial through Ogden. This section of roadway is has three lanes of travel in each direction, with a two-way, left turn lane (TWLTL) diving the two directions of traffic. This segment has on-street parking and right turn lanes to business lots and neighborhood streets. There is curb and gutter along this corridor. **Error! Reference source not found.** below is an aerial image from Google Earth, showing the extents of the problem segment. Roadview Explorer was used for the analysis of US-89 to determine if there were changes made. The analysis showed no significant changes to the roadway. It's important to note that the posted speed limit is 40 mph, not 35mph as suggested from the crash data

Segment Definition

This segment of US-89 is very flat with no horizontal or vertical curvature. The lane configuration is constant throughout the segment, with a two-way, left turn lane dividing the traffic flow for access to local businesses. There is space for a right turn lane and on-street parking on the right shoulder of the road, although it switched between these functions frequently along the segment. Although there is on any major intersections in this segment, there are many access points for businesses located along this arterial, especially a large access point for a large shopping mall/complex. The sidewalk is set back about 4 feet from the top back of curb. There are a few light poles along the segment. Table 5 provides a summary of the characteristics of the roadway.

Table 5: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	No	1/1.76	14/24.61	0', Curb and Gutter	No	No	6	No	No

Problem Definition

The safety problem along the segment of US-89 is an excess number of angles crashes at nearby intersections. While there are no reported fatalities, the 31 crashes listed in this report resulted in injury to the driver or others. Based on the data provided in **Error! Reference source not found.**, possible contributing factors are conflicts at intersections, teenage drivers, older drivers, light conditions, adverse roadway surface conditions, and speeding.

Countermeasures Recommendations

The following provides a list of suggested countermeasures for implementation at the hot spot segment on US-89, based on the problem spot identification and analysis methodology.

- Employ multiphase signal operation
- Optimize clearance intervals
- Restrict or eliminate turning maneuvers (including right turns on red)
- Employ signal coordination along a corridor or route
- Implement automated enforcement of red light running
- Restrict access to properties using driveways closures or turn restrictions
- Restrict cross median access near intersections
- Improve lighting near intersections and access points

B-7 I-80 from Milepost 3.993 to Milepost 41.278 Analysis

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spot Segments

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	I-80	**UCP Model Used:**	Severity Model
Road Direction:	Positive	**Ranking from Model:**	1
Beginning Mile Point:	3.993	**UDOT Region:**	2
Ending Mile Point:	41.278	**County:**	Tooele
Dates of Data Source:	2008-2012	**Date of Analysis:**	3-30-2015

Table 2: Segment Characteristics

Function Class:	Interstate	**AADT:**	7345
Number of Thru Lanes:	4	**Speed Limit (MPH):**	75

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	3.993	41.278	37.285

Micro Analysis

Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
3.993-41.278	83	6	10	20	1

Table 5: Data from Crash and Vehicle Files

Crash ID	Sub-Segment	First Harmful Event	Manner of Collision	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
10189905	1	Overturn/Rollover	NA	ROR,Median,ROR,Rollover	Rollover	Straight Ahead
10161354	1	Unknown	NA	ROR,Median,ROR, Rollover	Rollover	Straight Ahead
10189196	1	Unknown	NA	Median,ROR,Rollover	Rollover	Straight Ahead
10202756	1	Overturn/Rollover	NA	ROR,Rollover	Rollover	Straight Ahead
10351160	1	Overturn/Rollover	NA	ROR,Rollover	Rollover	Straight Ahead
10230515	1	Overturn/Rollover	NA	Rollover	Rollover	Straight Ahead
10230509	1	Motor Vehicle	Sideswipe	Median,Crash Cushion	Crash	Overtaking/Passing

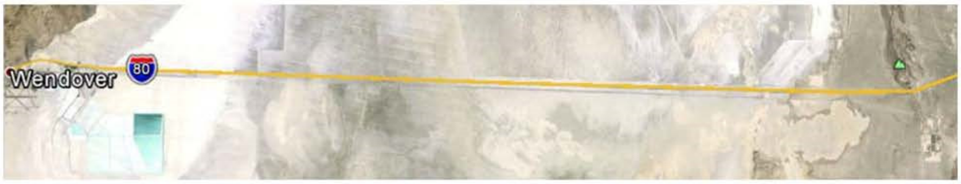
			Same		Cushion	
10286112	1	Unknown	NA	ROR,Median,ROR,Rollover	Rollover	Straight Ahead
10297616	1	Delineator Post	NA	ROR,Delineator,ROR,Rollover	Rollover	Straight Ahead
10340083	1	Overturn/Rollover	NA	ROR,Post,Rollover	Rollover	Straight Ahead
10362050	1	Motor Vehicle	Front to Rear	Motor Vehicle,ROR	Motor Vehicle	Turning Left
10387448	1	Overturn/Rollover	NA	ROR,Rollover	Rollover	Straight Ahead
10414963	1	Overturn/Rollover	NA	ROR,Equipment,Rollover	Rollover	Straight Ahead
10442316	1	Overturn/Rollover	NA	ROR,Rollover	Rollover	Straight Ahead
10448632	1	Overturn/Rollover	NA	ROR,Rollover	Rollover	Straight Ahead
10455345	1	Overturn/Rollover	NA	ROR,Rollover	Rollover	Straight Ahead

Table 6: Data from Roll-Up File

Crash ID	Sub-Segment	Speed Related	Overturn/ Rollover	Roadway Departure	Night Conditions	Single Vehicle	Improper Restraint	DUI	Drowsy Driving
10189905	1	N	Y	Y	Y	Y	Y	N	Y
10161354	1	N	Y	Y	N	Y	N	N	N
10189196	1	N	Y	Y	Y	Y	Y	N	N
10202756	1	Y	Y	Y	N	Y	N	N	N
10351160	1	Y	Y	Y	N	Y	N	Y	N
10230515	1	Y	Y	N	N	Y	N	N	N
10230509	1	N	N	Y	Y	N	N	N	N
10286112	1	N	Y	Y	N	Y	Y	N	N
10297616	1	N	Y	Y	Y	Y	Y	Y	N
10340083	1	N	Y	Y	Y	Y	Y	Y	N
10362050	1	N	N	N	N	N	Y	N	N
10387448	1	N	Y	Y	Y	Y	Y	N	N
10414963	1	N	Y	N	N	Y	N	N	N
10442316	1	N	Y	Y	Y	Y	N	Y	N
10448632	1	N	Y	Y	Y	Y	Y	Y	N
10455345	1	Y	Y	N	N	Y	Y	Y	N
Micro Total		4/16	14/16	12/14	8/16	14/16	9/16	6/16	1/16
Segment Total		4/16	14/16	12/14	8/16	14/16	9/16	6/16	1/16

Current Conditions and Historical Perspective

It was observed that I-80 from mile point 3.993-41.278 is an interstate highway that begins just outside of Wendover and continues to the first bend in the freeway. This section of interstate has two lanes of travel in each direction with a center median. For the entire section there are no barriers in the median or at the shoulders. The shoulders are all paved with rumble strips along most of the length of the roadway section. The figure below from Google Earth shows the section of intersection. Roadview Explorer was used to analysis the I-80 to determine if there were changes. The analysis showed very few changes can be seen for this segment of I-80 from 2009-2014. The changes included restriping and the addition of some rumble strips. At locations were the median was narrower the addition on cable barriers was also noted sometime between 2009 and 2011. The figure shows a portion of the segment in 2014.



Site Visit

A site visit was made to the hot spot on I-80. The visit was made to take measurements and verify assumptions about median, barriers, shoulder and grade. Figure 6-7 shows the typical lane and shoulder configuration along the hot spot. It was observed on the site that for most of the segment was flat and absent of curvature. The average measured distance across the center median was 305 feet. A median barrier was found on the segment at the first portion but ended after about 0.2 miles. One observation from the site visit was that after the shoulder there was a relatively abrupt drop of a few feet to the center median. Another was the existence of two cable barriers along the median from mile points 10.5 to 11.5 and from mile point 32.5 to 38.5. Figure 6-8 shows the typical median found along the segment. There is on average 6 feet of paved shoulder.

Segment Definition

This segment of I-80 is very flat with no horizontal or vertical curvature. The lane configuration is constant throughout the segment with two through lanes in each direction. The shoulders are all about 5' in width on both the left and right side of the roadway. The directions of travel are separated with a wide flat median that is on average about 300 feet wide and is situated a few feet lower than the roadway. There are rumble strips on both the right and center of the roadway for most of the length of the segment. In general this segment is flat straight and has a few of the possible safety measures.

Table 7: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	300' Flat	4/0.107	110/2.95	5'/Asphalt	Flat	None	4 Thru	No	Yes

Problem Definition

The safety problem along the segment of I-80 located between the mile points of 3.993 and 41.278 is an excess of ROR and rollover crashes resulting in high severities (level 5 fatal, level 4 incapacitating injury). Based on the crash data in table, possible contributing factors to the problem are speeding, DUI, and night conditions. The flat straight roadway geometry could also be a possible contributing factor.

Countermeasures

Evaluation

The following is a list of possible countermeasures for implementation at the hot spot segment located on I-80. The countermeasures listed are specific to the problem and not the site, and were compiled using the countermeasure matrices found in the NCHRP 500 Reports. The list is based on ROR collisions, DUI, and speed collisions. Only countermeasures related to ROR, rollover and DUI collisions were added to the list for evaluation.

- Install mid lane rumble strips
- Eliminate shoulder drop off
- Apply shoulder treatments such as eliminating shoulder drop off or widening shoulders
- Design safer slopes and ditches to prevent rollovers
- Install median and/or shoulder barriers
- Add or improve roadside hardware
- Widen left and right shoulder
- Conduct Regular Well-Publicized DWI Checkpoints

Selection and Recommendation

The following provides a list of suggested countermeasures for implementation at the hot spot segment on I-80 based on the hot spot identification and analysis methodology.

- Eliminate shoulder drop off
- Design safer slopes and ditches – redesign center median
- Install median barriers
- Install shoulder barriers
- Widen the left and right shoulder
- Conduct Regular Well-Publicized DWI Checkpoints

B-8 I-80 from Milepost 3.993 to Milepost 41.278 Report

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spots Report

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	I-80	**UCP Model Used:**	Severity Model
Road Direction:	Positive	**Ranking from Model:**	1
Beginning Mile Point:	3.993	**UDOT Region:**	2
Ending Mile Point:	41.278	**County:**	Tooele
Dates of Data Source:	2008-2012	**Date of Analysis:**	3-30-2015

Table 2: Segment Characteristics

Function Class:	Interstate	**AADT:**	7345
Number of Thru Lanes:	4	**Speed Limit (MPH):**	75

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	3.993	41.278	37.285

Micro Analysis

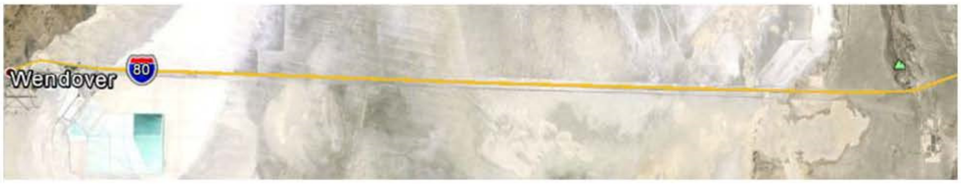
Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
3.993-41.278	83	6	10	20	1

Current Conditions and Historical Perspective

It was observed that I-80 from mile point 3.993-41.278 is an interstate highway that begins just outside of Wendover and continues to the first bend in the freeway. This section of interstate has two lanes of travel in each direction with a center median. For the entire section there are no barriers in the median or at the shoulders. The shoulders are all paved with rumble strips along most of the length of the roadway section. The figure below from Google Earth shows the section of intersection. Roadview Explorer was used to analysis the I-80 to determine if there were changes. The analysis showed very few changes can be seen for this segment of I-80 from 2009-2014. The changes included restriping and the addition of some rumble strips. At locations were the median was narrower the addition on cable barriers was also noted sometime between 2009 and 2011.



Segment Definition

This segment of I-80 is very flat with no horizontal or vertical curvature. The lane configuration is constant throughout the segment with two through lanes in each direction. The shoulders are all about 5' in width on both the left and right side of the roadway. The directions of travel are separated with a wide flat median that is on average about 300 feet wide and is situated a few feet lower than the roadway. There are rumble strips on both the right and center of the roadway for most of the length of the segment. In general this segment is flat straight and has a few of the possible safety measures.

Table 5: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	300' Flat	4/0.107	110/2.95	5'/Asphalt	Flat	None	4 Thru	No	Yes

Problem Definition

The safety problem along the segment of I-80 located between the mile points of 3.993 and 41.278 is an excess of ROR and rollover crashes resulting in high severities (level 5 fatal, level 4 incapacitating injury). Based on the crash data in table, possible contributing factors to the problem are speeding, DUI, and night conditions. The flat straight roadway geometry could also be a possible contributing factor.

Countermeasures Recommendations

The following provides a list of suggested countermeasures for implementation at the hot spot segment on I-80 based on the hot spot identification and analysis methodology.

- Eliminate shoulder drop off
- Design safer slopes and ditches – redesign center median
- Install median barriers
- Install shoulder barriers
- Widen the left and right shoulder
- Conduct Regular Well-Publicized DWI Checkpoints

B-9 SR-68 from Milepost 11.638 to Milepost 23.934 Analysis

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spot Segments

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	SR-68	**UCP Model Used:**	Severity Model
Road Direction:	Positive	**Ranking from Model:**	2
Beginning Mile Point:	11.628	**UDOT Region:**	3
Ending Mile Point:	23.934	**County:**	Utah
Dates of Data Source:	2008-2012	**Date of Analysis:**	4-29-2015

Table 2: Segment Characteristics

Function Class:	Minor Arterial	**AADT:**	1,110
Number of Thru Lanes:	2	**Speed Limit (MPH):**	55

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	11.628	23.934	12.296

Micro Analysis

Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
11.628-23.934	62	4	6	--	2

Table 5: Data from Crash and Vehicle Files

Crash ID	Sub-Segment	First Harmful Event	Manner of Collision	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
10177500	1	Rollover	N/A	ROR Right, ROR Left, Rollover, N/A	Rollover	Straight Ahead
10238138	1	Rollover	N/A	Rollover, N/A, N/A, N/A	Rollover	Straight Ahead
10291927	1	Embankment	N/A	ROR Right, Embankment, N/A, N/A	Embankment	Straight Ahead
10304550	1	Motor Vehicle in Transport	Head On	Operating Motor Vehicle, ROR Right, N/A, N/A	Motor Vehicle in Transit	Overtaking, Straight Ahead
10311648	1	Rollover	N/A	ROR Right, Embankment, Rollover, N/A	Rollover	Straight Ahead

10349772	1	Rollover	N/A	ROR Right, Crossed Centerline, Rollover, N/A	Rollover	Straight Ahead
10361476	1	Crossed Centerline	N/A	Crossed Centerline, ROR Right, Crossed Centerline, ROR Right	Rollover	Straight Ahead
10393711	1	Rollover	N/A	ROR Left, Other Pole, Rollover, Fence	Rollover	Straight Ahead
10418999	1	Rollover	N/A	ROR Right, Rollover, Embankment, N/A	Rollover	Slowing in Traffic Lane
10421750	1	Rollover	N/A	ROR Right, Rollover, Rollover, Embankment	Rollover	Straight Ahead
10422422	1	Rollover	N/A	ROR Right, Delineator Post, Rollover, N/A	Rollover	Straight Ahead

Table 6: Data from Roll-Up File

Crash ID	Sub-Segment	Improper Restraint	DUI	Speed Related	Roadway Geometry Related	Roadway Departure	Overturn/Rollover	Night Condition	Motorcycle Involved
10177500	1	Y	Y	N	Y	Y	Y	Y	N
10393711	1	Y	N	Y	Y	Y	Y	Y	N
10238138	1	N	N	Y	Y	N	Y	Y	Y
10291927	1	N	N	N	Y	Y	N	Y	Y
10304550	1	N	Y	N	Y	N	N	N	N
10311648	1	Y	N	Y	Y	Y	Y	Y	N
10349772	1	N	Y	N	Y	Y	Y	Y	N
10361476	1	Y	N	Y	Y	Y	Y	Y	N
10422422	1	Y	Y	Y	Y	Y	Y	Y	N
10421750	1	Y	N	N	Y	Y	Y	Y	N
10418999	1	N	N	N	Y	Y	Y	Y	Y
Segment Total		6/11	4/11	5/11	11/11	9/11	9/11	10/11	3/11

Current Conditions and Historical Perspective

It was observed that the 12 mile segment of SR-68, located south of Saratoga Springs, UT, is a two lane-two way highway. There are no rumble strips in the centerline or 2 foot asphalt shoulder of the road. Between mile post 11.628 and 23.980, there are many horizontal curves while reduce the speed limit from 55 mph to 45 mph, with some rolling effect with the vertical transition. In the proximity of a Geneva Rock facility, located near mile post 23, the shoulder the road is expanded from 2 feet to 11 feet, to accommodate for heavy truck traffic to the site. Using Roadview Explorer, there were no apparent changes to the geometry or features of the roadway, other than a portion of the road segment being repaved in in 2012.

Figure 1: Aerial photo of segment along SR-68 (Google Earth).

Site Visit

A site visit was made to the hot spot on SR-68 (MP 11.6-MP 24.0), west of Utah Lake and south of Saratoga Springs. The visit was made to determine if the signage along the corridor is adequate and to verify assumptions about median, shoulder, and grade. This is a two-lane two-way highway. It was observed that there was close to no shoulder at all, and that there was no centerline rumble strip. There were also some of the vertical curve crests that blocked sight distance of opposing traffic. It was observed that prior to the segment; the road is very straight, but that this section is extremely windy and curvy. The posted speed limit of 55 MPH is fine for the straight sections, but was too high for all of the curved sections. It was observed that all of the curves were fairly sharp curves, and that speed needed to be reduced dramatically to adequately make the curve. There were some signs for the curves informing the driver to slow down for the curve. There was one curve, however, that did not have any speed reduction sign at all. This curve could only be negotiated at a speed of approximately 35 MPH, which is well below the speed limit. It was also observed that many of the speed reduction signs were weathered and were not easily seen by the driver. There was a lack of chevron markings for a lot of the curves, while many of the curves had chevron markings. Most of the curves did not have barriers, even when there was a steep drop-off. There was also a lack of retro-reflectors for night time drivers.

Segment Definition

This segment of SR-68 has many horizontal curves, with some rolling in the vertical transitions. The lane and shoulder configuration is constant through the segment, with the exception of a wider shoulder near the Geneva Rock site, located near mile post 30. There are no rumble strips along the side of the road. There are a few speed reduction zones at curves, where the 55 mph speed limit is reduced to 45 mph.

Table 7: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	No	9/0.732	111/9.03	2', Asphalt	Flat	Class D, L = 442, R = 491	2 Lanes, Two Way	No	No

Problem Definition

Based on the crash data in Table 5, there are a significant amount of rollover incidents. These rollover incidents have caused fatal and incapacitating results. Based on Table 6, possible contributing factors to the problem are roadway geometry (horizontal curvature), speed, light conditions, and improper restraint.

Countermeasures

Evaluation

The following is a list of possible countermeasure for implementation on the hot spot segment along SR-68. The countermeasures listed are specific to the problem and not the site, and were compiled using the countermeasures matrices found in the NCHRP 500 Reports. The list is based on ROR crashes, rollovers, roadway departure, and speed related crashes.

- Install shoulder rumble strips
- Install centerline rumble strips
- Apply shoulder treatments like eliminating shoulder drop off or widening shoulders
- Design safer slopes and ditches to prevent rollovers
- Implement variable speed limits
- Use targeted conventional speed enforcement programs at locations known to have speeding related crashes
- Improve speed limit signage
- Implement active speed warning signs

Selection and Recommendation

The following provides a list of suggested countermeasures for implementation at the hot spot segment on I-68 based on the hot spot identification and analysis methodology.

- Install shoulder rumble strips
- Install centerline rumble strips

- Use targeted conventional speed enforcement programs at locations known to have speeding related crashes
- Improve speed limit signage
- Implement active speed warning signs at curves

B-10 SR-68 from Milepost 11.638 to Milepost 23.934 Report

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spots Report

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	SR-68	**UCP Model Used:**	Severity Model
Road Direction:	Positive	**Ranking from Model:**	2
Beginning Mile Point:	11.628	**UDOT Region:**	3
Ending Mile Point:	23.934	**County:**	Utah
Dates of Data Source:	2008-2012	**Date of Analysis:**	4-29-2015

Table 2: Segment Characteristics

Function Class:	Minor Arterial	**AADT:**	1,110
Number of Thru Lanes:	2	**Speed Limit (MPH):**	55

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	11.628	23.934	12.296

Micro Analysis

Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
11.628-23.934	62	4	6	--	2

Current Conditions and Historical Perspective

It was observed that the 12 mile segment of SR-68, located south of Saratoga Springs, UT, is a two lane-two way highway. There are no rumble strips in the centerline or 2 foot asphalt shoulder of the road. Between mile post 11.628 and 23.980, there are many horizontal curves while reduce the speed limit from 55 mph to 45 mph, with some rolling effect with the vertical transition. In the proximity of a Geneva Rock facility, located near mile post 23, the shoulder the road is expanded from 2 feet to 11 feet, to accommodate for heavy truck traffic to the site. Using Roadview Explorer, there were no apparent changes to the geometry or features of the roadway, other than a portion of the road segment being repaved in in 2012.

Segment Definition

This segment of SR-68 has many horizontal curves, with some rolling in the vertical transitions. The lane and shoulder configuration is constant through the segment, with the exception of a wider shoulder near the Geneva Rock site, located near mile post 30. There are no rumble strips along the side of the road. There are a few speed reduction zones at curves, where the 55 mph speed limit is reduced to 45 mph.

Table 5: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	No	9/0.732	111/9.03	2', Asphalt	Flat	Class D, L = 442, R = 491	2 Lanes, Two Way	No	No

Problem Definition

Based on the crash data in **Error! Reference source not found.**, there are a significant amount of rollover incidents. These rollover incidents have caused fatal and incapacitating results. Based on **Error! Reference source not found.**, possible contributing factors to the problem are roadway geometry (horizontal curvature), speed, light conditions, and improper restraint.

Countermeasures Recommendations

The following provides a list of suggested countermeasures for implementation at the hot spot segment on I-68 based on the hot spot identification and analysis methodology.

- Install shoulder rumble strips
- Install centerline rumble strips
- Use targeted conventional speed enforcement programs at locations known to have speeding related crashes
- Improve speed limit signage
- Implement active speed warning signs at curves

B-11 US-6 from Milepost 290.894 to Milepost 300.359 Analysis

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spot Segments

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	US-6	**UCP Model Used:**	Severity Model
Road Direction:	Positive	**Ranking from Model:**	3
Beginning Mile Point:	290.894	**UDOT Region:**	4, Price District
Ending Mile Point:	300.359	**County:**	Emery
Dates of Data Source:	2008-2012	**Date of Analysis:**	4-27-2015

Table 2: Segment Characteristics

Function Class:	Other Principal Arterial	**AADT:**	4,275
Number of Thru Lanes:	2	**Speed Limit (MPH):**	65

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	290.894	300.359	9.465

Micro Analysis

Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
290.894-300.359	16	0	5	--	3

Table 5: Data from Crash and Vehicle Files

Crash ID	Sub-Segment	First Harmful Event	Manner of Collision	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
10211769	1	Motor Vehicle in Transit	Sideswipe Opposite Direction	Crossed Centerline, Operating Motor Vehicle, ROR Left, Not Applicable	Motor Vehicle in Transport	Straight Ahead
10289104	1	Invalid	Sideswipe Opposite Direction	Crossed Centerline, Motor Vehicle in Transit, Other Fixed Object, Other Fixed Object	Motor Vehicle in Transport	Straight Ahead
10351408	1	Rollover	N/A	ROR Left, Rollover, Rollover, N/A	Rollover	Straight Ahead
10494266	1	Other Non-Collision	Sideswipe Opposite Direction	ROR Right, Other Non-Fixed Object, N/A, N/A	Other Non-Fixed Object	Straight Ahead
10499002	1	Other Non-Collision	N/A	Other Non-Collision, ROR Right, Traffic Sign Support, Rollover	Rollover	Straight Ahead

Table 6: Data from Roll-Up File

Crash ID	Sub-Segment	Roadway Departure	Overturn/Rollover	Commercial Motor Vehicle	Drowsy Driving	Roadway Geometry Related	Older Driver Involved	Single Vehicle	DUI
10211769	1	Y	N	Y	N	N	N	N	N
10289104	1	Y	Y	N	N	N	N	N	N
10351408	1	Y	Y	N	Y	N	Y	Y	N
10494266	1	Y	N	Y	N	N	N	N	N
10499002	1	N	Y	Y	Y	Y	N	N	N
Micro Total		4/5	3/5	3/5	2/5	1/5	1/5	1/5	0/5
Segment Total		4/5	3/5	3/5	2/5	1/5	1/5	1/5	0/5

Current Conditions and Historical Perspective

It was observed that this 10 mile segment, located south of Price, UT along US-6 (SR-191), is a two way two lane highway. There are rumble strips installed in the centerline and shoulders of the roadway. The terrain is flat and the segment is mostly straight some gentle curves before intersecting with I-70. Using Roadview Explorer to observe the roadway features, there were no apparent changes to the geometry or features of the roadway between 2010 and 2014. Figure 1 shows a screen shot of the road segment from the 2014 Roadview Explorer database. Figure 2 shows an aerial overview of the segment, with the general mileposts outlined.

Figure 1: Photo from Roadview Explorer 2014 database of segment along US-6, near mile post 290.

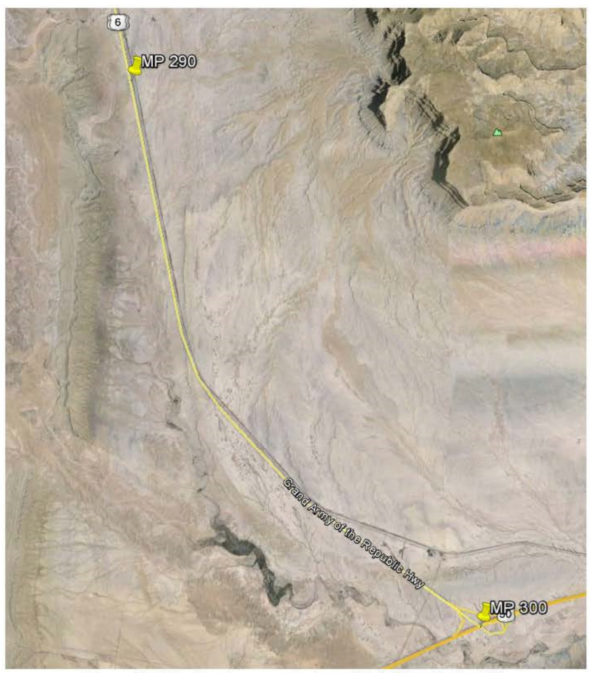


Figure 2: Extents of segment along US-6 (Google Earth).

Site Visit

A site visit was made to the hot spot on US-6 (MP 290 – MP 300) north of Green River. The purpose of this site visit was to determine if there were any major issues with the layout of the roadway and to see if the signage is adequate for the section. This is a two-lane two-way highway that is mostly straight with very gentle curves. It was observed that there were 6 ft. shoulders on the right. The highway is also raised approximately 5 ft. which produces a drop-off on the right. There are train tracks on the left side of the highway. There are also rumble strips in the middle of the road. The first eight miles (MP 290 – MP 298) is a passing zone, while the last two miles (MP 298 – MP 300) is a no passing zone. The signage appeared to be clear and easy to read. There were strong winds at the time. There was also no rest stop in this section, and the closest rest stop is 20 miles away (MP 270), which could be hard for drowsy drivers.

Segment Definition

This 10 mile segment of US-6 is a two way two lane highway on flat terrain. There are some gentle horizontal curved, but the roadway is mostly flat through this segment. There is no lighting along the segment. There are way-finding signs near mile post 3000 to help drivers merge onto I-70.There are rumble strips along the side of the road and in the center line.

Table 7: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	No	3/0.317	108/11.4	5'/Asphalt	Flat	Class, C, L = 1308 R = 825	2 Thru	No	Yes

Problem Definition

Based on the crash data in Table 5, there are a significant amount of crashes resulting from crossing the center line or veering off the road, resulting in a rollover accident. Based on Table 6, a commonality of these crashes includes commercial motor vehicles and/or drowsy drivers.

Countermeasures

Evaluation

The following is a list of possible countermeasure for implementation on the hot spot segment along US-6. The countermeasures listed are specific to the problem and not the site, and were compiled using the countermeasures matrices found in the NCHRP 500 Reports. The list is based on the crashes related commercial vehicles, road departures, and drowsy drivers.

- Modify speed limits in and increase enforcement to reduce truck and other vehicle speeds.
- Install should and/or centerline rumble strips
- Implement other roadway improvements to reduce the likelihood and severity of run-off-road and/or head-on collisions
- Improve access to safe stopping and resting areas
- Improve rest area security and services
- Strengthen graduated driver licensing requirements for young drivers
- Implement active speed warning signs

Selection and Recommendation

The following provides a list of suggested countermeasures for implementation at the hot spot segment on US-6 based on the hot spot identification and analysis methodology.

- Implement other roadway improvements to reduce the likelihood and severity of run-off-road and/or head-on collisions
- Improve access to safe stopping and resting areas
- Improve rest area security and services
- Implement active speed warning signs

B-12 US-6 from Milepost 290.894 to Milepost 300.359 Report

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spots Report

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	US-6	**UCP Model Used:**	Severity Model
Road Direction:	Positive	**Ranking from Model:**	3
Beginning Mile Point:	290.894	**UDOT Region:**	4, Price District
Ending Mile Point:	300.359	**County:**	Emery
Dates of Data Source:	2008-2012	**Date of Analysis:**	4-27-2015

Table 2: Segment Characteristics

Function Class:	Other Principal Arterial	**AADT:**	4,275
Number of Thru Lanes:	2	**Speed Limit (MPH):**	65

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	290.894	300.359	9.465

Micro Analysis

Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
290.894-300.359	16	0	5	--	3

Current Conditions and Historical Perspective

It was observed that this 10 mile segment, located south of Price, UT along US-6 (SR-191), is a two way two lane highway. There are rumble strips installed in the centerline and shoulders of the roadway. The terrain is flat and the segment is mostly straight some gentle curves before intersecting with I-70. Using Roadview Explorer to observe the roadway features, there were no apparent changes to the geometry or features of the roadway between 2010 and 2014 figure shows an aerial overview of the segment, with the general mileposts outlined.

Segment Definition

This 10 mile segment of US-6 is a two way two lane highway on flat terrain. There are some gentle horizontal curved, but the roadway is mostly flat through this segment. There is no lighting along the segment. There are way-finding signs near mile post 3000 to help drivers merge onto I-70.There are rumble strips along the side of the road and in the center line.

Table 5: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	No	3/0.317	108/11.4	5'/Asphalt	Flat	Class, C, L = 1308 R = 825	2 Thru	No	Yes

Problem Definition

Based on the crash data in **Error! Reference source not found.**, there are a significant amount of crashes resulting from crossing the center line or veering off the road, resulting in a rollover accident. Based on **Error! Reference source not found.**, a commonality of these crashes includes commercial motor vehicles and/or drowsy drivers.

Countermeasures Recommendations

The following provides a list of suggested countermeasures for implementation at the hot spot segment on US-6 based on the hot spot identification and analysis methodology.

- Implement other roadway improvements to reduce the likelihood and severity of run-off-road and/or head-on collisions
- Improve access to safe stopping and resting areas
- Improve rest area security and services
- Implement active speed warning signs

B-13 SR-173 from Milepost 8.516 to Milepost 8.775 Analysis

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spot Segments

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	SR-173	**UCP Model Used:**	UCSM
Road Direction:	Positive	**Ranking from Model:**	5
Beginning Mile Point:	8.516	**UDOT Region:**	2
Ending Mile Point:	8.775	**County:**	Salt Lake
Dates of Data Source:	2008-2012	**Date of Analysis:**	4-17-2015

Table 2: Segment Characteristics

Function Class:	Minor Arterial	**AADT:**	26,360
Number of Thru Lanes:	4	**Speed Limit (MPH):**	40

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	8.741	8.775	0.034

Micro Analysis

Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
8.741-8.775	6	1	5	5	5

Table 5: Data from Crash and Vehicle Files

Crash ID	Sub-Segment	First Harmful Event	Manner of Collision	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
10364447	1	Motor Vehicle	Front to Rear	Motor Vehicle, Motor Vehicle	Motor Vehicle	Straight Ahead, Stopped in Lane
10362518	1	Pedestrian	Unknown	Pedestrian	Pedestrian	Turning Left
10393002	1	Motor Vehicle	Angle	Motor Vehicle	Motor Vehicle	Straight Ahead, Turning Left
10416558	1	Motor Vehicle	Angle	Motor Vehicle	Motor Vehicle	Straight Ahead, Turning Left
10424833	1	Motor Vehicle	Angle	Motor Vehicle	Motor Vehicle	Straight Ahead, Straight Ahead

10453787	1	Motor Vehicle	Angle	Motor Vehicle	Motor Vehicle	Straight Ahead, Straight Ahead

Table 6: Data from Roll-Up File

Crash ID	Sub-Segment	Speed Related	Intersection Related	Roadway Geometry	Teenage Driver	Older Diver	Aggressive Driving	DUI	Drowsy Driving
10364447	1	N	Y	N	N	N	N	N	N
10362518	1	N	Y	N	N	N	N	N	N
10393002	1	N	Y	Y	N	N	N	N	N
10416558	1	N	Y	N	N	N	N	N	N
10424833	1	N	Y	N	N	N	N	N	N
10453787	1	N	Y	N	N	N	N	N	N
Micro Total		0/6	6/6	1/6	0/6	0/6	0/6	0/6	0/6
Segment Total		0/6	6/6	1/6	0/6	0/6	0/6	0/6	0/6

Current Conditions and Historical Perspective

It was observed that SR-73 (5300 South) from mile point 8.741 to mile point 8.775 is a minor Arterial at the intersection with Murray Boulevard (700 West). This section of roadway has two lanes of travel in each direction with a center median. The median to the east is a raised median, and the median to the west is a center left turn lanes. At the intersection each direction has a dedicated left turn lane with approximately 200 ft of storage. Both approaches include a dedicated right turn lane at the intersection. The intersection is signal controlled with left turn phasing on the cross street and on the SR-173 approaches. The Figure 6-4 below from Google Earth shows the section of intersection. Using Roadview Explorer was used to analyze the SR-173 to determine if there were and changes. The analysis showed no changes can be seen for this segment of SR-173 from 2010-2014. The figure shows a portion of the segment in 2014.

Site Visit

A site visit was conducted at the problem spot on SR 173 to take measurements. Along with taking measurements the approach made from each direction was driven to get a feel for sight distances and any obstructions that might exist to reduce visibility while approaching the intersection. After this was done the intersection was observed for a time to help understand how it operates. It was observed that the signal at this intersection seems to be operating properly with no particular problems observed. Special attention was made to the eastbound approach as 4 out of the 6 crashes involved a vehicle form this approach. It was observed that at the intersection the pedestrian crosswalks were hindered by raised median on the northbound and westbound approach which could be a concern as this is a marked school crossing. It was also observed that the approach angle for the eastbound and westbound movements was 72 degrees. While driving the eastbound approach the vertical and horizontal curvature did reduce sight distance as well as obstruction from vegetation on the south side of the road. Although the visibility was obstructed the sight distance did appear to be sufficient. The figure shows the eastbound approach to the intersection.

Segment Definition

The problem spot on SR-173 is located primarily at mile point 8.77. This spot is part of a larger hot spot segment on SR-173 between mile points 8.516 and 8.775. The problem spot is located at the signalized intersection of 5300 South and Murray Boulevard (700 West) in Murray, Utah. The posted speed limit on State Street in the area is 40 mph, while the posted speed limit on 5300 South is also 35 mph. The problem spot occurs for traffic traveling on 5300 South, which has two lanes in each direction. For the eastbound traffic there is a left turn lane and right turn lane with a storage length of approximately 200 feet. For the southbound traffic there is a left turn lane and right turn lane with a storage length of approximately 200 feet. At the intersection there is no shoulder but there is a gutter, curb, and sidewalk. There is a raised median on the east side that separates opposing traffic at the intersection. Lane widths are slightly larger than 12 feet. There are pedestrian crosswalks on all legs of the intersection including a school crossing on the west side of the intersection.

Table 7: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	Raised, 4 ft	1/3.861	11/42.5	Curb and Gutter, 11 Feet	Slight Slope	Class A, L=450, R=2631	4 Thru, Left and Right Turn	No	No

Problem Definition

The safety problem occurring at the problem spot on SR-173 is an excessive number of angled collisions between a vehicle turning left and a vehicle driving straight in the cross travel direction resulting in high severity collisions (level 5 fatal, level 4 incapacitating injury). Based on the crash data in tables, possible contributing factors to this problem are intersection geometry and layout.

Countermeasures

Evaluation

The following is a list of possible countermeasures for implementation at the problem spot located on SR-173. The countermeasures listed are specific to the problem and not the site, and were compiled using the countermeasure matrices found in NCHRP 500 Series. The list is based on signalized intersection collisions and includes countermeasures related to left turns for evaluation.

- Optimize clearance intervals
- Provide/improve left turn channelization
- Improve visibility of signals and signs at intersection
- Provide targeted conventional enforcement of traffic laws
- Control speed on approaches
- Employ signal coordination along a corridor or route
- Install advance warning signs
- Improve signal coordination
- Restrict turning movements

Selection and Recommendation

The following provides a list of suggested countermeasures for implementation at the problem spot on SR-173 based on the hot spot identification and analysis methodology.

- Reduce approach speeds
- Optimize clearance intervals for left turn movements
- Improve signal coordination along the corridor
- Install advance warning signs
- Improve visibility of signals and signs at intersection

B-14 SR-173 from Milepost 8.516 to Milepost 8.775 Report

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spots Report

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	SR-173	**UCP Model Used:**	UCSM
Road Direction:	Positive	**Ranking from Model:**	5
Beginning Mile Point:	8.516	**UDOT Region:**	2
Ending Mile Point:	8.775	**County:**	Salt Lake
Dates of Data Source:	2008-2012	**Date of Analysis:**	4-17-2015

Table 2: Segment Characteristics

Function Class:	Minor Arterial	**AADT:**	26,360
Number of Thru Lanes:	4	**Speed Limit (MPH):**	40

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	8.741	8.775	0.034

Micro Analysis

Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
8.741-8.775	6	1	5	5	5

Current Conditions and Historical Perspective

It was observed that SR-73 (5300 South) from mile point 8.741 to mile point 8.775 is a minor Arterial at the intersection with Murray Boulevard (700 West). This section of roadway has two lanes of travel in each direction with a center median. The median to the east is a raised median, and the median to the west is a center left turn lanes. At the intersection each direction has a dedicated left turn lane with approximately 200 ft of storage. Both approaches include a dedicated right turn lane at the intersection. The intersection is signal controlled with left turn phasing on the cross street and on the SR-173 approaches. The Figure 6-4 below from Google Earth shows the section of intersection. Using Roadview Explorer was used to analyze the SR-173 to determine if there were and changes. The analysis showed no changes can be seen for this segment of SR-173 from 2010-2014. The figure shows a portion of the segment in 2014.

Segment Definition

The problem spot on SR-173 is located primarily at mile point 8.77. This spot is part of a larger hot spot segment on SR-173 between mile points 8.516 and 8.775. The problem spot is located at the signalized intersection of 5300 South and Murray Boulevard (700 West) in Murray, Utah. The posted speed limit on State Street in the area is 40 mph, while the posted speed limit on 5300 South is also 35 mph. The problem spot occurs for traffic traveling on 5300 South, which has two lanes in each direction. For the eastbound traffic there is a left turn lane and right turn lane with a storage length of approximately 200 feet. For the southbound traffic there is a left turn lane and right turn lane with a storage length of approximately 200 feet. At the intersection there is no shoulder but there is a gutter, curb, and sidewalk. There is a raised median on the east side that separates opposing traffic at the intersection. Lane widths are slightly larger than 12 feet. There are pedestrian crosswalks on all legs of the intersection including a school crossing on the west side of the intersection.

Table 5: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	Raised, 4 ft	1/3.861	11/42.5	Curb and Gutter, 11 Feet	Slight Slope	Class A, L=450, R=2631	4 Thru, Left and Right Turn	No	No

Problem Definition

The safety problem occurring at the problem spot on SR-173 is an excessive number of angled collisions between a vehicle turning left and a vehicle driving straight in the cross travel direction resulting in high severity collisions (level 5 fatal, level 4 incapacitating injury). Based on the crash data in tables, possible contributing factors to this problem are intersection geometry and layout.

Countermeasures Recommendations

The following provides a list of suggested countermeasures for implementation at the problem spot on SR-173 based on the hot spot identification and analysis methodology.

- Reduce approach speeds
- Optimize clearance intervals for left turn movements
- Improve signal coordination along the corridor
- Install advance warning signs
- Improve visibility of signals and signs at intersection

B-15 SR-48 from Milepost 7 to Milepost 7.4 Analysis

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spot Segments

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	SR-48	**UCP Model Used:**	Severity Model
Road Direction:	Positive	**Ranking from Model:**	8
Beginning Mile Point:	7.000	**UDOT Region:**	2
Ending Mile Point:	7.400	**County:**	Salt Lake
Dates of Data Source:	2008-2012	**Date of Analysis:**	4-8-2015

Table 2: Segment Characteristics

Function Class:	Minor Arterial	**AADT:**	21,535
Number of Thru Lanes:	4	**Speed Limit (MPH):**	45

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	7.025	7.100	0.400

Micro Analysis

Crash Data

The following is a list of the direction vehicles were traveling for the severe crashes.

- Crash ID: 10299982
  - Southbound, Eastbound
- Crash ID: 10345001
  - Westbound, Southbound
- Crash ID: 10369720
  - Northbound, Westbound
- Crash ID: 10458277
  - Westbound, Northbound
- Crash ID: 10512891
  - Eastbound (all three vehicles)

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
7.025	7.100	1	4	--	8

Table 5: Data from Crash and Vehicle Files

Crash ID	Sub-Segment	First Harmful Event	Manner of Collision	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
10299982	1	Motor Vehicle in Transport	Angle	N/A, N/A, N/A, N/A	N/A	Turning Left, Straight Ahead
10345001	1	Motor Vehicle in Transport	Angle	N/A, N/A, N/A, N/A	N/A	Straight Ahead, Turning Left
10369720	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead
10458277	1	Motor Vehicle in Transport	Angle	Operating Motor Vehicle, N/A, N/A, N/A	Motor Vehicle in Transport	Straight Ahead, Straight Ahead
10512891	1	Motor Vehicle in Transport	Front to Rear	Operating Motor Vehicle, Operating Motor Vehicle, Operating Motor Vehicle, N/A	Motor Vehicle in Transport	Straight Ahead, Stopped in Traffic Lane, Stopped in Traffic Lane

Table 6: Data from Roll-Up File

Crash ID	Sub-Segment	Intersection Related	Distracted Driving	Teenage Driver	Night Conditions	DUI	Speed Related	Adverse Weather	Pedestrian Involved
10299982	1	Y	N	N	Y	N	N	N	N
10345001	1	Y	N	N	N	N	N	N	N
10369720	1	Y	N	N	N	N	N	N	N
10458277	1	Y	N	N	N	N	N	N	N
10512891	1	Y	Y	Y	N	N	N	N	N
Micro Total		5/5	1/5	1/5	1/5	0/5	0/5	0/5	0/5
Segment Total		5/5	1/5	1/5	1/5	0/5	0/5	0/5	0/5

Current Conditions and Historical Perspective

It was observed that SR-48 (New Bingham Highway) between mile point 7.025 and mile point 7.100 is a minor arterial at the intersection of 4455 W (Airport Road/Welby Park Drive) in West Jordan, Utah. This section of roadway has two lanes of travel in each direction, with a raised lane dividing median on the west side of the intersection. At the intersection, each direction has a dedicated left turn lane, with approximately 200 feet of storage. Both approaches have a dedicated right turn lanes. The intersection is a signal controlled. Using Roadview Explorer, it was observed that the raised median on the west side of the intersection was installed between 2010 and 2011. The posted speed limit is 50 mph, not 45 mph as indicated on the crash records. Figure 1 is an aerial photo from Google Earth of the intersection.

Figure 1: Aerial photo of intersection of SE-48 and Airport Road (Google Earth).

Site Visit

A site visit was made to the hot spot on SR-48. All the crashes were at the intersection of New Bingham Hwy and Airport Rd, so the four approaches were driven to see if there are any noticeable problems. New Bingham Hwy has 2 thru lanes, 1 right turn lane and 1 left turn lane in each direction. At the intersection, Airport Rd has 1 thru lane, 1 right turn lane and 2 left turn lanes southbound, and 1 thru lane, 1 turn left lane and 1 turn right lane northbound. Left turns are signalized (left green arrows) in Airport Rd. However, New Bingham Hwy doesn't have left turn arrows. The east side and west side of New Bingham Hwy has a speed limit of 45 mph and 50 mph, respectively. The west side of New Bingham Hwy also has a median that goes from Airport Rd to the trax crossing (about 0.2 miles). Visibility was good for all four approaches and there were about 2 seconds to clear the intersection.

Segment Definition

The hot spot segment is at the intersection of SR-48 and 4455 W (Airport Road/Welby Park Drive), where SR-48 is a four lane highway, with two lanes in each direction. There is a left turn and right turn lane servicing both directions of SR-48, each with approximately 200 feet of storage. The intersection is signalized, but there is not turn phasing given to vehicles along SR-48. There is an 11 foot asphalt shoulder on each side of SR-48. The speed limit of vehicles along SR-48 is 50 mph.

Table 7: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	12'/Asphalt	1/2.5	19/47.5	Curb and Gutter, 11 feet	Slight Slope	No	4 Thru, Left and Right Turn	No	No

Problem Definition

The safety problem occurring at this segment of SR-48 is the number of angled collisions. The recurrence of angled crashes suggests a problem with the approach configuration. As summarized in

Table 6, the greatest commonality of the crashes was that they occurred at an intersection. There are no other apparent factors which have led to the severity of the crashes.

Countermeasures

Evaluation

The following is a list of possible countermeasure for implementation on the hot spot segment along SR-68. The countermeasures listed are specific to the problem and not the site, and were compiled using the countermeasures matrices found in the NCHRP 500 Reports. The list is based on signalized intersection collisions.

- Employ multiphase signal operation
- Optimize clearance intervals
- Restrict or eliminate turning maneuvers (including red right turns on red)
- Provide/improve left turn channelization
- Provide/improve right turn channelization
- Improve visibility of intersections on approach
- Improve visibility of signals and signs at intersections

Selection and Recommendation

The following provides a list of suggested countermeasures for implementation at the hot spot segment on SR-68 based on the hot spot identification and analysis methodology.

- Employ multiphase signal operation
- Optimize clearance intervals
- Restrict or eliminate turning maneuvers (including red right turns on red)
- Improve visibility of intersections on approach
- Improve visibility of signals and signs at intersections

B-16 SR-48 from Milepost 7 to Milepost 7.4 Report

The following reports are protected under 23 USC 409.

Safety Analysis on Hot Spots Report

Introduction

The purpose of this report is to summarize and present preliminary results from a safety-specific micro analysis on an identified hot spot segment. This report includes identification of the roadway segment and sub-segments, micro analysis data, and segment definition including roadway characteristics. A discussion of the problem at the location including possible countermeasures is also included. This report is intended to provide an abridged review of the analysis and is not intended to be a full analytical report.

Segment Identification

Table 1: Segment Metadata

Road Name:	SR-48	**UCP Model Used:**	Severity Model
Road Direction:	Positive	**Ranking from Model:**	8
Beginning Mile Point:	7.000	**UDOT Region:**	2
Ending Mile Point:	7.400	**County:**	Salt Lake
Dates of Data Source:	2008-2012	**Date of Analysis:**	4-8-2015

Table 2: Segment Characteristics

Function Class:	Minor Arterial	**AADT:**	21,535
Number of Thru Lanes:	4	**Speed Limit (MPH):**	45

Table 3: Sub-Segment Metadata

Sub-Segment	Beginning Mile Point	Ending Mile Point	Length
1	7.025	7.100	0.400

Micro Analysis

Crash Data

Table 4: Crash Count and Severity

Mile Points	# of Crashes	# Severity 5	# Severity 4	# Severity 3	Segment Rank
7.025	7.100	1	4	--	8

Current Conditions and Historical Perspective

It was observed that SR-48 (New Bingham Highway) between mile point 7.025 and mile point 7.100 is a minor arterial at the intersection of 4455 W (Airport Road/Welby Park Drive) in West Jordan, Utah. This section of roadway has two lanes of travel in each direction, with a raised lane dividing median on the west side of the intersection. At the intersection, each direction has a dedicated left turn lane, with approximately 200 feet of storage. Both approaches have a dedicated right turn lanes. The intersection is a signal controlled. Using Roadview Explorer, it was observed that the raised median on the west side of the intersection was installed between 2010 and 2011. The posted speed limit is 50 mph, not 45 mph as indicated on the crash records. The figure is an aerial photo from Google Earth of the intersection.

Segment Definition

The hot spot segment is at the intersection of SR-48 and 4455 W (Airport Road/Welby Park Drive), where SR-48 is a four lane highway, with two lanes in each direction. There is a left turn and right turn lane servicing both directions of SR-48, each with approximately 200 feet of storage. The intersection is signalized, but there is not turn phasing given to vehicles along SR-48. There is an 11 foot asphalt shoulder on each side of SR-48. The speed limit of vehicles along SR-48 is 50 mph.

Table 5: Roadway Characteristics

Segment	Median	IPM	SPM	Shoulder	Grade	Curve	Lanes	Wall/Barrier	Rumble
1	12'/Asphalt	1/2.5	19/47.5	Curb and Gutter, 11 feet	Slight Slope	No	4 Thru, Left and Right Turn	No	No

Problem Definition

The safety problem occurring at this segment of SR-48 is the number of angled collisions. The recurrence of angled crashes suggests a problem with the approach configuration. As summarized in **Error! Reference source not found.**, the greatest commonality of the crashes was that they occurred at an intersection. There are no other apparent factors which have led to the severity of the crashes.

Countermeasures Recommendations

The following provides a list of suggested countermeasures for implementation at the hot spot segment on SR-68 based on the hot spot identification and analysis methodology.

- Employ multiphase signal operation
- Optimize clearance intervals
- Restrict or eliminate turning maneuvers (including red right turns on red)
- Improve visibility of intersections on approach
- Improve visibility of signals and signs at intersections