Report No. UT-15.10

USE OF ROADWAY ATTRIBUTES IN HOT SPOT IDENTIFICATION AND ANALYSIS

Prepared For:

Utah Department of Transportation
Traffic & Safety, Research Divisions

Submitted By:

Brigham Young University
Dept. of Civil & Environmental Engineering

Authored By:

Grant G. Schultz, Ph.D., P.E., PTOE
Associate Professor

David R. Bassett, EIT
Graduate Research Assistant

Mitsuru Saito, Ph.D., P.E.
Professor

C. Shane Reese, Ph.D.
Professor, Statistics

Final Report
October 2015

RESEARCH

UDOT Keeping Utah Moving

Utah Department of Transportation - Research Division
4501 South 2700 West - P.O. Box 148410 - SLC,UT 84114-8410

DISCLAIMER

The authors alone are responsible for the preparation and accuracy of the information, data, analysis, discussions, recommendations, and conclusions presented herein. The contents do not necessarily reflect the views, opinions, endorsements, or policies of the Utah Department of Transportation or the U.S. Department of Transportation. The Utah Department of Transportation makes no representation or warranty of any kind, and assumes no liability therefore.

This report is protected under 23 USC 409.

ACKNOWLEDGMENTS

This research was made possible with funding from the Utah Department of Transportation (UDOT) and Brigham Young University (BYU). Special thanks to the several professionals at UDOT and BYU who played key roles as members of the Technical Advisory Committee (TAC). The members of the committee were:

- W. Scott Jones – UDOT Traffic & Safety
- Tim Taylor – WCEC/UDOT Traffic & Safety
- Travis Jensen – WCEC/UDOT Traffic & Safety
- Charles Allen – InterPlan Company;
- Grant G. Schultz – BYU Associate Professor;
- Mitsuru Saito – BYU Professor;
- Daniel Jean – BYU Graduate Student;
- David R. Bassett – BYU Graduate Student;
- Casey S. Knecht – BYU Graduate Student;
- Aaron A. Cook – BYU Undergraduate Student; and
- C. Shane Reese – BYU Professor.

TECHNICAL REPORT ABSTRACT

1. Report No. UT- 15.10	2. Government Accession No. N/A	3. Recipient's Catalog No. N/A
4. Title and Subtitle Use of Roadway Attributes in Hot Spot Identification and Analysis		5. Report Date October 2015 6. Performing Organization Code R0402229
7. Author(s) Grant G. Schultz, Ph.D., P.E., PTOE; David R. Bassett, EIT; Mitsuru Saito, Ph.D., P.E.; and C. Shane Reese, Ph.D.		8. Performing Organization Report No.
9. Performing Organization Name and Address Brigham Young University Department of Civil and Environmental Engineering 368 Clyde Building Provo, UT, 84602		10. Work Unit No. 11. Contract or Grant No. 14-8287
12. Sponsoring Agency Name and Address Utah Department of Transportation 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410		13. Type of Report & Period Covered Final Report October 2013 to October 2015 14. Sponsoring Agency Code PIN No. 10304

15. Supplementary Notes
Prepared in cooperation with the Utah Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

16. Abstract
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 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" in UDOT Report No. UT-13.15. 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 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 vertical 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 inclusion and defining of the roadway attributes. These methods and procedures were used to help in the identification of safety hot spots to be analyzed and countermeasures selected. Examples of how the methods are to function are given with sites from Utah's state roadway network.

17. Key Words Crash prediction, transportation safety, Utah Crash Prediction Model (UCPM), Highway Safety Manual (HSM), Hierarchical Bayes, Empirical Bayes, Poisson Mixture Model, crash analysis, hot spots, safety, roadway attributes		18. Distribution Statement Not restricted. Available through: UDOT Research Division 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410 www.udot.utah.gov/go/research		23. Registrant's Seal N/A
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 157	22. Price N/A	

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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
MP	Milepoint

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

EXECUTIVE SUMMARY

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 safety goals, 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 that can be utilized within the UCPM. 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 a 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 in Utah with its six primary steps: network screening, diagnosis, countermeasure selection, economic appraisal, project prioritization, and effectiveness evaluation. The addition of roadway attributes data (including the Light Detection and Ranging (LiDAR) roadway inventory data) was included as part of the network screening, diagnosis, and countermeasure selection, which are included in the methodology titled "Hot Spot Identification and Analysis" found in UDOT Report No. UT-13.15. Procedures and a systemization process were created to convert raw data into new roadway attributes, such as grade and vertical sag/crest curve location. Methods were also developed to combine and associate the attributes to crashes on problem segments and possible problem spots within the segments to help in the identification of safety hot spots so that they can be analyzed and countermeasures selected. The inclusion of roadway asset data allows 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. Specific examples from Utah's state roadway network are used to show how the methods function.

1.0 INTRODUCTION

1.1 Problem Statement

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 report and a general overview of the organization of the report.

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 is 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. The model results have been integrated into 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).

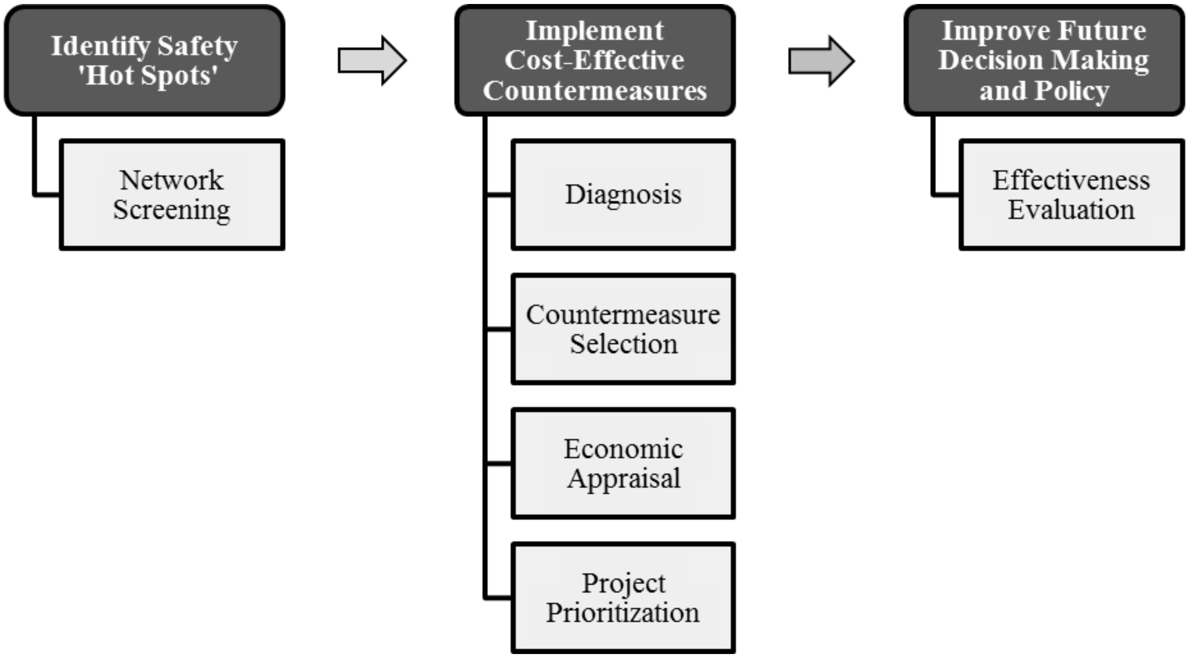


Figure 1-1: Framework for highway safety mitigation (adapted from AASHTO 2010).

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, and 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. They are also used to review countermeasure selection methods for the identified locations.

1.3 Scope

This research adds roadway characteristics and attributes to the UCPM to increase flexibility and functionality in modeling safety. In addition, the Utah Crash Severity Model (UCSM) is developed to analyze severe crashes on Utah roadways. The UCPM was used to determine which road segments were most likely to have a larger number of crashes than expected, while the UCSM was used to determine which segments were most likely to have a larger number of severe crashes. LiDAR roadway surveys and calibration and sensitivity analysis were used in determining these hot spots.

1.4 Outline of Report

The report is organized into seven 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 to identify segments and statistical methods used in roadway attribute sensitivity analysis. This chapter also includes statistical outputs and a discussion of the results. Chapter 5 discusses the process used to determine 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 uses specific examples and data to review the processes and steps presented in Chapter 5. Chapter 7 provides research conclusions and recommendations for future research to be considered.

2.0 LITERATURE REVIEW

2.1 Overview

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 provides background information on 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 UDOT 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).

2.2 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, methods can be employed to improve and create more efficient safety mitigations, which then can be implemented to reduce the number of fatal and serious roadway injuries (Schultz et al. 2013).

2.3 Crash Analysis Techniques

Crash analysis techniques are crucial to continuous improvement of roadway safety. Over the years many models and methods have been developed and employed to review and analyze roadway safety. 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 provides additional predictive models.

2.3.1 Traditional Descriptive Analysis

Traditional descriptive analysis is designed to use historical data alone. The methods focus on summarizing, quantifying, and analyzing these data. 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. Traditional analysis methods generally do not consider RTM, which may result in focusing on non-critical locations, 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).

2.3.2 Predictive Analysis

As the need for more advanced safety analysis has increased, there has been a shift from 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 differ according to the model being used and the person conducting the analysis, factors which both can cause varying results (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).

2.3.3 Recent Predictive Models

Recent models aid the continuing effort to improve and advance crash analysis. Two recent methods are the Quantile Regression (QR) 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 QR 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 that causes a right skewed distribution. This technique claims to allow for relaxed restrictions of the response variable by the researcher. This statistical model is used to predict crashes in two ways, one by location and the other by probability. Further information on the QR 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 CPMs analyze at the site level, or more specifically, a single roadway segment 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 uses a conditionally autoregressive (CAR) Bayesian spatial model. Whereas most applications of the CAR are limited to a sole type of roadway 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).

2.4 Purpose of Crash Analysis

The primary purpose of crash analysis is to locate and identify potentially unsafe areas. The crash analysis methods and models used in traditional descriptive analysis and predictive analysis are designed to help engineers locate unsafe areas and prioritize them. Once locations are identified, further analysis is required to determine what roadway attributes might contribute to 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).

2.5 Model Variables and Attributes

Crash analysis techniques use a number of different variables or attributes to analyze a site. 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, gender, intoxication, and inattention. 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.

2.5.1 Fundamental Model Attributes

Some attributes are used in most 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). Segment crash counts can be computed from larger counts (Hauer et al. 2002) or with GIS tools (Schultz et al. 2012). Another attribute 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).

2.5.2 Roadway Attributes

Roadway attributes have long been a focus of safety analysis. Traditional descriptive analysis uses roadway attributes in before and after studies to determine the effect a change of roadway characteristics has on crashes at a specific location. Advances in predictive methods have generally employed roadway attributes in two different ways depending on the model. The one used in the HSM and other models is as a statistical weighting used to predict crash counts.

The other is use of attributes to create 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 provides a list of CMFs that incorporate "the effects of geometric design and traffic control features" (AASHTO 2010, pp. 10-14). The following subsections discuss significant roadway attributes used in predictive models.

2.5.2.1 HSM Model Attributes. The HSM predictive model uses select roadway attributes to create a CMF that weights the crash count. One main goal of the HSM is using roadway attributes to predict the effect of possible crash reduction countermeasures 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 HSM uses three steps to determine attributes for use in creating CMFs: literature review, inclusion process, and expert panel review. The transportation safety literature review "mostly dated from the 1960s to June 2008" (AASHTO 2010, p. D-7) consists of a five-step process to create a CMF. This process can be found on page D-7 of the HSM and 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).

- Lane width and number of lanes
- Shoulders width, type, and material
- Roadside hazard rating
- Horizontal curvature and length

- Vertical curvature and length
- Centerline rumble strips
- Auxiliary lanes such as passing lanes and two-way left-turn lanes
- Lighting
- Grade level
- Median type and width

2.5.2.2 Other Predictive Model Attributes. Other predictive analysis models generally use an abbreviated subset of the attributes listed above. Availability is the main limitation of attributes used in other models. A QR study done by the University of Texas at Austin to determine the influence of roadway attributes on crashes excluded lighting, auxiliary lanes, hazard rating, and other attributes because the dataset from the Highway Safety Information System (HSIS) dataset for Washington State did not contain those data sources (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).

2.5.3 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 used to generate accurate GIS maps and models. LiDAR technology has been employed in scientific research for decades, but has only recently found its way into transportation safety research. LiDAR equipment was initially deployed in aircraft but can now be mounted to street vehicles. The latter method makes documenting roadway attributes much easier (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 of collecting roadway attributes with LiDAR is that all attributes can be collected at the same time as part of the same dataset. This increases attribute location accuracy both in relation to the road segment and between the different attributes. These attribute data can then be used in conjunction with analysis tools to identify hazardous road segments by comparing attributes present at a given site with attributes known to increase or decrease the likelihood of a crash (Pradhan and Rasdorf 2009).

2.6 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. Two basic categories of objective analysis employ the use of crash frequency: traditional descriptive and predictive analysis. Traditional descriptive analyses use summation and quantification to identify areas of concern, whereas predictive analyses are based on advanced statistical models. These methods and techniques are used to locate road segments and intersections where safety improvements can be implemented.

The statistical models used in the various predictive analyses generally make use of crash and roadway attributes. Crash attributes are typically associated with human factors, whereas roadway attributes are characteristics of a roadway segment or intersection that might affect crash frequency or severity. Roadway attributes are used in a number of ways to predict crash frequency and severity. The predicted values are compared to historical data to highlight locations with the greatest disparities. The HSM contains a comprehensive list of roadway attributes for use in crash analysis and as weighting factors. Other models use similar, but shorter, lists of attributes based on their functionality and attribute data availability. LiDAR technology provides a new method for acquiring accurate attribute data. Roadway attribute data are crucial for identifying countermeasures to reduce crash frequency and severity. The next chapter reviews and discusses the data needs for this project.

3.0 DATA COLLECTION

3.1 Overview

Data are a primary portion of any model. Data can affect which models are used, as well as the effectiveness of the models. Availability and quality are two major factors to consider when choosing the type and method of crash analysis. 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 require data, while lack of quality may cause certain data to be removed from the model, thus making it essentially unavailable. Accuracy is important, as it is a determining factor of model results validity.

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, the reader is referred to the report titled "Traffic and Safety Statewide Model and GIS Modeling" in the literature (Schultz et al. 2012).

3.2 General Data Considerations

Several general considerations 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 some of the general considerations of any dataset that might be used in analysis. These four considerations are discussed further in the following subsections.

3.2.1 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 to automate data preparation. There are many benefits of automating data preparation including speed, efficiency, and, in most cases, increased accuracy. However, automation propagates simple errors 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).

3.2.2 Availability

Data availability can potentially limit the methods (i.e., the tools used to analyze the data) and depth of analysis. Assessment of availability and access is one of the first steps in determining whether the input data are viable. Widely-available data encourage analysis and sharing of results (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)) is 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 future accuracy. Although unique one-time collection and use of datasets is sometimes necessary, there is little value after the initial use (Schultz et al. 2012).

3.2.3 Coverage

Coverage relates to the extent of information to which data refer. Lack of coverage could limit the scope of analysis. Coverage is based on data completeness and overall range. Completeness refers to missing data, whereas range refers to the geographic area, date, or time period from which the data were collected. Coverage constraints may vary depending on the statistical model being used. For this research, data covering the entire state of Utah were used. Each dataset's coverage should be reviewed to determine its range and completeness. It is important to note that the dataset with the least time and geographic coverage will be the analysis level's limiting factor. Certain roadway attributes will not exist at every segment or intersection, so "none" or "zero" need to be attribute coding options. As with availability, long-term and short-term access should be reviewed. Any coverage limitation will decrease analysis output (Schultz et al. 2012).

3.2.4 Usability

Data usability should be considered to reduce unneeded data collection and preparation effort. Usability generally refers to type, format, and usefulness. 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).

3.3 Data Management and Systemization

An objective of this research was improving 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 automation and documentation. Systemization is important when more than a one-time analysis is desired. It provides a level of repeatability and consistency, allowing for similar analyses to be performed on multiple datasets. The following subsections describe data uniformity methods applied to the utilized datasets, systemization improvements with a focus on automated data preparation, and process documentation in the form of a user manual.

3.3.1 Data Uniformity

Generally, data are required from multiple datasets, which makes uniformity important for achieving compatibility between them. Relational data are important considerations when using multiple datasets with tools such as ArcGIS. It is particularly important to verify that datasets can be spatially or linearly related. 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 (MP) of the segment
5. "END_MILEPOINT": Ending MP of the segment

These fields correspond with the State Routes Linear Referencing System (LRS) dataset that is required for use in the model 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, the "LABEL" field mentioned above was used for this identifying field.

Typically, roadway mileposts increase from west to east and south to north. For this research, positive travel direction ("P") follows the direction of increasing mileposts. The "N" direction code indicates that MPs 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 MPs that match the "P" direction, meaning the MPs 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).

3.3.2 Automation

Automation is an important aspect of systemization. It typically uses 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 ArcGIS tools. These tools are used to segment roadways and perform crash counts (Schultz et al. 2012). The automation portion of this research included creating scripts to make data preparation and presentation of results easier and faster. Additional automation was required due to changes in collection and management of required datasets.

3.3.3 Documentation

Documentation is a critical aspect for reproducing consistent and repeatable analyses. A user's guide was created to document automation scripts and step-by-step instructions related to data collection and result presentation. Scripts designed for repeated use with different datasets should include descriptions of the script's function and 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 dataset variations.

Previously created scripts were reviewed for function and completeness. A few of the scripts were found to be designed with one-time analysis as the primary function. Flexibility and function were added to the code and written comments and descriptions were also added to facilitate future review and modification. The comments included descriptions of the variables used in the script with details about the data type and format needed for proper functionality. A detailed overview was added to the start of each script, including a discussion of the needs, function, and brief explanation of the purpose behind the script.

This documentation effort resulted in a complete UCPM User's Guide (Bassett et al. 2015) 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 the R programming language. 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 how the data should look once preparation is complete. The guide provides a detailed step-by-step tutorial with 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.

3.4 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 Portal 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. 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 the Open Data Portal were downloaded in shapefile format to facilitate the data being used in ArcGIS. The comma separated variable (CSV) format was chosen for the crash data, based on the needs of the program used to prepare and clean the data. The curvature data were only available in the shapefile format. The datasets associated with roadway attributes collected through LiDAR were available as shapefiles. UDOT currently plans to update the LiDAR datasets every two years. Permanent traffic counters placed throughout the state are used to produce AADT on an annual basis. The crash data are also updated annually. The other data will be updated as noted in Table 3-1.

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	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	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

3.5 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, roadway segmentation, model calibration, hot spot microanalysis, and roadway attribute analysis. The following sections describe these tasks and how the data are used in each one.

3.5.1 Data Preparation

Three general data groups were prepared for use in the models: segmentation data, crash data, and roadway attributes. The data all require similar preparation methods, even though they are used in very different ways. Modifications were made in formatting, organization, and filtering. Table 3-1 contains a complete list of the datasets used for this analysis. Each had to undergo some modification to create the uniformity discussed in Section 3.3.1.

The State Route LRS data was used as the basis 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 model, and impact information. The crash data required the most preparation including combining the data into one dataset inclusive of the years from 2008 to 2012 that could be used for this analysis and the different data types. Redundant data 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. The roadway data were used to create an ArcGIS layer for segment analysis. For additional information and details on the data preparation processes, refer to the literature (Schultz et al. 2012, Schultz et al. 2013).

3.5.2 Segmentation Process

The purpose of segmentation 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 UCSM. This process is necessary so that every segment created has consistent attributes and characteristics along the entire segment length. For this project the state route system was segmented using five datasets: functional class, AADT, speed limit, number of through lanes, and urban code. These datasets were prepared to include the five fields listed in Section 3.3.1. The process was completed using an ArcGIS tool called "Overlay." This tool, using the base layer of the State Route LRS, segmented each roadway 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).

3.5.3 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 based on how the code is written to provide additional variables to use in the analysis. It is important to note that each segment must contain the proper variables to be considered valid.

Users much choose a particular crash severity (or combination of severities) on which to apply the model. The use of different severity combinations will produce different hot spot locations. Hot spots are the segments determined to have the highest probability of high crash rates based on the parameters used in the model. Hot spots vary according to the model severity input because different segments exhibit different crash severities (Schultz et al. 2013).

Another consideration related to the severity input is the amount of crash data available for each severity. Limiting the severity reduces the number of crashes on each road segment, which can reduce model output statistical significance.

This project is focused on using severities K, A, and B in the traditional KABCO scale of crash severity ranking. 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 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 was converted to KABCO for ease of common convention. Excel and ArcGIS can narrow the crash severity types to those that are wanted for a specific model run.

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 correlate with the number of crashes. The covariates found in the datasets listed in Table 3-1 were initially run through a Bayesian horseshoe selection method to determine which have a high probability of not being zero. The covariates include crash data and roadway attribute variables. 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 covariate subsets 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). 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 the top ranking models to determine if they produce results with statistically significant differences, as well as whether the results are valid. Additional information on the datasets, how they are used in this analysis, and the methodology associated with the model output sensitivity analysis can be found in Chapters 5 and 6.

The processes reviewed in this section 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, refer to the literature (Schultz et al. 2012).

3.5.4 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 hot spots that warrant additional analysis. Once a list of hot spots has been created, microanalysis can be performed on each of them. This analysis is done to determine if each segment as a whole is problematic or if there are specific locations along the segment where the majority of the crashes occur.

The analysis also includes a review of the possible characteristics that can be addressed through countermeasures. Crash data are primarily used for this level of microanalysis. Additional analysis was conducted on 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 hot spot analysis methodology is described in greater detail in Chapters 5 and 6.

3.5.5 Roadway Attribute Analysis

Hot spot analysis provides a list of locations that meet the minimum crash per segment requirements. 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 hot spots. The data can then be used to determine which roadway attributes are correlated to the crashes 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. Examples include datasets for intersections per mile (IPM) and 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 grade values. 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 3.5.4. More information on the roadway attribute datasets can be found in Chapters 5 and 6. Other datasets such as lane widths and speed limits should also be considered in roadway attribute microanalysis.

3.6 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, 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. Five distinct tasks are part of this project: data preparation, segmentation, calibration, microanalysis, and roadway attribute analysis.

4.0 STATISTICAL MODEL

4.1 Overview

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 model outputs. A comparison of the UCPM and UCSM is also included in this section. The crash data in this chapter is protected under 23 USC 409.

4.2 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 and 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 dictate (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.

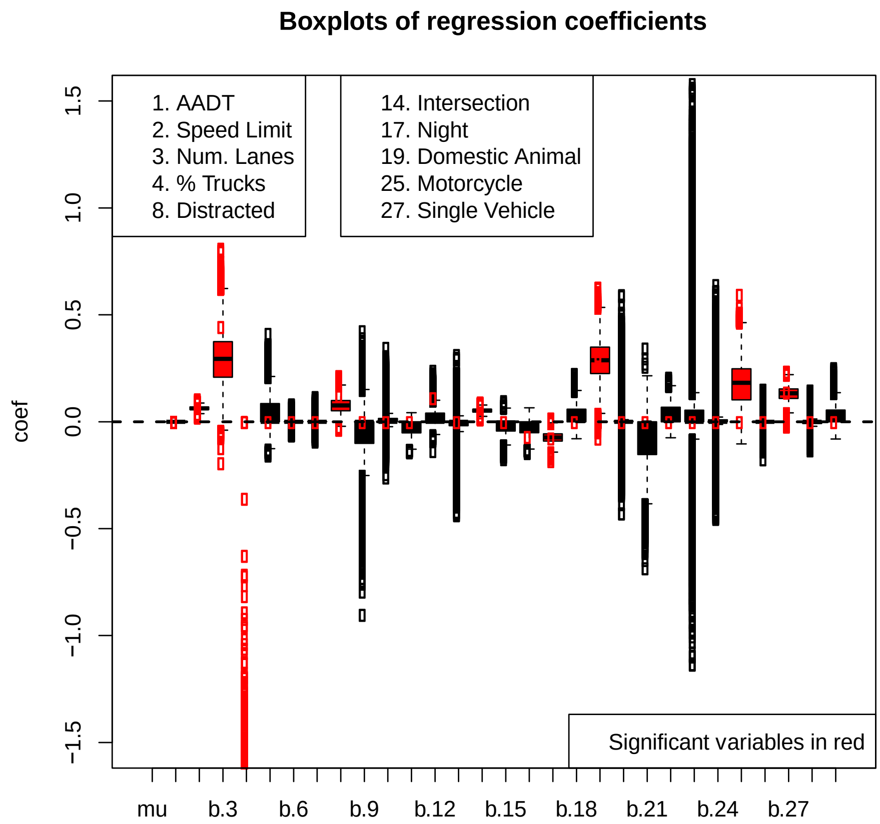


Figure 4-1: Results after running Bayesian horseshoe selection method.

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 the figure, 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.

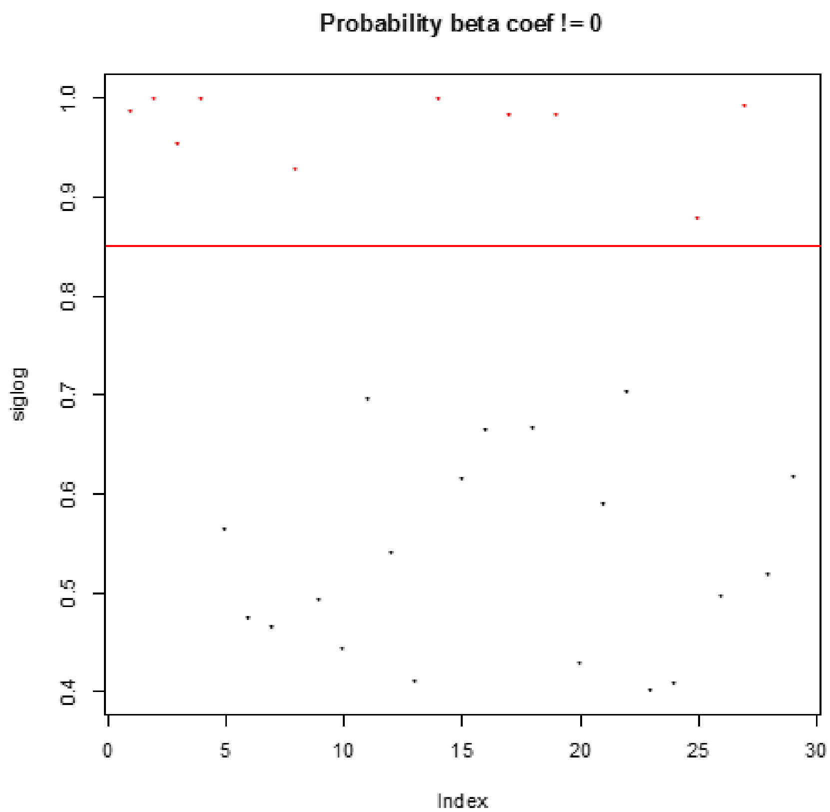


Figure 4-2: Probability that the respective coefficient is not equal to zero.

4.3 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.

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

where:

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}.

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

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

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. 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 $\gamma_{0j}, \gamma_{1j}, \gamma_{2j}, \gamma_{3j}, \gamma_{4j}, \gamma_{5j}, \gamma_{6j}, \gamma_{7j}, \gamma_{8j}, \gamma_{9j}$, 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.

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

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

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

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

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.

4.4 Model Development

The UCPM 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.

4.5 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 UCPM 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, and having the same covariate characteristics such as 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.

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 because it can be compared to the actual crash value and the difference can 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.

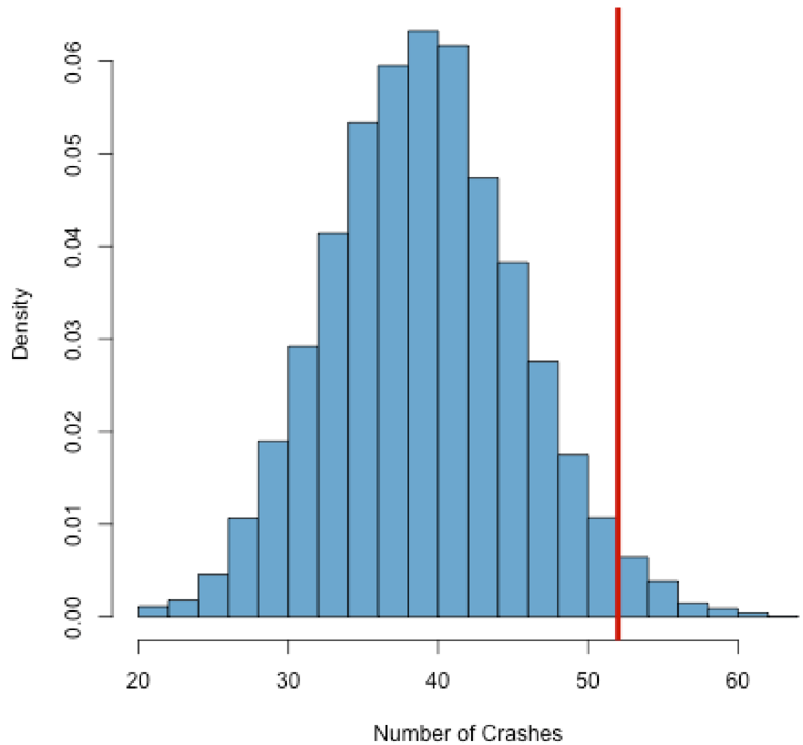


Figure 4-3: Example of a posterior predictive distribution for a single road segment.

4.6 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.

4.6.1 Utah Crash Prediction Model

The UCPM creates a distribution of the number of crashes that could occur. The mean of the distribution represents the expected number of crashes on a specific segment based on the given characteristics of that segment. Based on the distribution of crashes for the segment, a percentile for the segment based on the actual number of crashes on the segment can be calculated. The closer the percentile is to 1.0, the higher the probability that the segment is a hot spot. 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 characteristics associated with crashes, drivers, and 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.

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

The model was run with severity levels B, A, and K. The model results are presented in Section 6.1.

4.6.2 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 that can be analyzed further.

This model can be run with the same dataset as the crash prediction model with one exception. The UCSM 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 UCPM, the probabilities will be for the same severity group as used in for the inputs. The UCSM has flexibility with regard to parameters used in the model. Based on the data used for this analysis the following variables were included in the model.

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

The model results are presented in Section 6.1.

4.7 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 were developed using MCMC and Gibbs sampling methods. By comparing the posterior predictive distribution with the actual number of crashes for a given segment the UCPM can determine if more crashes have occurred on that segment than would normally be expected. The distributions can be used in post analysis to rank each segment to determine which should be the focus of further analysis. Two models were developed for use. 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.

5.0 ROADWAY ATTRIBUTES IDENTIFICATION AND ANALYSIS

5.1 Overview

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, segment definition, roadway attribute definition, problem definition, countermeasure evaluation, selection and recommendation of feasible countermeasures, and completion of 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 the analysis. An application of the methodology with examples is provided in Chapter 6.

5.2 Identifying Problematic Segments for Review

The primary method for identifying problematic segments comes through the statistical procedures of the UCPM and UCSM, which are defined and discussed in Chapter 4. These two models produce different output variables, which require varied methods to rank outputs. The models use the same input data but are run against different severity groups. The UCPM is run against severity levels B, A, and K, while the UCSM is run against only severity levels A and K.

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 as well as the model probability are used.

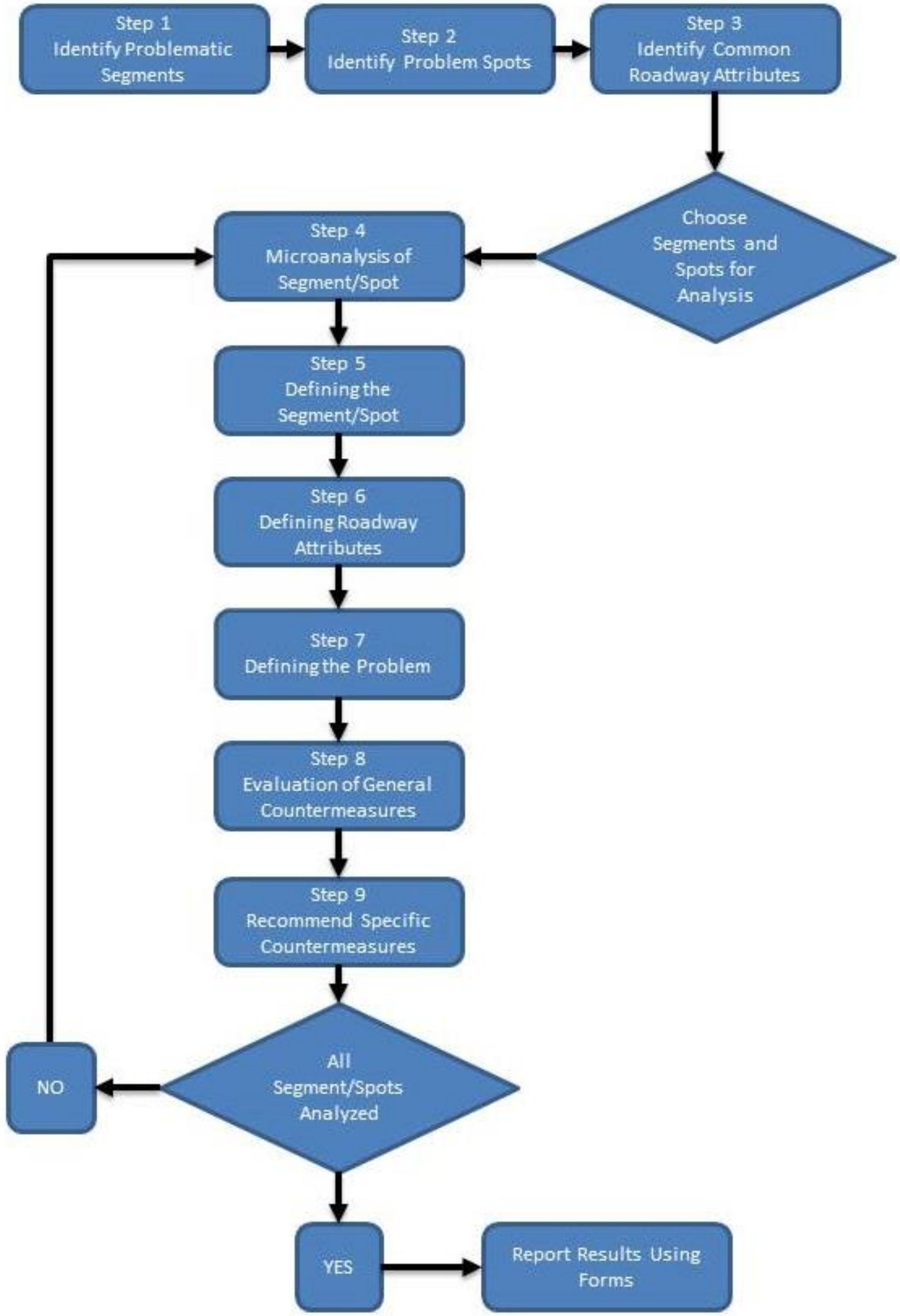


Figure 5-1: Methodology flowchart.

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 as well as the probability that the number of expected crashes occurred are used. Based on the combination of the actual vs. predicted and the probability that the number of expected crashes occurred 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%

5.3 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 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 segment length. The model looks at the segment as a whole with total crashes accounted for along the entire segment length. The segments produced by the methodology described previously can have a wide range of lengths (Schultz et al. 2013). Analysis is necessary 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 segment length and should include all crashes that occurred on the segment within the crash severity group. Problem spots should only be analyzed based on crashes occurring on the reduced section.

ArcGIS has a number of tools for determining locations of problem spots. The two main tools are Strip Analysis and Sliding Scale Analysis (Esri 2014). Both were used and evaluated as part of previous research (Schultz et al. 2012, Schultz et al. 2013). There is not a significant difference between the outputs of these tools, and the Sliding Scale Analysis has a few advantages over the Strip Analysis. For this reason, the Sliding Scale Analysis was used for this research. This tool produces an output file called High Accident Locations or HALs (Esri 2014). Sliding Scale Analysis 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). The user can use the tool to create a list of possible spots along the segments that need further analysis.

5.4 Identifying Common Roadway Attributes within the Segments

As the segment length increases, the likelihood of roadway attribute variation increases. The segments produced by the segmentation process are generally long enough for roadway attribute variation. 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 analysis area, an accurate association can be made between the problem spots and each roadway attribute.

The association of roadway attributes with the micro-segments is accomplished with the Spatial Join and Overlay Route Event linear referencing tools found in ArcGIS (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.

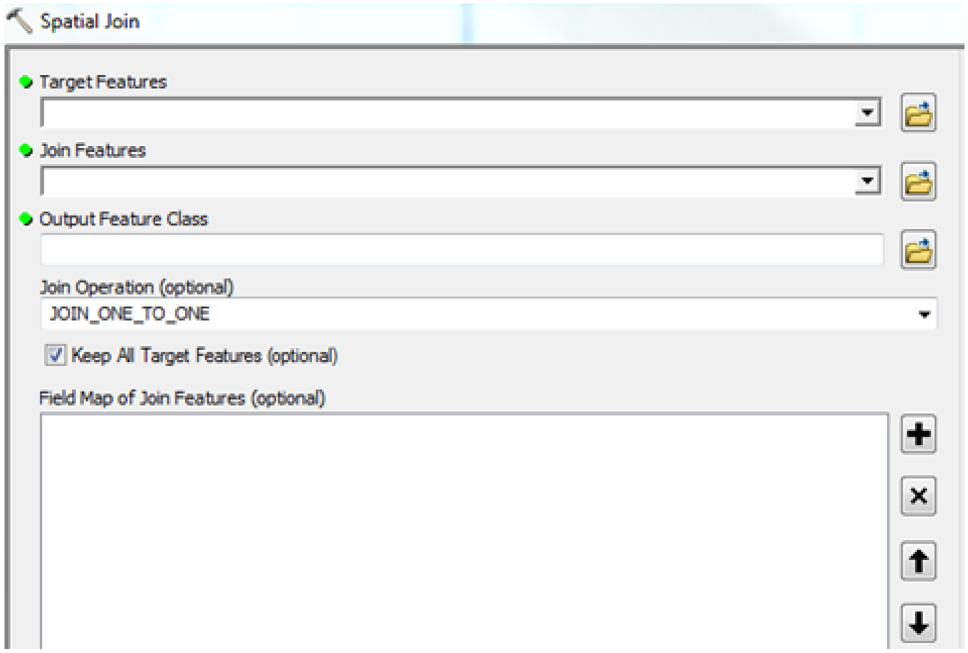


Figure 5-2: Spatial Join (Esri 2014).

With the joining of the data, the roadway attributes can be associated with the micro-segments through the Spatial Join tool or the Overlay Route Event tool. Each tool provides the same end result of roadway attributes at the given micro-segment location but the methods used and the presentation of the results differ. Each method is reviewed in the following sections.

5.4.1 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 attribute 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 to combine 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 analyst preference.

5.4.2 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). It allows the user to create roadway segments based on single or multiple roadway attributes and combines the segmentation process base file with the selected attribute data, 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 more than two 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 after joining of the segment and roadway attributes, based on the user's preference.

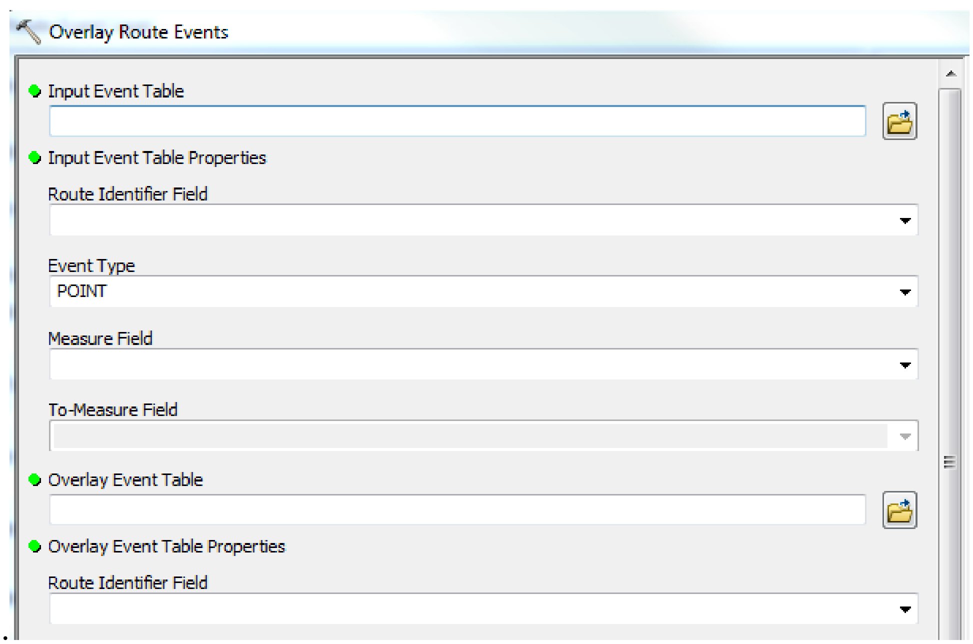


Figure 5-3: Overlay Event Table (Esri 2014).

5.5 Microanalysis of Problematic Segments and Spots

Identifying hot spots, using the statistical model and GIS, and determining roadway attributes at the hot spot locations provides the user with the necessary data to perform segment or spot microanalysis. "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 factors pertinent to microanalysis, such as crash data, LiDAR/roadway attribute data, Internet tools, site visits, and communicating with experts.

5.5.1 Crash Data

The purpose of reviewing crash data is to identify common characteristics at the locations being studied (Schultz et al. 2013). Crash data files are typically large and include information about all the crashes in the study area, not just the ones occurring at the microanalysis locations. Crash datasets can be filtered to only include crashes needed for the analysis with the use of ArcGIS tools such as Select by Location and Spatial Join (Esri 2014).

Crash data come in multiple files based on the information type. Crash datasets should be compiled into a single file because doing so makes it easier to look for common characteristics that could be contributing to safety problems (Schultz et al. 2013). Data compilation and review considerations include: crash sequence of events, vehicle maneuvers, manner of collision, speed, roadway geometry, and intersection presence.

5.5.2 LiDAR/Roadway Attribute Data

The purpose of reviewing roadway attribute data is to identify trends in the types of attributes present at the different hot spots. Each roadway attribute has different fields that may or may not be useful for analysis. The data should be filtered to include only the fields of interest in order to reduce file size and increase review speed. Attributes should then be combined into a single dataset with all attributes listed for each problem spot and problem segment. Table 5-2 contains a list of the attribute fields considered for each hot spot or segment.

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 exist at any point along the segment?
Shoulder	Material	The material at the shoulder location
	Edge Type	The type of edge (e.g., curb and gutter, none, etc.)
	Width	Width of the shoulder
Median	Type	Type of median
	Island	Is there an island?
	Width	Width of the median at location
Intersection	IPM	Number of intersections 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	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

5.5.3 Internet Tools

Internet-based tools such as Google Earth (Google, Inc. 2015a), Google Maps (Google, Inc. 2015b), and UDOT's Roadview Explorer (UDOT 2015b) can assist with microanalysis by providing visual aids of the locations being analyzed. These tools allow users to become more familiar with the locations before performing a site visit. They can also provide information about the history and future of a site that a visit cannot. This is done by looking at past years' data available for the site. Future construction projects can be overlaid in the mapping tools to determine whether changes are planned for the site. Internet tools can also help with preparing for site visits by providing perspectives unavailable on site, such as a bird's eye view. Internet data sources should be reviewed for accuracy and quality (Schultz et al. 2013).

5.5.4 Site Visits

Site visits are important to the microanalysis process because they provide firsthand knowledge of existing conditions and allow for a more complete view of safety concerns. Many items needed for a full analysis can only be learned by being on-site and evaluating the locations from a user perspective. "A site visit allows the analyst to verify or dismiss conclusions drawn from other analysis methods" (Schultz et al. 2013). Site visits can also provide insights into countermeasures that could be used to mitigate safety issues (Schultz et al. 2013).

5.5.5 Communicating with Experts

Communicating with people familiar with site conditions provides a unique perspective. Law enforcement agencies, local and state government officials, traffic engineers, and local department of transportation (DOT) employees have a specific understanding of the past, present, and future of the area. 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). Information gained by communicating with experts and stakeholders provides greater understanding, helps ensure that information isn't overlooked, helps select countermeasures, and provides support for the countermeasures (Schultz et al. 2013).

5.6 Defining the Segment

Segments should be defined based on the MP range after the microanalysis step is completed. The definition process provides an opportunity to increase understanding of site characteristics by including roadway attributes in the definition. Additional information on defining the segment is discussed in the literature (Schultz et al. 2013).

5.7 Defining the Roadway Attributes

Some roadway attributes should be included for all analyzed segments. Number of through lanes and speed limit were used in this research and are included as part of the segment definitions. Additional roadway attributes to consider include intersection type, roadway geometry, median, and other characteristics appropriate for 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 attributes significant to that site.

5.8 Defining the Problem

A clear problem definition makes countermeasure selection easier. This step defines the problem cause and contributing factors, thus making it possible to list potential countermeasures and evaluate their feasibility. If the problem is not successfully defined at first, the process should be repeated 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).

5.9 Evaluation of Possible Countermeasures

Lists of possible countermeasures should include all treatments that may mitigate the safety concerns. “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 implementation timeline, cost, and ability to mitigate the safety problems. For a more complete list of questions, refer to the previous research (Schultz et al. 2013).

5.10 Selection and Recommendation of Feasible Countermeasures

The full list of possible countermeasures is reduced to only those options that are feasible and expected to mitigate the safety concern at the site in question (Schultz et al. 2013). The final step is choosing the countermeasure(s) that will have the greatest impact on improving safety. It is possible that no countermeasure(s) can be recommended. If this occurs, analysts may want to review previous steps to determine if any information was overlooked that could help determine a suitable countermeasure. “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).

5.11 Completing Analysis Reports

To support the methodology discussed in this chapter and previous research (Schultz et al. 2013), formal reports were created to document analysis results. Two report forms were created – one to document the full analysis and another to report the findings. The full analysis report form includes sections for each of the analysis steps. Models used for selection and ranking are also included. Tables are provided to include all crash and roadway geometry characteristics related to the problem definition.

The second form is the hot spot summary report delivered to UDOT. It 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. It should be completed after the analysis is concluded and all information is documented.

Both forms include written descriptions of the data needed, where to find them, and how to process them. A copy of both forms is provided in Appendix A.

5.12 Chapter Summary

The hot spot identification and analysis methodology is comprised of the following steps:

- Problem area identification
- Common roadway attribute definition
- Microanalysis
- Segment definition
- Roadway attribute definition
- Problem definition
- Countermeasure evaluation
- Countermeasure selection
- Analysis report completion

Microanalysis consists of reviewing crash data and roadway attributes found at the locations of interest. Site visits and discussions with people familiar with those locations are also very important for gathering information to fully evaluate and select countermeasures.

Road attributes play a part in analysis, definition, and countermeasure selection. A number of software programs including ArcGIS, Excel, and Internet tools such as Google Maps, Google Earth, and Roadview Explorer can be used to locate, categorize, associate, and analyze roadway attributes and segments.

6.0 EXAMPLES AND RESULTS

6.1 Overview

This chapter is designed to demonstrate the analysis process methodology outlined in Chapter 5 through the use of examples that provide the reader with an improved understanding of the process and steps. This chapter follows the steps in the hot spot analysis methodology: identifying problematic segments for review, 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, and selection and recommendation of feasible countermeasures to complete the analysis reports. The 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. The crash data in this chapter is protected under 23 USC 409.

6.2 Identifying Problematic Segments for Review

A statistical model must be chosen to provide the base dataset identification of the problem segments or hot spots. For this research, crash data from 2008 to 2012 were used. Each model required a different subset of the crash data. For the UCPM, the crash data were filtered to include only severity levels B, A, and K. Total crash counts for each segment and crash counts for each attribute selected by the Bayesian horseshoe selection method were included in this model. The UCPM required 100,000 iterations for each segment to obtain posterior predictive distributions of the number of crashes expected to occur.

For the UCSM, the crash data were filtered to include a subset of the data that included only severity levels A and K to focus the model on the most severe types of crashes. The data for this model include total crash counts for all severity levels and a subset of the crash data for severity levels A and K. The UCSM required 10,000 iterations for each segment to obtain the probabilities and numbers 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 then used to rank segments.

For the UCSM a binomial flag was used to show whether crashes were severe or not. The UCSM was used to determine the probability of a crash being severe if one were to occur. The model was then used to determine the expected number of severe crashes on a given road segment using the total crashes and the probability that the crashes were severe. The actual crash data model inputs were used to determine the probability that the expected number of crashes actually occurred. This probability was used in the ranking process. A low probability of the expected number of severe crashes occurring coincides with a higher ranking. Both models compared actual crashes to 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 methods described above. These segments are ordered from highest ranking downward to the 20th ranking.

Table 6-1: Top 20 UCPM Hot Spots

Route	Beginning MP	Ending MP	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 MP	Ending MP	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

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 severity levels A and K, 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.

6.3 Identify Problem Spots within the Segments

The Sliding Scale analysis tool was used to select possible problem spots within the top 20 segments from both models. Three parameters were required to run the analysis and to determine if problem spots exist: window length, step length, and number of crashes per window.

For analysis of the UCSM top 20 segments, a window length of 1/20 of a mile and step length of 1/40 of a mile were used. A minimum of five crashes per window was used as the threshold to be considered a HAL. Five crashes were selected based on the use of five years of crash data, which would provide an average of one severe crash per year.

For analysis of the UCPM top 20 segments, a window length of 1/20 of a mile and step length of 1/40 of a mile were used, as we done with the UCSM. The crash count threshold for the UCPM needed to be determined to allow for the larger severity group (and resulting larger number of crashes) used in the model. Two minimum crash thresholds were tested. The first was the same as the UCSM – using five crashes of severity levels A and K. The second threshold was 25 crashes per window when using severity levels B, A, and K; where 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 analysis indicated that when adding severity level B, the total crashes used in the model are five times as many crashes than when only using severity levels A and K.

Sliding Scale analysis showed that two problem spots existed within the Top 20 UCSM segments. 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

Neither of the two UCPM minimum thresholds was satisfied for any of the Top 20 segments identified in that model. The sensitivity analysis showed that the 25 crashes per year including severity level B produced similar results as the five 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.

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 body of this report documents the analysis results for the highest ranked problem segment from the UCSM (I-80 from MP 3.993-41.278) and the problem spot located along the 6th highest problem segment (SR-173 from MP 8.516-8.775). These two segments were selected to represent a linear segment and a spot location. Both were selected from the UCSM for severity group consistency.

Analysis results of the 2nd and 3rd ranked problem segments from the UCSM, the problem spot located on the 12th ranked problem segment of the UCSM results, and the top three ranked problem segments from the UCPM results can be found in Appendix B. Appendix B includes two documents for each of the eight segments analyzed – a full report and a results summary.

6.4 Identifying Common Roadway Attributes within the Segments

The Spatial Join tool was applied to the top 20 segments for both models, plus the two problem spots identified from Sliding Scale analysis of the UCSM Top 20 segments. 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, and produced 11 combined datasets.

Three primary parameters were used to run the spatial join tool: target feature class, join feature class, and join operation. The join features class was used to add each roadway attribute at one attribute per run. The "join one to many" (Esri 2014) option was selected as the join operation parameter to collect every variation of roadway attributes. Segment lengths usually do not match roadway attribute segments, so 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 for all 20 segments from both models plus the two problem areas identified from Sliding Scale analysis of the UCSM Top 20 segments. The remaining steps (beginning with Section 6.5 below) were only completed for the top three problem segments from each model and the two problem spots from the UCSM.

6.5 Microanalysis of Problematic Segments and Spots

This section focuses on how microanalysis was applied to the example segments, including a description of crash data LiDAR and roadway attributes, Internet tools, site visits, and communicating with experts.

6.5.1 Crash Data

The crash data were provided in CSV file format for six separate datasets in each of the years 2008 to 2012 (a total of 30 files). Of the six datasets, four were used in the analysis; crash, location, rollup, and vehicle. Although the information in these four datasets was not modified, it was reorganized to make analysis easier. The first step was combining the five yearly files into a single file for each of the four datasets. Then, the four datasets were combined into a single one. The files were compiled using the unique identifier of CRASH_ID that was common to all crash datasets. The crash data originated from the DI-9 forms used by law enforcement officers to document crashes.

The crash dataset was used to pull general information about the crash such as crash conditions, road conditions, light conditions, horizontal alignment, weather conditions, and harmful events. Data fields for first harmful event, collision type, and manner of collision were used for this study.

Crash rollup data are quick reference datasets compiled by UDOT to show 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, the field is marked with a “Y.” Otherwise it is marked with an “N.”

As a general rule, only factors marked “Y” on 40 percent or more of all crashes for a given road segment were included in the analysis. However, when only a few or none of the factors exceeded 40 percent, the fields for driving under the influence (DUI), aggressive driving, speed related, intersection-related, roadway geometry related, and teenage driver were used in regardless of the number of “Y” responses. It is easy to see common characteristics that could be contributing to safety problems when all of the data are compiled into a single file for the segment being analyzed.

The crash vehicle data were also used to determine information on the progression of the crash. This data includes sequence of events, vehicle maneuvers, number of vehicles, and harmful events. Sequence of events and vehicle maneuver were used for this study. The data were organized by crash ID and vehicle ID. Each crash ID includes information 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, they are important and should be considered. The data were reviewed if there were comments, but this information was not added to this report. The crash comments file could be referred to when defining the segment problem 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 all eight analysis segments completed are provided in Appendix B.

6.5.1.1 Crash Data for Hot Spot on I-80. A compilation of the data from the crash, vehicle, and rollup datasets for I-80 MP 3.993-41.278 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 (MP 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 (MP 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 (MP 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

Review of these data tables showed a common trend of rollover and ROR collisions occurring while the vehicles were traveling straight or passing. The possible contributing factors are speeding, night conditions, and DUI.

6.5.1.2 Crash Data for Problem Spot on SR-173. A compilation of the crash data from the crash, vehicle, and rollup datasets for SR-173 MP 8.741-8.775 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.

Table 6-7: Crash File – SR-173 (MP 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 (MP 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 (MP 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

Review of the data tables for the problem spot on SR-173 showed a trend of angle collisions at a signalized intersection. These types of collisions happened while vehicles were traveling straight and turning left. The possible contributing factor is roadway geometry.

6.5.2 LiDAR Data/Roadway Attributes Data

This section focuses on applying roadway attributes to the example segments.

6.5.2.1 Roadway Attributes for Hot Spot on I-80. This segment of I-80 has very little variation in grade. It ranges from 0 percent to -0.88 percent. The absence of vertical curves was expected due to the lack of grade change. 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 sides 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 37-38 feet wide with an installed cable barrier. There are rumble strips on both the right and center of the roadway for most of the segment length. There are four intersections as part of a single interchange at the beginning of the segment and a rest stop located at approximately MP 9.8, producing an IPM of only 0.107. There are 110 signs distributed fairly evenly over the entire segment, producing a SPM of 2.95. Table 6-10 includes the compiled roadway attributes for this segment. 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

6.5.2.2 Roadway Attributes for Problem Spot on SR-173. SR-173 has variation in grade along the segment ranging from 1.1 percent to -1 percent. These grade changes 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 LT and RT lanes for both major approaches.

The roadway includes paved shoulders that terminate in curb and gutter. The average shoulder width is 11 feet and varies from 0 feet (at the intersection) to 16 feet. 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 horizontal curve situated at 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. There are no rumble strips, barriers, or walls at this location. One intersection is present, producing an IPM of only 3.86. There are 11 signs located along the length of full segment, located primarily at the intersection and problem area. These signs produced a SPM of 42.5 due to short segment length. Table 6-11 includes the compiled roadway attributes for this segment.

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

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

6.5.3 Internet Tools

This section focuses on how Internet tools were applied to the example segments.

6.5.3.1 Internet Tools for Hot Spot on I-80. I-80 from MP 3.993-41.278 begins just east of Wendover and continues to the first horizontal curve. 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 shoulders. The shoulders are paved with rumble strips present along most of the length. Figure 6-1 shows a Google Earth image of this segment.

Figure 6-1: Birds eye view of I-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 between 2009 and 2014. The analysis showed that very few changes were made. The changes that were made included restriping and the addition of rumble strips near the rest stop. At locations where the median was narrower, cable barriers were added 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: I-80 in 2009 (UDOT 2015b).

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

6.5.3.2 Internet Tools for Problem Spot on SR-173. SR-173 (5300 South) from MP 8.741-8.775 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 TWLTL. 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 this intersection.

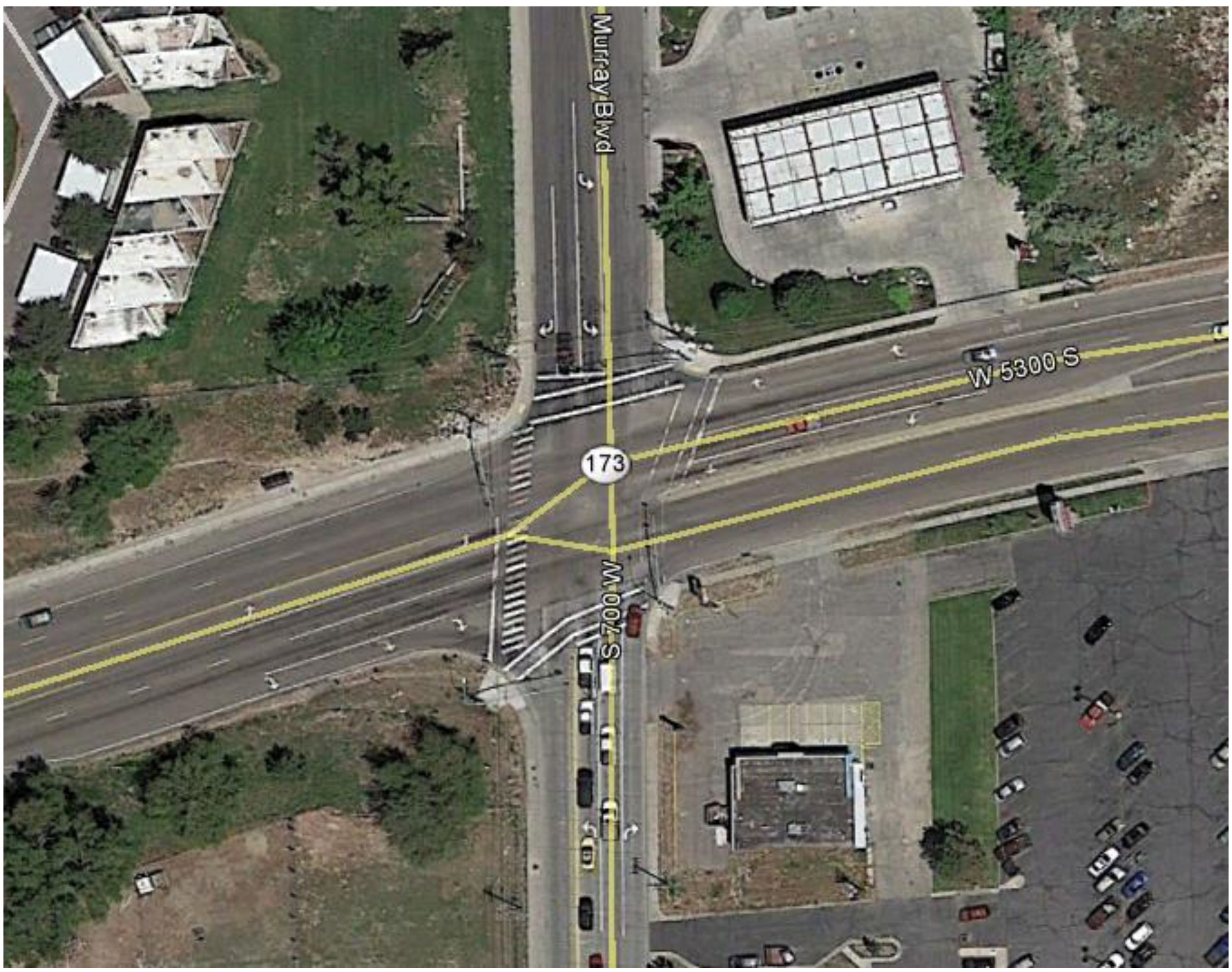


Figure 6-4: Birds eye view of SR-173 (Google, Inc. 2015a).

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

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

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

6.5.4 Site Visits

Site visits allow assumptions to be verified before selecting countermeasures, including changes not represented by Internet tools. This section will focus on how this step is used and the results from applying these tools to the example segments.

6.5.4.1 Site Visit for Hot Spot on I-80. A site visit was made to the I-80 segment 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. Most of the segment was flat and straight. The average measured distance across the center median was 305 feet. A median barrier was present in the westernmost section but ended after about 0.2 miles. Beyond the inside shoulder there was a relatively abrupt drop of a few feet to the center median. Median cable barriers were present between MP 10.5-11.5 and MP 32.5-38.5. 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 I-80.

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

6.5.4.2 Site Visit for Problem Spot on SR-173. A site visit was conducted at the problem spot on SR-173 on April 23, 2015 to take measurements and get a feel for sight distances and any obstructions that might limit visibility on intersection approaches. After this was done, intersection traffic patterns were observed to help understand operations. The signal seemed to operate properly with no obvious problems. Special attention was made to the eastbound approach as 4 of the 6 crashes involved a vehicle from this approach.

Pedestrian crosswalks were hindered by a raised median on the northbound and westbound approaches, which could be a concern as this is a marked school crossing. The approach angle for the eastbound and westbound movements was 72 degrees. Vertical and horizontal curvature as well as obstruction from vegetation on the south side of the road reduces visibility but sight distance still 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.

6.5.5 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). A meeting with UDOT provided insight into how their uPlan Internet tool could be used to see future, current, and past construction projects at the site being analyzed.

6.6 Defining the Segment

The following subsections provide the results of the segment definition step for I-80 and SR-173, respectively.

6.6.1 I-80

The hot spot problem segment on I-80 is located between MP 3.993-41.278. The roadway segment is a divided interstate with two travel lanes in each direction. The posted speed limit was 75 mph during the study period and has since been raised 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 along the westernmost segment. The median and ditch together average 300 feet in width. The inside shoulder is 5 feet wide. The outside shoulder is paved and 10 feet wide. The lanes are 12 feet wide and seem adequate. The problem appears to be along the entire segment length.

6.6.2 SR-173

The problem spot on SR-173 is located primarily at MP 8.77, which is the intersection of 5300 South and Murray Boulevard (700 West). This spot is part of a larger hot spot problem segment on SR-173 between MP 8.516-8.775. 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 primary problem spot occurs for traffic traveling on 5300 South, which has two lanes in each direction. The eastbound and southbound directions have LT lanes and RT lanes with storage lengths of approximately 200 feet. At the intersection there is no shoulder, but there is a gutter, curb, and sidewalk. A raised median on the east side separates opposing traffic. 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.

6.7 Defining the Roadway Attributes

The following subsections define the roadway attributes for the I-80 and SR-173 segments, respectively.

6.7.1 I-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 inside and outside shoulders are all about 5 feet in width. 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 segment length.

6.7.2 SR-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, LT, and RT lanes. The roadway includes a variable width paved shoulder curb and gutter. A raised median on the east side of the intersection separates 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.

6.8 Defining the Problem

The following subsections define the problem for I-80 and SR-173 segments, respectively.

6.8.1 I-80

The safety problem along the I-80 segment is an excess of ROR and rollover crashes resulting in severity levels A and K crashes. Based on the crash data in Tables 6-4, 6-5, and 6-6, possible contributing factors are speeding, DUI, and light conditions (i.e., night time driving). The flat, straight roadway geometry could also be a possible contributing factor.

6.8.2 SR-173

The safety problem at the SR-173 spot location is an excessive number of right angle collisions between vehicles turning left and vehicles driving straight through, resulting in severity levels A and K crashes. Based on the crash data in Tables 6-7, 6-8, and 6-9, possible contributing factors are intersection geometry and layout.

6.9 Evaluation of Possible Countermeasures

The purpose of safety analysis, segment definition, and problem definition is to create a comprehensive list of all possible countermeasures that can be evaluated to improve safety. The list is then evaluated to eliminate unfeasible countermeasures for the segment being analyzed. The following subsections provide the results of this step for I-80 and SR-173, respectively.

6.9.1 I-80

The following is a list of possible countermeasures for the I-80 hot spot problem segment.

- Install mid-lane rumble strips
- Eliminate shoulder drop off
- Widen shoulders
- Design safer slopes and ditches to prevent rollovers
- Install median and/or shoulder barriers
- Add or improve roadside hardware
- Widen inside and outside shoulders
- Conduct regular well-publicized driving while intoxicated (DWI) checkpoints

This list was evaluated based on the criteria and questions found in Section 5.9. The countermeasures are specific to the problem and not the site, and were compiled using the countermeasure matrices found in past research (Schultz et al. 2013). Only countermeasures related to ROR, rollover, and DUI collisions were evaluated.

6.9.2 SR-173

The following is a list of possible countermeasures for the SR-173 problem spot location.

- 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
- Install or improve signal coordination along a corridor or route
- Install advance warning signs
- Restrict turning movements

This list was evaluated based on the criteria and questions found in Section 5.9. The countermeasures 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.

6.10 Selection and Recommendations of Feasible Countermeasures

The final step in the methodology is selecting countermeasures for implementation. The possible countermeasures listed in Section 6.9 were evaluated for feasibility. The following subsections provide the results of this step in the methodology. Economic considerations were not analyzed as this was beyond the scope of this project. All countermeasures were selected based on their proven status from the NCHRP Report 500 series.

6.10.1 I-80

The following provides a list of suggested feasible countermeasures for the I-80 hot spot problem segment.

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

6.10.2 SR-173

The following provides a list of suggested feasible countermeasures for the SR-173 problem spot location.

- 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

6.11 Chapter Summary

This chapter discussed hot spot identification and analysis methodology steps. It illustrated them by using two specific examples – the 1st ranked hot spot problem segment located on I-80 between MP 3.993-41.278 and the highest crash count problem spot located on SR-173 at MP 8.77. A discussion of the locations and results for each of the individual methodology steps was covered.

For both of these examples, a list of possible countermeasure recommendations is provided for implementation. The main purpose of this chapter was to show how to follow the methodology to improve roadway safety by selecting feasible countermeasures for implementation at known hot spots. Appendix B includes two documents (a full report and a results summary) for each of the eight segments analyzed.

7.0 CONCLUSION

7.1 Overview

The purpose of this research was to advance 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 model update included the addition of roadway asset data (including the LiDAR roadway inventory data) to allow closer examination of the data, identify key roadway characteristics that contribute to crashes, and then search on those characteristics to identify and prioritize safety projects statewide. This included improving the methodology for 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.

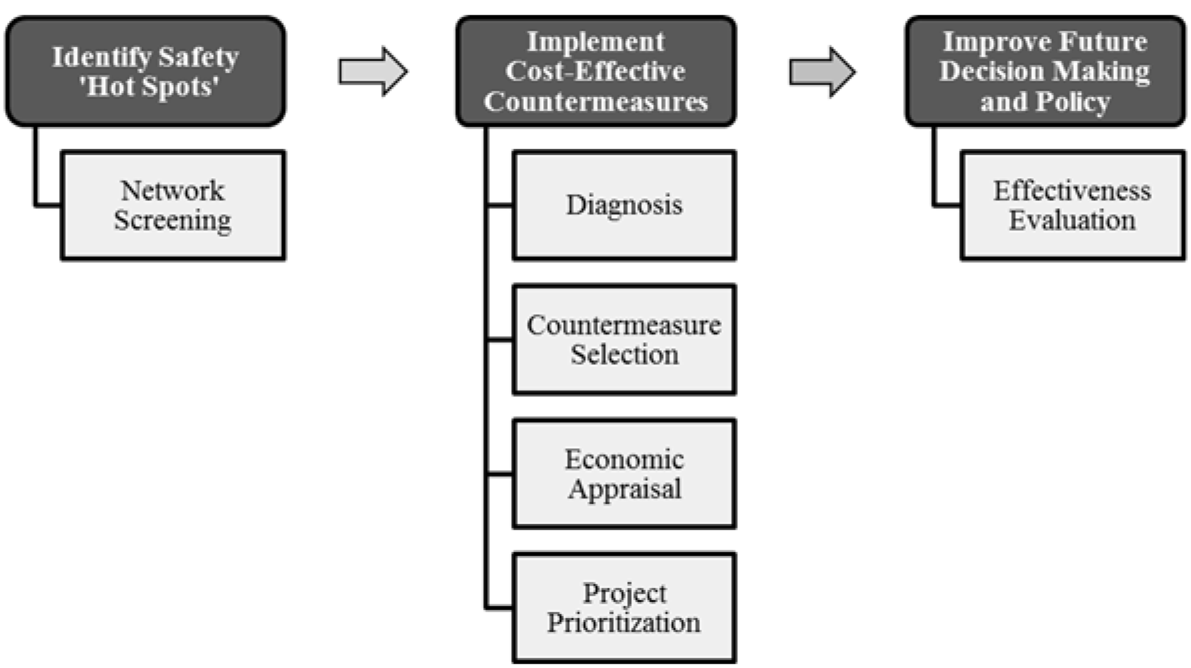


Figure 7-1: Framework for highway safety mitigation (adapted from AASHTO 2010).

This chapter briefly summarizes the enhancements 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.

7.2 Roadway Attributes Summary

Procedures were improved and created to associate roadway attributes with the segments and crash data for use with the models and analysis. These procedures include the use of ArcGIS tools such as Spatial Join and Overlay Route Event to combine the roadway attributes with the respective road segments. By associating the roadway data with the segment or crash, further analysis can be conducted to determine roadway characteristics along problem segments or at problem spots. Roadway attributes must be available in a spatial format in order for this process to work. Sub-steps were added to the "Hot Spot Identification and Analysis" methodology (Schultz et al. 2013). These sub-steps involve 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" to include defining the roadway attributes for the problem segment.

7.3 Variable Selection Summary

Adding roadway attributes and crash characteristics to the model required development of a selection method to determine whether those attributes and characteristics were helpful in determining locations for further analysis. A Bayesian horseshoe selection method was developed for this purpose. The data preparation process included associating all desired roadway attributes with each crash. The Bayesian horseshoe selection method provides an output of the statistically significant parameters that were determined to be helpful. These parameters were then be collected, combined, and used in the UCPM.

7.4 UCPM and UCSM Summary

Utah has generally experienced a decrease in severe crashes (severity levels A and K) in recent years. This decrease reduces the quantity of data that can be used in the UCPM. A limitation of the UCPM is that fewer data points can lead to reduced accuracy. Severity level B crashes were added to the model to overcome this limitation. This addition skewed the UCPM outputs to segments that had only a few or none of severity levels A and K crashes. These outputs are still useful, but require an additional method to focus solely on the high severity crashes. The UCSM was created to address this need.

The UCSM uses Bayesian statistics with a binomial indicator to focus on a specific severity level with limited data by including data for all crash severities and for a single desired crash severity. Locations of potential safety problems can be identified for further analysis through the use of both the UCPM and UCSM. Locations chosen for further analysis based on model results are shown in Tables 7-1 and 7-2.

Table 7-1: Analyzed UCPM Hot Spots

Route	Beginning MP	Ending MP	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 MP	Ending MP	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	7.000	7.400	Minor Arterial	71	6	4.576	0.020	0.003

7.5 Future Research

Four areas of recommended future research were identified. These areas would be consistent with past research and continue to aid UDOT in meeting their goal of improved safety. These areas of research are development of an intersection predictive crash model with the use of parameter selection, development of a methodology to accomplish the next two steps of the framework for highway safety mitigation (economic appraisal and project prioritization), implementation of the model at a national level using available data from other states, and development of a graphical user interface (GUI) for all of the models.

7.5.1 Intersection Predictive Crash Model

The purpose of using roadway and crash attributes in models is to increase crash prediction ability. Attributes and characteristics can be selected to focus on specific areas of analysis. Further research is recommended to develop an intersection crash prediction model.

7.5.2 Continued Methodology Development

The enhanced methodology described in this report 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 two steps (economic appraisal and project prioritization). Further research to develop such a methodology is recommended.

7.5.3 Implementation on a National Level

The research described in this paper developed a step-by-step data preparation process to take data in various forms and produce a single dataset for use in the crash models. Crash data from additional sources could be formatted into datasets for use in the models. Further research is recommended to gather and evaluate other states' crash data to see if they would be suitable for the models.

7.5.4 Development of a GUI for the Model Interface

Further research is recommended to develop a user-friendly GUI for adding crash data and running the models. Doing so would help produce desired results more efficiently and make it easier for future analysts to use the models.

REFERENCES

American Association of State and Highway Transportation Officials (AASHTO). (2010). Highway Safety Manual. Washington, DC.

Antonucci, N. D., Hardy, K. K., Slack, K. L., Pfefer, R., and Neuman, T. R. (2004). "NCHRP Report 500: Volume 12: A Guide for Reducing Collisions at Signalized Intersections." National Cooperative Highway Research Program. Transportation Research Board, Washington, DC.

Bassett, D., Farnsworth J., Cook A., and Roundy R., (2015). " The Utah Crash Prediction Model: User's Guide." Brigham Young University, Provo, UT.

Carvalho, C. M., Polson, N. G., and Scott, J. G. (2008), "The Horseshoe Estimator for Sparse Signals," Discussion Paper 2008-31, Duke University Department of Statistical Science.

Esri. (2014). "Linear Referencing with ArcGIS Desktop." <http://www.esri.com/software/arcgis/arcgis-for-desktop/features> (June 21, 2014).

Gelfand, A. E., and Smith, A. F. M. (1990), "Sampling-Based Approaches to Calculating Marginal Densities," *Journal of the American Statistical Association*, 85, pp. 398-409.

Goodwin, A., Foss, R., Hedlund J., Sohn, J., Pfefer, R., Neuman, T. R., Slack, K. L., Hardy, K. K., (2005). "NCHRP Report 500: Volume 16: A Guide for Reducing Alcohol-Related Collisions." National Cooperative Highway Research Program. Transportation Research Board, Washington, DC.

Google, Inc. (2015a). "Google Earth." <www.google.com/earth.index.html> (August 20, 2013).

Google, Inc. (2015b). "Google Maps." <https://maps.google.com > (July 26, 2013).

Gross, F., Persaud, B., and Lyon, C. (2010). "A Guide to Developing Quality Crash Modification Factors." Report FHWA-SA-10-032. Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

Hadi, M. A., Aruldhas, J., Chow, L., and Wattleworth, J. A. (1995). "Estimating Safety Effects of Cross-Section Design for Various Highways Types Using Negative Binomial Regression." *Transportation Research Record: Journal of the Transportation Research Board*, 1500, Transportation Research Board, Washington, DC, 169-177.

Hauer, E. (1997). "Observational Before-After Studies in Road Safety: Estimating the Effect of Highway and Traffic Engineering Measures on Roadway Safety", Pergamon, Oxford UK.

Hauer, E., Harwood, D. W., Council, F. M., and Griffith, M. S. (2002). "Estimating Safety by the Empirical Bayes Method: A Tutorial." *Transportation Research Record: Journal of the Transportation Research Board*. 1784, Transportation Research Board, Washington, DC, 126-131.

Herbel, S., Laing, L., and McGovern, C. (2010). "Highway Safety Improvement Program (HSIP) Manual." Report DTFH61-05-D-00026. Federal Highway Administration, Washington, DC.

National Oceanic and Atmospheric Administration (NOAA). (2014). "What is LiDAR?" <http://oceanservice.noaa.gov/facts/lidar.html> (July 16, 2014).

Neuman, T. R., Pfefer, R., Slack, K. L., Lacy, K., and Zegeer, C. (2003a). "NCHRP Report 500: Volume 3: A Guide for Addressing Collisions with Trees in Hazardous Locations." National Cooperative Highway Research Program. Transportation Research Board, Washington, DC.

Neuman, T. R., Pfefer, R., Slack, K. L., Hardy, K. K., McGee, H., Prothe, L., Eccles, K., and Council, F. (2003b). "NCHRP Report 500: Volume 4: A Guide for Addressing Head-On Collisions." National Cooperative Highway Research Program. Transportation Research Board, Washington, DC.

Neuman, T. R., Pfefer, R., Slack, K. L., Hardy, K. K., Harwood, D. W., Potts, I. B., Torbic, D. J., and Rabbani, E. R. K. (2003c). "NCHRP Report 500: Volume 5: A Guide for Addressing Unsignalized Intersection Collisions." National Cooperative Highway Research Program. Transportation Research Board, Washington, DC.

Neuman, T. R., Pfefer, R., Slack, K. L., Hardy, K. K., Council, F., McGee, H., Prothe, L., and Eccles, K. (2003d). "NCHRP Report 500: Volume 6: A Guide for Addressing Run-Off-Road Collisions." National Cooperative Highway Research Program. Transportation Research Board, Washington, DC.

Neuman, T. R., Nitzel, J. J., Antonucci, N., Nevill, S., and Stein, W. (2008). "NCHRP Report 500: Volume 20: A Guide for Reducing Head-On Crashes on Freeways." National Cooperative Highway Research Program. Transportation Research Board, Washington, DC.

Neuman, T. R., Slack, K. L., Hardy, K. K., Bond, V. L., Potts, I., and Lerner, N. (2009). "NCHRP Report 500: Volume 23: A Guide for Reducing Speeding-Related Crashes." National Cooperative Highway Research Program. Transportation Research Board, Washington, DC

Olsen, A. N., Schultz, G. G., Thurgood, D. J., and Reese, C. S. (2011). "Hierarchical Bayesian Modeling for Before and After Studies." *Compendium of the Transportation Research Board 90th Annual Meeting*, Transportation Research Board, Washington, DC.

Pradhan, A., and Rasdorf, W., (2009). "GIS and LiDAR Use for Identification of Potential Road Hazard Locations." *Computing in Civil Engineering*, pp. 125-134.

Qin, X., Ivan, J. N., and Ravishanker, N. (2004). "Selecting Exposure Measures in Crash Rate Prediction of Two-Lane Highway Segments." *Accident Analysis and Prevention*, 36(2), 183-191.

Qin, X., Ivan, J. N., Ravishanker, N., and Lui, J. (2005). "Hierarchical Bayesian Estimation of Safety Performance Functions for Two-Lane Highways Using Markov Chain Monte Carlo Modeling." *Journal of Transportation Engineering*, pp. 131, 345-351.

R Project for Statistical Computing (RPSC). (2012). "What is R," <http://www.r-project.org> (May 2, 2012).

Ramsey, F. L., and Schafer, D. W. (2002). *The Statistical Sleuth: A Course in Methods of Data Analysis.* Third Edition, International Edition.

Saito, M., Schultz, G. G., and Brimley, B. K. (2011). "Transportation Safety Data and Analysis, Volume 2: Calibration of the Highway Safety Manual and Development of New Safety Performance Functions," Report UT-10.12b, Utah Department of Transportation Traffic and Safety, Research Divisions, Salt Lake City, UT.

Schultz, G. G., Thurgood, D. J., Olsen, A. N., and Reese, C. S. (2010). "Transportation Safety Data and Analysis, Volume 1: Analyzing the Effectiveness of Safety Measures using Bayesian Methods." Report UT-10.12a, Utah Department of Transportation Traffic and Safety, Research Divisions, Salt Lake City, UT.

Schultz, G. G., Dudley, S. C., and Saito, M. (2011). "Transportation Safety Data and Analysis, Volume 3: Framework for Highway Safety Mitigation and Workforce Development." Report UT-10.12c, Utah Department of Transportation Traffic and Safety, Research Divisions, Salt Lake City, UT.

Schultz, G. G., Johnson, E. S., Black, C. W., Francom, D., and Saito, M. (2012). "Traffic and Safety Statewide Model and GIS Modeling." Report UT-12.06, Utah Department of Transportation Traffic and Safety, Research Division, Salt Lake City, UT.

Schultz, G. G., Farnsworth, J. S., Roundy, R., Saito, M., Reese, C. S., and Briggs, T. (2013). "Hot Spot Identification & Analysis Methodology." Report UT-13.15, Utah Department of Transportation Traffic and Safety, Research Division, Salt Lake City, UT.

Strathman, J. G., Dueker, K. J., Zhang, J., and Williams, T. (2001). "Analysis of Design Attributes and Crashes on the Oregon Highway System." Report FHWA-OR-RD-09-01. Oregon Department of Transportation (ODOT), Salem OR. and Federal Highway Administration, Washington, DC.

Utah Automated Geographic Resource Center (AGRC), (2014). "Utah GIS Portal." <http://www.gis.utah.gov/ > (January 12, 2015).

Utah Department of Transportation (UDOT). (2014). "Utah DOT Leveraging LiDAR for Asset Management Leap." <https://www.udot.utah.gov/public/ucon/uconowner.gf?n= 8336606666333974> (July 16, 2014).

Utah Department of Transportation (UDOT). (2015a). "UDOT Open Data." <http://www.udot.uplan.opendata.arcgis.com> (Oct 8, 2014).

Utah Department of Transportation (UDOT). (2015b). " UDOT Roadview Explorer." <http://roadview.udot.utah.gov> (Mar 3, 2015).

Utah Traffic Records Coordinating Committee (Utah TRCC) (2012). "Utah Investigators Vehicle Crash Report Instruction Manual." Uniform Crash Report DI-9. Utah Driver's License Division, Utah.

Wu, H., Gao, L., and Zhang, Z., (2014). "Analysis of Crash Data Using Quantile Regression for Counts." *Journal of Transportation Engineering*, 140(4).

Zeng, Q., and Huang, H., (2014). "Bayesian Spatial Joint Modeling of Traffic Crashes on an Urban Road network." *Accident Analysis and Prevention*, 67(1), pp 105-112.

Zero Fatalities: A Goal We Can Live With. (2013). "Utah Strategic Highway Safety Plan." Version 3. <http://ut.zerofatalities.com/downloads/SHSP-ZeroFatalities.pdf> (May 10, 2013).

Zou, Y., K. J., Zhang, Y., and Lord, D. (2013). "Analyzing Different Functional Forms of the Varying Weight Parameter for Finite Mixture of Negative Binomial Regression Models." *Analytic Methods in Accident Research*, 1(0), pp 39-52.

APPENDIX A: BLANK ANALYSIS REPORTS

A-1 Full Analysis Report

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 Summary 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.

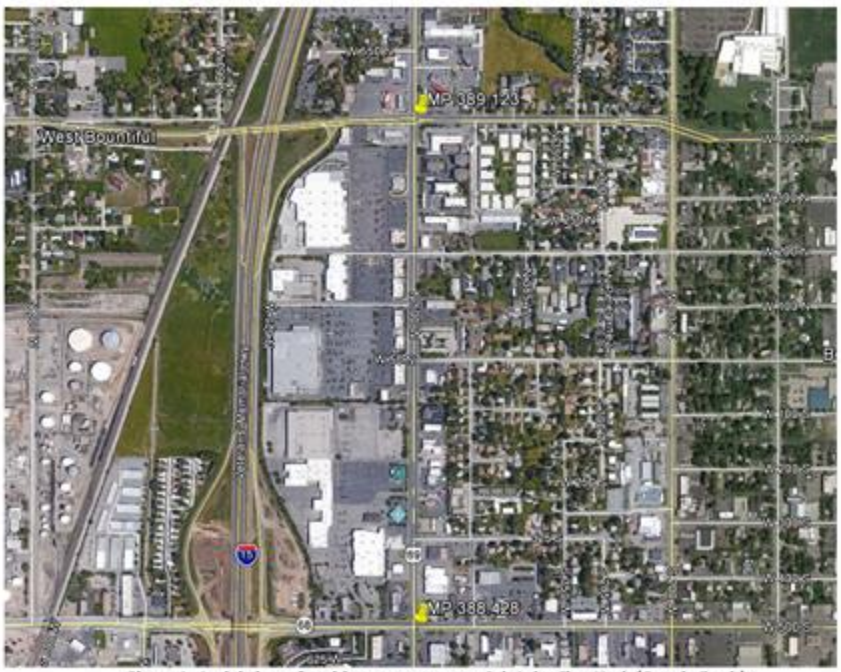


Figure 1: Aerial view of problem segment near Salt Lake City, Utah (Google Earth).

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.

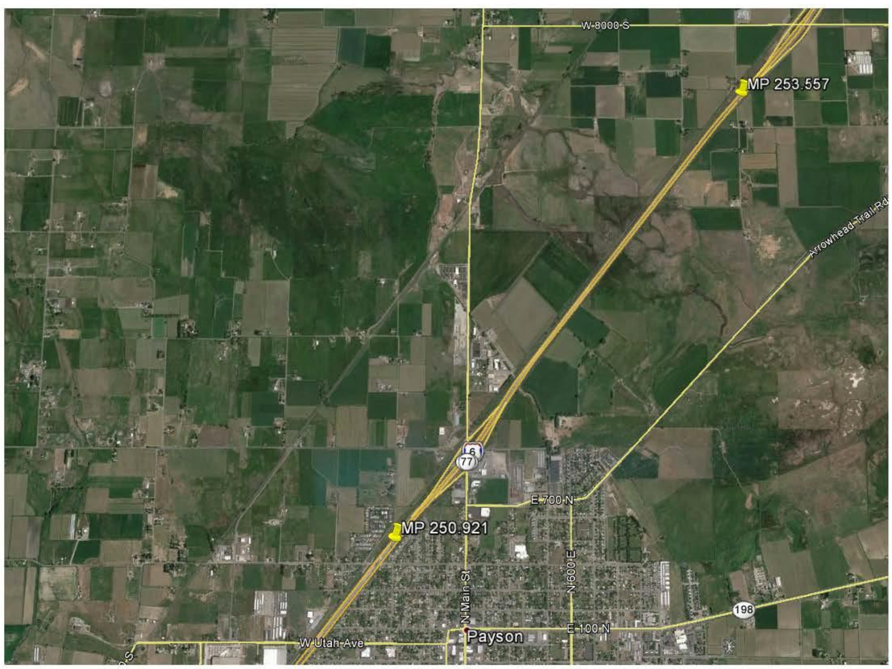


Figure 1: Aerial view of problem segment near Payson, Utah (Google Earth).

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

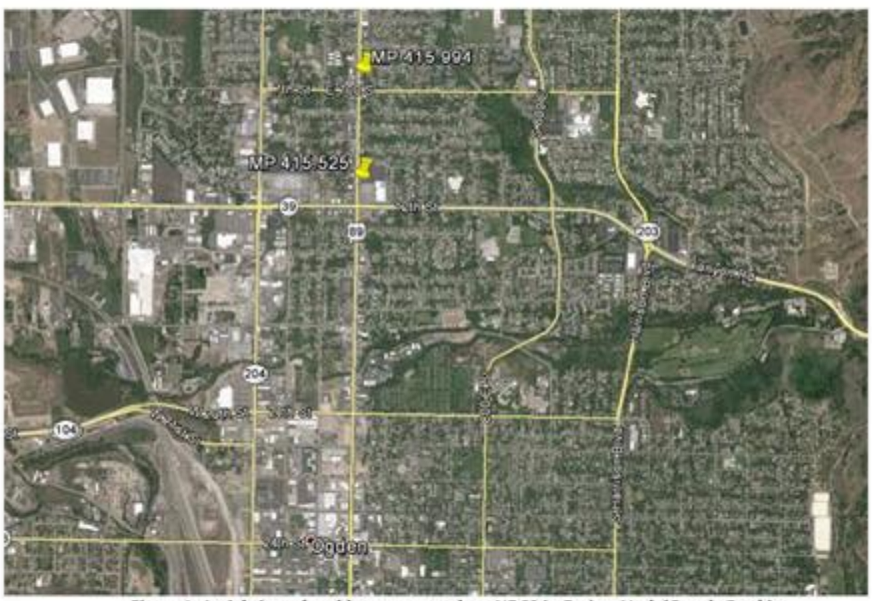


Figure 1: Aerial view of problem segment along US 89 in Ogden, Utah (Google Earth).

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.

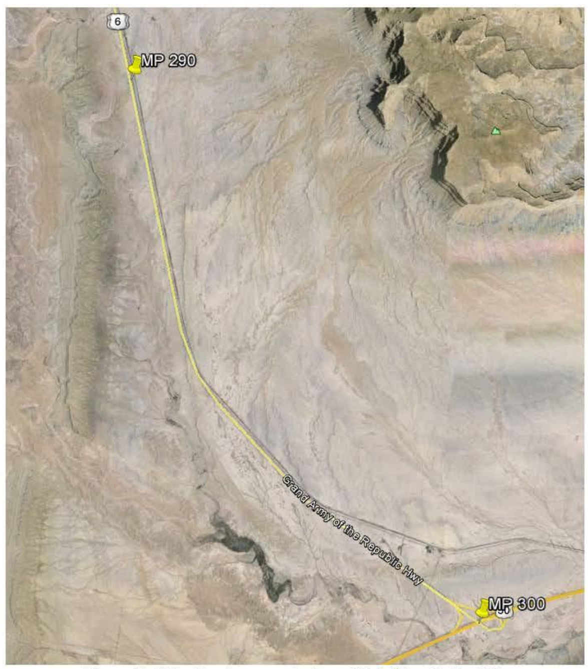


Figure 2: Extents of segment along US-6 (Google Earth).

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

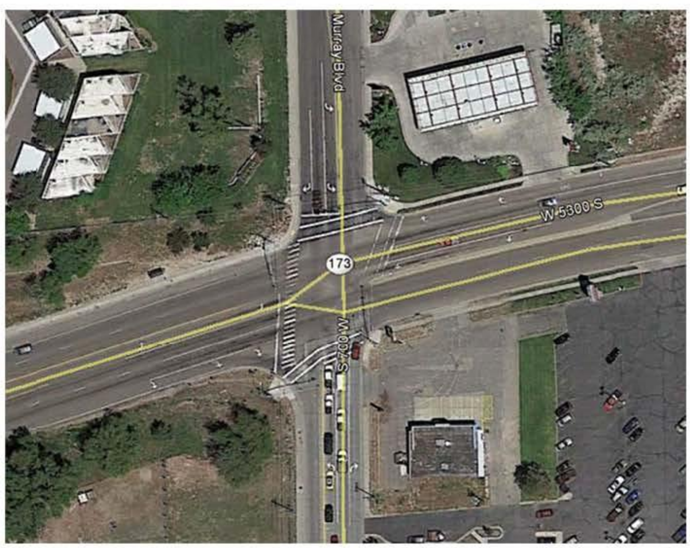
10453787	1	Motor Vehicle	Angle	Motor Vehicle	Motor Vehicle	Straight Ahead, Straight Ahead

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

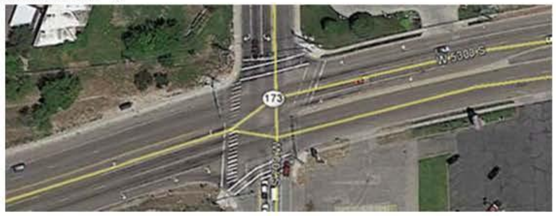
Crash Data

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