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Hot Spot Identification and Analysis Methodology

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ABSTRACT

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The Utah Department of Transportation (UDOT) Traffic and Safety Division continues to advance the safety of roadway sections throughout the state. To aid UDOT in meeting their goal the Department of Civil and Environmental Engineering at Brigham Young University (BYU) has worked with the Statistics Department in developing analysis tools for safety. The most recent of these tools has been the development of a hierarchical Bayesian Poisson Mixture Model (PMM) statistical model of traffic crashes and safety on UDOT roadways statewide and the integration of the results of this model in a Geographic Information System (GIS) framework.

This research focuses on the enhancement of the framework for highway safety mitigation in Utah with its six primary steps: 1) network screening, 2) diagnosis, 3) countermeasure selection, 4) economic appraisal, 5) project prioritization, and 6) effectiveness evaluation. The framework was enhanced by developing a methodology for accomplishing the steps of network screening, diagnosis, and countermeasure selection. This methodology is titled, “Hot Spot Identification and Analysis.”

The hot spot identification and analysis methodology consists of the following seven steps: 1) identify problematic segments with safety concern, 2) identify problem spots within the segments, 3) micro analysis of problematic segments and spots, 4) defining the segment, 5) defining the problem, 6) evaluation of possible countermeasures, and 7) selection and recommendation of feasible countermeasures. The methodology is to help in the identification of hot spots with safety concerns so that they can be analyzed and countermeasures can be identified to mitigate the safety issues. Examples of how the methodology is to function are given with specific examples from Utah’s state roadway network.

Keywords: Poisson Mixture Model, hot spots, countermeasures, safety

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1 INTRODUCTION

The Utah Department of Transportation (UDOT) Traffic and 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 continued 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 provides the background information and objectives related to this research report as well as a brief overview of the organization of the report.

1.1 Background

To aid UDOT in meeting their goal of advancing the safety of roadway sections throughout the state, 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 and safety by functional classification, vehicle miles traveled (VMT), speed limit, and other factors on UDOT roadways statewide and the integration of the results of this model in a Geographic Information System (GIS) framework. The development of these tools, combined with previous research focused around evaluating effectiveness of safety improvements, have helped set the stage for this phase of the research.

The framework for highway safety mitigation in Utah, as outlined in Figure 1-1, consists of six primary steps: 1) network screening, 2) diagnosis, 3) countermeasure selection, 4) economic appraisal, 5) project prioritization, and 6) effectiveness evaluation (Schultz et al. 2011). The framework provides a logical and comprehensive context within which efforts to improve highway safety can be made. As outlined in the framework, first, safety hot spots in a roadway network may be identified through network screening by comparing actual safety performance with expected performance at a site using statistical methods outlined in the literature (AASHTO 2010, Schultz et al. 2011). If the actual safety performance at a site has a significantly higher number of crashes than expected, the site is considered a hot spot and should be examined more closely to determine cost-effective countermeasures that could be implemented. To determine the countermeasure to implement, a thorough analysis of the site must be conducted and countermeasures selected. The countermeasures can then be evaluated for economic viability and compared and prioritized to find a preferred alternative for implementation. The last objective of the framework is to improve future decision making and policy through a thorough effectiveness evaluation of implemented highway safety improvement projects (Schultz et al. 2011).

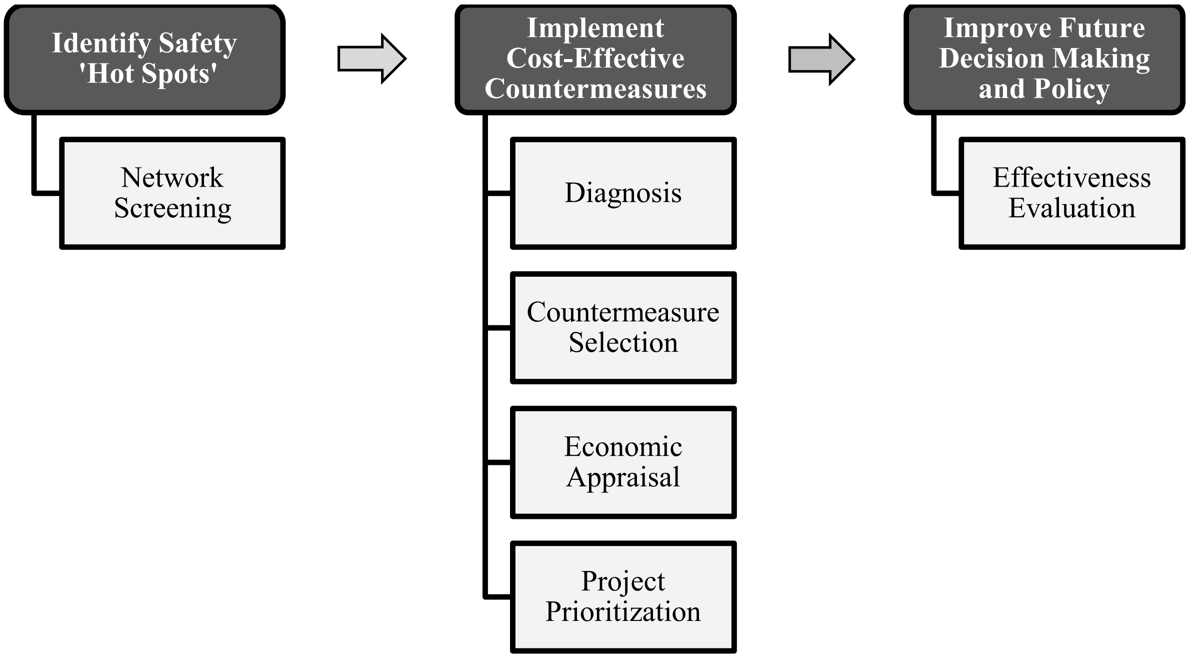

Figure 1-1: Framework for highway safety mitigation (Schultz et al 2011).

1.2 Objectives

The primary objective of this research is to advance the level of safety research in the state of Utah further by applying the framework for highway safety mitigation across the state and building upon recently completed research to provide UDOT with transportation safety research that goes beyond today and addresses the future of the system and the needs of tomorrow. This objective is accomplished by the development of a methodology for accomplishing the first three steps of the framework for highway safety mitigation. This methodology is titled, "Hot Spot Identification and Analysis," and covers the network screening, diagnosis, and countermeasure selection steps.

1.3 Organization

This report is organized into the following chapters: 1) introduction, 2) literature review, 3) data, 4) statistical model, 5) hot spot identification and analysis methodology, 6) methodology examples and results, and 7) conclusions. A list of references, list of acronyms, and appendices follow the indicated chapters.

Chapter 1 presents the background and objectives of this study.

Chapter 2 is a literature review outlining the safety, crash analysis techniques, and countermeasures based on crash type.

Chapter 3 discusses the data used in this analysis. General data considerations are given along with the importance of data uniformity so that the data can be easily used for specific steps of the methodology process.

Chapter 4 discusses the theoretical basis for the hierarchical Bayesian model that was developed for the identification of hot spot segments. A summary of the components used to develop the model and the resulting output of the model is also discussed.

Chapter 5 is a general discussion on the steps of the hot spot identification and analysis methodology. The discussion provides a brief overview of the methodology steps along with general considerations to follow for the methodology.

Chapter 6 is an in-depth discussion on each of the methodology steps with specific examples for each step. This chapter goes into detail on how the data are to be used and when they should be used.

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

2 LITERATURE REVIEW

A literature review was performed on traffic safety and possible countermeasures available for roadway safety improvement. This chapter gives the reader a background into safety, crash analysis techniques, and crash type countermeasures. The countermeasure literature review focuses mainly on the National Cooperative Highway Research Program (NCHRP) Report 500 series. For more detail on the safety and crash analysis techniques, the reader should refer to previous research related to this topic (Saito et al. 2011, Schultz et al. 2010, Schultz et al. 2011, Schultz et al. 2012).

2.1 Safety

Traffic and roadway safety is defined several ways. A subjective definition is based on the perception of how safe the transportation system 'feels' to an observer or user. An objective definition is based on a quantitative measure of safety. This quantitative measure is typically a crash frequency or crash severity (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). To understand safety it is also important to understand 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).

Improving roadway safety is a main focus for UDOT. The importance of safety can be seen in Utah's current safety campaign which is a comprehensive and integrated plan aimed to reduce serious injuries and fatalities. This safety campaign was implemented in 2003 by UDOT and other safety agencies throughout the state including the Utah Department of Public Safety (UDPS), Utah Department of Health (UDOH), and the Utah Transit Authority (UTA). The goal is to reduce the number of serious injuries and fatalities throughout the state with the ultimate goal of zero fatalities. "Zero Fatalities: A Goal We Can All Live With™" is the title of this safety campaign (Zero Fatalities 2013). As the importance of safety is better understood and considered, greater strides can be made to reduce the number of fatalities that occur on roadways.

2.2 **Crash Analysis Techniques**

Crash analysis techniques and methods are very important for improving traffic safety. There are many different techniques and methods that can be employed to analyze safety of a roadway. Each method has advantages and disadvantages depending on the intent of the analysis and available data (Herbel et al. 2010, Schultz et al. 2012). These techniques and methods fall under one of two categories: traditional descriptive analysis and predictive analysis. The purpose of crash analysis in any form is to find unsafe areas on the roadway network.

2.2.1 Traditional Descriptive Analysis

A traditional descriptive analysis focuses on summarizing, quantifying, and analyzing historical crash data. Methods involved in traditional analysis include before and after studies, crash rate, crash frequency, and equivalent property damage only (PDO) analysis. These methods can be useful in identifying and prioritizing sites that are in need of safety improvements and evaluating safety effectiveness; however, these methods generally neglect to take into consideration regression to the mean (RTM) bias. When RTM bias is not accounted for it may result in ineffective investments in 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).

2.2.2 Predictive Analysis

Advances in safety evaluation are creating a shift away from traditional analysis toward quantitative predictive analysis. These quantitative predictive analyses are used to determine the expected number and severity of crashes at a site of interest. Predictive highway safety analyses make use of advanced statistical models to address RTM bias. These models use regression analysis to predict the number of crashes that are expected under a given set of conditions. Generally, these statistical models incorporate both historic crash data as well as crash data from similar sites (Schultz et al. 2011). Predictive analysis methods 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. 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, Strathman et al. 2001).

2.2.3 *Purpose of Crash Analysis*

The purpose of performing crash analyses is to find unsafe areas or hot spots on the roadway network. Both the traditional descriptive analysis and the predictive analysis methods and techniques are tools used by engineers to help in the determination of unsafe locations on the roadway network that should be analyzed further. After the hot spot has been identified it is then necessary to determine the cause of the problem and identify countermeasures to implement. The NCHRP has developed an extensive list of possible countermeasures for implementation on hot spots based on the prevalent problem on the roadway segment. The following section provides a review of the possible crash type countermeasures based on the NCHRP Report 500 series (Neuman et al. 2003a).

2.3 **Crash Type Countermeasures**

AASHTO approved its Strategic Highway Safety Plan in 1998. This safety plan was developed by the AASHTO Standing Committee for Highway Traffic Safety with the help of the FHWA, the National Highway Traffic Safety Administration (NHTSA), and the TRB Committee on Transportation Safety Management. Strategies in 22 emphasis areas that affect highway safety are included in this plan (Neuman et al. 2003a).

In response to the emphasis areas outlined in the AASHTO Strategic Highway Safety Plan, the NCHRP developed the Report 500 series. This series includes multiple volumes each based on a specific type of highway crash. It was developed to assist state and local agencies in reducing injuries and fatalities in specific target areas. Each volume includes an introduction, a description of the problem being addressed, the strategies and countermeasures to address that problem, and a model implementation process.

Each volume within the Report 500 series targets a specific type of highway crash. Within the volume there are several objectives identified to help in the reduction of that specific type of highway crash. Under each objective, several different strategies and countermeasures are provided to help accomplish this objective. Every countermeasure is placed in one of the following three categories: proven (P), tried (T), and experimental (E). In the literature if a category is not provided for a countermeasure, then NA will be used, which is defined as "not available." These categories will be consistently referenced in this section of the literature review. Each of these three categories is defined as (Neuman et al. 2003a):

- *Proven (P)* - These countermeasures have been implemented in one or more location. Properly designed evaluations of the countermeasure have been conducted to show its effectiveness. Implementation of the countermeasure can be done with a good degree of confidence.
- *Tried (T)* - These countermeasures have been implemented in a number of locations and may even be accepted as standards, but for which valid evaluations have not been found. They should be applied with caution and after careful consideration. Implementation can proceed with a degree of assurance that there will not likely be any negative impact on safety and they will very likely have a positive impact.
- *Experimental (E)* - These countermeasures have shown significant promise by at least one agency to be tried on a small scale in at least one location. Consideration for these countermeasures should only come after other countermeasures have been shown to be inappropriate or not feasible. Where they are considered, implementation should initially occur using a controlled and limited pilot study that includes a properly designed evaluation component. Only after careful testing and evaluation, if

the countermeasure has shown it can be effective, should broader implementation be considered.

The following sections provide a more in-depth discussion on several of the volumes within the NCHRP Report 500 series. For each volume, a detailed description of the problem crash type will be given along with the objectives to help with crash reduction. In addition, a list of countermeasures and strategies for each of the given objectives will be provided for consideration. The countermeasures in these lists were selected to provide a wide range of possible mitigation solutions in each of the three categories of proven, tried, and experimental. The topics focused on include:

1) Collisions with trees (NCHRP 500 Volume 3)
2) Head-on collisions (NCHRP 500 Volume 4)
3) Unsignalized intersection collisions (NCHRP 500 Volume 5)
4) Run-off-road collisions (NCHRP 500 Volume 6)
5) Horizontal curve collisions (NCHRP 500 Volume 7)
6) Utility pole collisions (NCHRP 500 Volume 8)
7) Collisions involving pedestrians (NCHRP 500 Volume 10)
8) Signalized intersection collisions (NCHRP 500 Volume 12)
9) Collisions involving heavy trucks (NCHRP 500 Volume 13)
10) Drowsy and distracted driving (NCHRP 500 Volume 14)
11) Work zone collisions (NCHRP 500 Volume 17)
12) Head-on crashes on freeways (NCHRP 500 Volume 20)
13) Speed related crashes (NCHRP 500 Volume 23)

2.3.1 Collisions with Trees

Volume 3 of the NCHRP Report 500 is titled: "A Guide for Addressing Collisions with Trees in Hazardous Locations" (Neuman et al. 2003a). Collisions with trees generally result in severe or fatal crashes on rural roads. Because of the nature of rural roads, trees are the most common object struck in run-off-road (ROR) collisions that result in a fatality. Collisions with trees are a subset of ROR collisions, which are discussed in more detail in section 2.3.4. There are several different objectives to help in the reduction of collisions with trees. These objectives and a sample of their countermeasures are listed in the following subsections (Neuman et al. 2003a). A complete list of objectives and countermeasures is found in Appendix A, Table A-1.

2.3.1.1 Prevent trees from growing in hazardous locations. This objective takes the approach that prevention is better than the cure. While trees provide many benefits, they can also create hazardous conditions if they are located too close to a road. Not only do they become a fixed object hazard, they can also reduce sight distance, block signs, and obstruct a driver's vision of pedestrians. The proactive approach of preventing tree growth in hazardous locations can greatly reduce many of these risks. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003a):

- Develop and implement planting guidelines to prevent trees from growing in hazardous locations (T)
- Mowing and vegetation control guidelines (P)

2.3.1.2 Eliminate the hazardous conditions and/or reduce the severity of the crash. This objective can be broken down into two different objectives. The first is to eliminate the hazardous conditions on the roadway. The second is to reduce the severity of the crash. If it is determined that collisions with trees is a problem then both of these should be looked at separately. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003a):

- Remove trees in hazardous locations (P)
- Shield motorists from striking trees (P)

2.3.2 Head-On Collisions

Volume 4 of the NCHRP Report 500 is titled: "A Guide for Addressing Head-on Collisions" (Neuman et al. 2003b). The area of emphasis for Volume 4 is head-on collisions associated with highway segments and does not deal with intersections. A head-on collision typically occurs when a vehicle crosses the centerline or median of a roadway and crashes into a vehicle approaching in the opposite direction. Head-on collisions can also occur when motorists knowingly or unknowingly travel in the wrong direction on a travel lane. Head-on collisions may also be caused by a motorist when trying to execute a passing maneuver on a two-lane road. There are several different objectives to help in the reduction of head-on collisions. These objectives and a sample of their countermeasures are listed in the following subsections (Neuman et al. 2003b). A complete list of objectives and countermeasures is found in Appendix A, Table A-2.

2.3.2.1 Keep vehicles from encroaching into opposite lanes. To reduce the number of head-on collisions the objectives are to keep vehicles from encroaching into the opposite lane and to reduce the severity of the crashes that occur. These objectives are similar to those cited in section 2.3.4 with respect to ROR collisions and that section should be referred to as needed. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003b):

- Install centerline rumble strips for two-lane roads (T)
- Provide wider cross sections on two-lane roads (E)
- Provide center two-way, left-turn lanes for four- and two-lane roads (T)
- Reallocate total two-lane roadway widths to include a narrow “buffer median” (T)

2.3.2.2 Minimize the likelihood of crashing into oncoming vehicles. The number of head-on collisions can be reduced by improving two-lane locations that experience a high number of passing related collisions. This improvement is accomplished through the construction of passing lanes or short four-lane sections to allow for vehicles to pass slow vehicles in both directions. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003b):

- Use alternating passing lanes or four-lane sections at key locations (T)
- Install median barriers for narrow width medians on multilane roads (T)

2.3.3 Unsignalized Intersection Collisions

Volume 5 of the NCHRP Report 500 is titled: “A Guide for Addressing Unsignalized Intersection Collisions” (Neuman et al. 2003c). Intersections comprise a small part of the overall highway system; however, it is not unusual for crashes to be concentrated at intersections because they are the points on the roadway system where traffic movements most frequently conflict with one another. There are many objectives to help in the reduction of crashes at unsignalized intersections. These objectives and a sample of their countermeasures are listed in the following subsections (Neuman et al. 2003c). A complete list of objectives and countermeasures is found in Appendix A, Table A-3.

2.3.3.1 Improve management of access near unsignalized intersections. Driveway access at or near an intersection may confuse drivers using the intersection and create vehicle-to-vehicle conflicts. Good access management includes the closure, relocation, and/or restriction of driveways within 250 feet of an intersection. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003c):

- Implement driveway closures/relocations (T)
- Implement driveway turn restrictions (T)

2.3.3.2 Reducing the frequency and severity of intersection conflicts through geometric design improvements. Improvements to intersection geometry can reduce the frequency and severity of crashes. This can be accomplished by the separation of through and turning lanes at the intersection, restricting or eliminating turning maneuvers, providing acceleration or deceleration lanes, and relocating the intersection. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003c):

- Provide left-turn lanes at intersections (P)
- Provide longer left-turn lanes at intersections (T)
- Provide right-turn lanes at intersections (P)
- Provide longer right-turn lanes at intersections (T)
- Provide full-width paved shoulders in intersection areas (T)
- Close or relocate “high-risk” intersections (T)
- Realign intersection approaches to reduce or eliminate intersection skew (P)

2.3.3.3 Improve sight distance at unsignalized intersections. Collisions at unsignalized intersections may occur because of the limited sight distance for the drivers approaching the intersections. Provision of clear sight triangles in each quadrant of the intersection can help reduce the possibility of crashes due to sight obstructions. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003c):

- Clear sight triangles on stop- or yield-controlled approaches to intersections (T)
- Change horizontal or vertical alignment of approaches to provide additional sight distance (T)
- Eliminate parking that restricts sight distance (T)

2.3.3.4 Improve availability of gaps in traffic and assist drivers in judging gap sizes at unsignalized intersections. Some of the collisions at unsignalized intersections occur because drivers may have difficulty judging the size of available gaps between vehicles. Drivers must judge when a gap size is sufficient to enter the traffic stream. At times drivers who are stopped to wait for the oncoming traffic stream often choose to proceed when oncoming vehicles are too close, thus increasing the probability of a collision. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003c):

- Re-time adjacent signals to create gaps at stop-controlled intersections (T)
- Provide roadside markers or pavement markings to assist drivers in judging the suitability of available gaps for making turning and crossing maneuvers (E)

2.3.3.5 Improve driver awareness of intersections as viewed from the intersection approach. Some of the intersection-related collisions occur because the driver may be unaware of the intersection upon approach. This can be a problem for drivers approaching an unsignalized intersection at high speeds, especially in an area where unsignalized intersection spacing is high. With such high speeds a driver can become aware of the intersection after it is too late to slow down or stop, thus increasing the risk of a collision. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003c):

- Improve visibility of intersections by providing enhanced signing and delineation (T)
- Improve visibility of the intersection by providing lighting (P)
- Install larger regulatory and warning signs at intersections (T)
- Call attention to the intersection by installing rumble strips on approaches (T)
- Install flashing beacons at stop-controlled intersections (T)

2.3.3.6 Choose appropriate intersection traffic control to minimize crash frequency and severity. It may become necessary to apply some form of traffic control device. The type of traffic control device chosen for an intersection has a strong effect on the frequency and severity of crashes that occur at the intersection. Unsignalized intersections generally have fewer crashes than comparable signalized intersections but the application of appropriate traffic control devices can reduce crash severity. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003c):

- Avoid signalizing through roads (T)
- Provide all-way stop control at appropriate intersections (P)
- Provide roundabouts at appropriate locations (P)

2.3.3.7 Improve driver compliance with traffic control devices and traffic laws at intersections. Many collisions are caused by noncompliance with traffic control devices and traffic laws at intersections. Greater enforcement has been shown to be an effective measure in improving safety at intersections. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003c):

- Provide targeted enforcement to reduce stop sign violations (T)
- Provide targeted public information on safety problems at specific intersections (T)

2.3.3.8 Reduce operating speeds on specific intersection approaches. Implementation of speed-reducing measures may help approaching drivers with additional time to make safe and proper intersection-related decisions. Speed-reducing countermeasures will get the drivers attention allowing the driver to be more aware of roadway conditions and thus reducing the potential for conflicts. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003c):

- Provide targeted speed enforcement (P)
- Provide traffic calming on intersection approaches through a combination of geometry and traffic control devices (P)

2.3.3.9 Guide motorists more effectively through complex intersections. Some intersections are complex and require the driver to perform unusual or unexpected maneuvers. Providing more effective guidance through the intersection with the use of signing and pavement markings will minimize the potential for collisions due to vehicles leaving their appropriate travel lane. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003c):

- Provide turn path markings (T)
- Provide lane assignment signing or marking at complex intersections (T)

2.3.4 Run-Off-Road Collisions

Volume 6 of the NCHRP Report 500 is titled: "A Guide for Addressing Run-Off-Road Collisions" (Neuman et al. 2003d). A ROR crash involves a vehicle that leaves the travel lane and encroaches on the shoulder of the roadway or beyond. After leaving the travel lane, the vehicle may hit one or more of a number of different natural or artificial objects, such as bridges, walls, poles, embankments, guardrails, parked vehicles, pedestrians, and trees. ROR crashes typically involve only a single vehicle. There are many objectives to help in the reduction of ROR collisions. These objectives and a sample of their countermeasures are listed in the following subsections (Neuman et al. 2003d). A complete list of objectives and countermeasures is found in Appendix A, Table A-4.

2.3.4.1 Keep vehicles from encroaching on the roadside. One of the objectives of roadway design for safety is to keep the vehicle in the travel lane. Motorists do not generally move onto the shoulder or leave the roadway purposely unless they need to pull over to stop their vehicle. However, many errant vehicles may leave the travel lane onto the shoulder resulting in a ROR crash. The reasons for errant vehicles leaving the travel lane are varied and include, but are not limited to: avoiding a vehicle, object, or animal in the travel lane; inattentive driving due to distraction, drowsiness, or fatigue; the effects of pavement conditions; and traveling too fast through a curve or down a grade. A secondary objective of roadway design for safety is to help those drivers that leave the travel lane to safely recover on the shoulder and return to the travel lane. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003d):

- Install shoulder rumble strips (T)
- Provide enhanced shoulder or in-lane delineation and marking for sharp curves (P/T/E)
- Provide improved highway geometry for horizontal curves (P)
- Provide enhanced pavement markings (T)
- Eliminate shoulder drop-offs (E)
- Widen and/or pave shoulders (P)

2.3.4.2 Minimize the likelihood of crashing into an object or overturning if the vehicle travels off the shoulder. If a motorist leaves the travel lane onto the roadside, the probability of a crash occurring depends upon the roadside features. Features of the roadside that could affect ROR crashes are the presence and location of fixed objects, shoulder edge drop-off, sideslopes, ditches, and trees. If the roadside has a flat slope without any objects, and a well compacted soil that is able to support the vehicles tires, then the probability of a serious crash is minimized. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003d):

- Design safer slopes and ditches to prevent rollovers (P)
- Remove/relocate objects in hazardous locations (P)
- Delineate trees or utility poles with retro-reflective tape (E)

2.3.4.3 Reduce the severity of the crash. The last objective of ROR collisions, reducing the severity of the crash, is accomplished by changes in the design of the roadside features. This can be done by making the roadside features more forgiving or by modifying the side slopes to prevent rollovers. The following strategies and countermeasures are associated with this objective (Neuman et al. 2003d):

- Improve design of roadside hardware (T)
- Improve design and application of barrier and attenuation system (T)

2.3.5 Horizontal Curve Collisions

Volume 7 of the NCHRP Report 500 is titled: "A Guide for Reducing Collisions on Horizontal Curves" (Torbic et al. 2004). A horizontal curve is a curve that changes the alignment or direction of the roadway (FHWA 2013). In this volume no distinction is made regarding whether or not the strategy is more applicable at an isolated horizontal curve located between two long tangent sections or whether it should be applied to horizontal curves located along curvilinear alignments. All of the strategies have the potential to be effective for both types of horizontal curves and can be used in combination to improve safety. The most common crash types on horizontal curves are ROR and head-on collisions. There are many objectives to aid in the reduction of horizontal curve collisions. These objectives and a sample of their countermeasures are listed in the following subsections (Torbic et al. 2004). A complete list of objectives and countermeasures is found in Appendix A, Table A-5.

2.3.5.1 Reduce the likelihood of a vehicle leaving its lane by either crossing the roadway centerline or leaving the roadway at a horizontal curve. This objective helps prevent collisions on horizontal curves and creates an environment in which a driver is less likely to leave the travel lane, thus reducing the number of collisions that could possibly occur. The following strategies and countermeasures are associated with this objective (Torbic et al. 2004):

- Install shoulder rumble strips (P)
- Widen the roadway (P)
- Improve and/or restore superelevation (P)

2.3.5.2 Minimize the adverse consequences of leaving the roadway at a horizontal curve. This objective is to reduce the severity of the consequences associated with leaving the travel way on a horizontal curve. This can be done by providing the driver with an opportunity to correct driving mistakes and safely return to the travel lane. These strategies and countermeasures help reduce the severity of a collision resulting from leaving the travel lane. The following strategies and countermeasures are associated with this objective (Torbic et al. 2004):

- Design safer slopes and ditches to prevent rollovers (P)
- Remove/relocate objects in hazardous locations (P)
- Add or improve roadside hardware (T)

It should be noted that many of the strategies associated with reducing horizontal curve collisions are also used in the head-on and ROR collisions sections of this report, which are section 2.3.2 and section 2.3.4, respectively. The reader should look to those sections for additional information.

2.3.6 Utility Pole Collisions

Volume 8 of the NCHRP Report 500 is titled: "A Guide for Reducing Collisions Involving Utility Poles" (Lacy et al. 2004). A utility pole crash is defined as any crash involving a pole. Utility pole crashes are a subset of ROR crashes. These crashes are fixed object crashes that involve vehicles that leave the travel lane, encroach on the roadside, and strike a utility pole. A collision with a utility pole may be considered the first harmful event in a ROR collision but in some collisions it is considered a secondary event that may be as severe as, or even more severe than, the first harmful event. There are many objectives to help in the reduction of utility pole collisions. These objectives and a sample of their countermeasures are listed in the following subsections (Lacy et al. 2004). A complete list of objectives and countermeasures is found in Appendix A, Table A-6.

2.3.6.1 Treat specific utility poles at high crash and high risk locations. This objective deals with locations that have been recognized as high crash and high risk locations. Once these high crash and high risk locations have been located it becomes important to takes steps to protect drivers from possible collisions with utility poles. The following strategies and countermeasures are associated with this objective (Lacy et al. 2004):

- Remove poles at high crash locations (P)
- Relocate poles at high crash locations farther from the roadway (P)
- Shield drivers from poles at high crash locations (P)
- Improve drivers' ability to see poles at high crash locations (E)

2.3.6.2 Prevent placing utility poles at high risk locations. This objective is to develop utility pole placement policies so that no new poles will be placed at high risk locations. These policies should also include instructions about the periodic replacement of high risk poles by utility companies. These policies should deal mainly with poles located in the recovery area. The following strategy is associated with this objective (Lacy et al. 2004):

- Develop, revise, and implement policies to prevent placing or replacing poles within the recovery area (T)

2.3.6.3 Treat several utility poles along a corridor to minimize the likelihood of a crash into a utility pole if a vehicle runs off the road. This last objective targets utility poles located along long sections of roadways where crashes are spread out along the entire length of the segment. Because these crashes are not clustered in one potential high risk location it is important to implement strategies that reduce the overall likelihood of crashing into any of the utility poles along that segment. The following strategies and countermeasures are associated with this objective (Lacy et al. 2004):

- Place utilities underground (P)
- Relocate poles along the corridor farther from the roadway to less vulnerable locations (P)
- Decrease the number of poles along the corridor (P)

None of the objectives, strategies, or countermeasures in this volume focus on keeping the vehicle from leaving the roadway. This is an important objective when trying to reduce the number of collisions with utility poles. To find more information about possible strategies and countermeasures to implement for keeping vehicles from leaving the roadway refer to Volume 6 related to ROR collisions, and as discussed in section 2.3.4.

2.3.7 Collisions Involving Pedestrians

Volume 10 of the NCHRP Report 500 is titled: "A Guide for Reducing Collisions Involving Pedestrians" (Zegeer et al. 2004). Walking is a basic activity for all humans. In the 2011 AASHTO Green Book it states that "pedestrians are a part of every roadway environment and attention should be paid to their presence in rural as well as urban areas." It continues to state that "…pedestrians are the lifeblood of our urban areas, especially in the downtown and other retail areas" (AASHTO 2011, p. 2-78). Pedestrians are legitimate users of the roadway system and their safety cannot be overlooked. Reducing collisions involving pedestrians and improving their overall safety can be accomplished through a number of objectives. These objectives and a sample of their countermeasures are listed in the following subsections (Zegeer et al. 2004). A complete list of objectives and countermeasures is found in Appendix A, Table A-7.

2.3.7.1 Reduce pedestrian exposure to vehicular traffic. Reducing the amount of time a pedestrian is exposed to traffic can also reduce the number of pedestrian collisions that occur. There are a number of strategies to reduce exposure of pedestrians to traffic but most of these strategies involve the separation of pedestrian travel ways from vehicle travel ways. The following strategies and countermeasures are associated with this objective (Zegeer et al. 2004):

- Provide sidewalks/walkways and curb ramps (P)
- Install or upgrade traffic and pedestrian signals (P/T/E)
- Install overpasses/underpasses (P)

2.3.7.2 Improve sight distance and/or visibility between motor vehicles and pedestrians. Drivers and pedestrians need to be aware of potential pedestrian vehicle conflict points. When drivers are unaware of pedestrians there is a greater risk of striking a pedestrian. Improving visibility between motor vehicles and pedestrians is accomplished through improved sight distance, lighting, and advance warning signs. With improved sight distance and lighting, not only can drivers make safer decisions, but pedestrians will be able to better judge the risk associated with using the roadway. The following strategies and countermeasures are associated with this objective (Zegeer et al. 2004):

- Provide crosswalk enhancements (P/T)
- Implement lighting/crosswalk illumination measures (P)
- Install signals to alert motorists of pedestrian crossings (T/E)

2.3.7.3 Reduce vehicle speed. Speed is an important factor in both the occurrence of pedestrian crashes and the severity of injury sustained by pedestrians involved in a crash. Reducing the travel speed of vehicles in high pedestrian areas will help to reduce the number and severity of crashes involving pedestrians. The following strategies and countermeasures are associated with this objective (Zegeer et al. 2004):

- Implement road narrowing measures (T)
- Install traffic calming at intersections (P/T)

2.3.7.4 Improve pedestrian and motorist safety awareness and behavior. Drivers and pedestrians need to be aware of the risk involved with using the roadway. This is accomplished through training and enforcement campaigns. Providing educational training programs and enforcement campaigns can help to change behavior and improve safety. The following strategies and countermeasures are associated with this objective (Zegeer et al. 2004):

- Provide education, outreach, and training (P)
- Implement enforcement campaigns (T)

2.3.8 Signalized Intersection Collisions

Volume 12 of the NCHRP Report 500 is titled: "A Guide for Reducing Collisions at Signalized Intersections" (Antonucci et al. 2004). Intersections are a small part of the overall highway system; however, it is not unusual for crashes to be concentrated at intersections because they are the points on the roadway system where traffic movements most frequently conflict with one another. Signalized intersections are generally the most heavily traveled intersections and contain the most conflict points. A well designed roadway along with effective traffic control can result in a signalized intersection that operates efficiently and safely; however, regarding the overall design, safety can still be a concern. There are many objectives to reduce crashes at signalized intersections. These objectives and a sample of their countermeasures are listed in the following subsections (Antonucci et al. 2004). A complete list of objectives and countermeasures is found in Appendix A, Table A-8.

2.3.8.1 Reduce frequency and severity of intersection conflicts through traffic control and operational improvements. Potential conflict points can be reduced by improving the method of assigning right-of-way at signalized intersections. This can be accomplished by improving or modifying signal phasing and timing, providing additional traffic control devices and pavement markings, and restricting turning movements. The following strategies and countermeasures are associated with this objective (Antonucci et al. 2004):

- Optimize clearance intervals (P)
- Employ signal coordination (P)
- Remove unwarranted signals (P)

2.3.8.2 Reduce frequency and severity of intersection conflicts through geometric improvements. Reducing the frequency of possible vehicle-to-vehicle conflicts at intersections can reduce the frequency and severity of intersection crashes. This can be accomplished by incorporating geometric designs that separate through traffic and turning movements, restrict or eliminate turning movements, and possibly close or relocate intersections. The following strategies and countermeasures are associated with this objective (Antonucci et al. 2004):

- Provide/improve left-turn channelization (P)
- Revise geometry of complex intersections (P, T)
- Construct special solutions (T)

2.3.8.3 Improve sight distance at signalized intersections. Collisions at signalized intersections may occur because of the limited sight distance for drivers approaching the intersections. Provision of clear sight triangles in each quadrant of the intersection can help reduce the possibility of crashes due to sight obstructions. The following strategies and countermeasures are associated with this objective (Antonucci et al. 2004):

- Redesign intersection approaches (P)
- Clear sight triangles (T)

2.3.8.4 Improve driver awareness of intersection and signal control. Some collisions at intersections occur because one or more drivers may be unaware of the approaching intersection until it is too late to avoid a collision. The improvement of signing and delineation can help warn drivers of the approaching intersection. The following strategies and countermeasures are associated with this objective (Antonucci et al. 2004):

- Improve visibility of intersections on approaches (T)
- Improve visibility of signals and signs at intersections (T)

2.3.8.5 Improve driver's compliance with traffic control devices. Collisions at a signalized intersection many times can be caused by noncompliance with traffic control devices. Public education and enforcement can be effective in reducing traffic law violations and improving the overall safety at the intersection. The following strategies and countermeasures are associated with this objective (Antonucci et al. 2004):

- Implement automated enforcement of red-light running (P)
- Provide public information and education (T)
- Control speed on approaches (E)

2.3.8.6 Improve access management near signalized intersections. Additional workload on a driver is created when there is complex navigation, braking, and decision making required by the driver on the intersection approach. This additional workload may lead to collisions at or near the intersection. To reduce signalized intersection collisions there needs to be restrictions on driveways and cross median turning movements near signalized intersections. The following strategies and countermeasures are associated with this objective (Antonucci et al. 2004):

- Restrict access to properties by using driveway closures or turn restrictions (T)
- Restrict cross-median access near intersections (T)

2.3.8.7 Improve safety through other infrastructure treatments. There are many other intersection improvements that can be made to improve safety and reduce the severity of collisions. Many of these improvements deal with improving the current infrastructure at the signalized intersections. The following strategies and countermeasures are associated with this objective (Antonucci et al. 2004):

- Restrict or eliminate parking on intersection approaches (P)
- Provide skid resistance in the intersection and on approaches to the intersection (T)
- Relocate signal hardware out of the clear zone (T)

2.3.9 Collisions Involving Heavy Trucks

Volume 13 of the NCHRP Report 500 is titled: "A Guide for Reducing Collisions Involving Heavy Trucks" (Knipling et al. 2004). Heavy trucks are defined by the Federal Motor Carrier Safety Administration (FMCSA) as having a gross vehicle weight rating (GVWR) of 10,001 pounds or more (FMCSA 2003). Over 90 percent of heavy trucks involved in traffic fatalities have a GVWR greater than 26,000 pounds. Heavy truck crashes are more likely to result in serious injuries and fatalities than crashes involving light vehicles because of the size, weight, and stiffness of the vehicle. There are many objectives to help in the reduction of collisions involving heavy trucks. These objectives and a sample of their countermeasures are listed in the following subsections (Knipling et al. 2004). A complete list of objectives and countermeasures is found in Appendix A, Table A-9.

2.3.9.1 Reduce driver fatigue related crashes. Because of the long hours of driving demanded by trucking companies and the greater hazard potential posed by the heavy vehicle, driver fatigue has become a major factor in heavy truck crashes. Fatigue-related crashes are preventable and can be reduced with implementation of strategies designed to help heavy truck drivers find areas to rest when they become fatigued. Not only should drivers be able to find areas to rest when needed but there also needs to be methods to help them realize when they become too fatigued to continue driving safely. The following strategies and countermeasures are associated with this objective (Knipling et al. 2004):

- Increase utilization of existing parking spaces (E)
- Create additional parking spaces (T)

2.3.9.2 Strengthen commercial driver's license (CDL) requirements and enforcement. A CDL is a special license needed for drivers operating large vehicles, transporting more than 15 passengers, or carrying hazardous material. In 1986, Congress enacted legislation establishing mandatory federal standards for state licensing programs. The Motor Carrier Safety Improvement Act of 1999 strengthened this legislation and created the FMCSA to administer and regulate the legislation passed. Even with the strong federal requirements needed to obtain a CDL there are still problems with the program. These problems are associated with states not complying with all of the provisions of the CDL and the fraudulent issuing of licenses. The following strategies and countermeasures are associated with this objective (Knipling et al. 2004):

- Improve test administration for the CDL (T)
- Increase fraud detection of state and third party testers (T/E)

2.3.9.3 Increase knowledge about sharing the road. About 85 percent of fatalities resulting from heavy vehicle crashes occur in the other vehicle involved in the crash. Most of these crashes are a result of passenger vehicle driver errors. Drivers of passenger vehicles need to understand how heavy trucks use the road differently from other vehicles. When passenger vehicles understand how to share the road with trucks there is less potential for collisions. The following strategies and countermeasures are associated with this objective (Knipling et al. 2004):

- Incorporate sharing the road information into driver materials (T)
- Promulgate share the road information through print and electronic media (T)

2.3.9.4 Improve maintenance of heavy trucks. Maintenance of heavy trucks is one of the most fundamental activities of safety management. Both the FMCSA and individual states have various regulations and enforcement programs to ensure that all heavy trucks using the roadway are functioning properly. The following strategies and countermeasures are associated with this objective (Knipling et al. 2004):

- Increase and strengthen truck maintenance programs (NA)
- Conduct post-crash inspection to identify major problems and problem conditions (E)

2.3.9.5 Identify and correct unsafe roadway infrastructure and operational characteristics. The physical and operational characteristics of heavy trucks often place them near the safety limits imposed by the traffic environment and the geometric highway design (Harwood et al. 2003a and 2003b). There is a heightened safety concern with roadway features such as lane width, grades, horizontal curves, and interchange ramps related to heavy trucks where there may not be concern with smaller, lighter vehicles. Even though roadway design guidelines are based on the consideration of various large vehicle designs, the margin for driver error is less for these large vehicles than for smaller vehicles. Most of the strategies provided with this objective are designed to either impact the speed of the heavy truck or overcome the loss of control due to excessive speeds. The following strategies and countermeasures are associated with this objective (Knipling et al. 2004):

- Install interactive truck rollover signs (P)
- Identify and treat truck crash roadway segments (E)

2.3.9.6 Improve and enhance truck safety data. Trucks cross over many state lines and travel through many jurisdictions. Because of this, drivers can incur traffic violations in multiple jurisdictions. One of the purposes of the CDL is to limit truck drivers to holding a single license and to establish a reporting system that compiles a single record that incorporates data from all jurisdictions. It is important that this information is shared and easily accessible to be useful for safety improvement implementation. The following strategy is associated with this objective (Knipling et al. 2004):

- Increase the timeliness, accuracy, and completeness of truck safety data (NA)

2.3.9.7 Promote industry safety initiatives. This objective focuses on how to educate and train those within the trucking industry about safety concerns. The key to this objective is to make sure that the industry knows how and where to find information about safety concerns and the possible technologies and strategies that can be used in increasing safety. The following strategies and countermeasures are associated with this objective (Knipling et al. 2004):

- Perform safety consultations with carrier safety management (P)
- Promote development and deployment of truck safety technologies (E)

2.3.10 Drowsy and Distracted Driving

Volume 14 of the NCHRP Report 500 is titled: "A Guide for Reducing Crashes Involving Drowsy and Distracted Drivers" (Stutts et al. 2005). The focus of this volume is to reduce the number of collisions that occur due to driver distraction or fatigue. Distracted driving is caused by an object or event that draws the attention of the driver from the task of driving. The presence of a triggering event is the distinguishing feature that differentiates a distracted driver from an inattentive driver. The driver can be distracted visually, audibly, and/or cognitively. Drowsy driving has no triggering event but is the progressive withdrawal of attention from the road and traffic. Both drowsy and distracted driving lead to decreased driving performance and an increased risk of being involved in a crash. According to NHTSA, driver inattention is the causation factor in 25-30 percent of crashes (Wang et at. 1996). There are many objectives to help in the reduction of drowsy and distracted driving crashes. These objectives and a sample of their countermeasures are listed in the following subsections (Stutts et al. 2005). A complete list of objectives and countermeasures is found in Appendix A, Table A-10.

2.3.10.1 Make roadways safer for drowsy and distracted drivers. The purpose of this objective is to tailor the roadway infrastructure to respond to distracted or drowsy drivers. By addressing changes to the roadway it will be possible to either reduce the likelihood that crashes will occur or reduce the severity of the crashes that do occur. The following strategies and countermeasures are associated with this objective (Stutts et al. 2005):

- Install shoulder and/or centerline rumble strips (P/T)
- Implement other roadway improvements to reduce the likelihood and/or severity of ROR collisions caused by drowsy and distracted drivers (P/T)

2.3.10.2 Provide safe stopping and resting areas. Increasing opportunities to rest or attend to other activities that otherwise may disrupt driving will enhance the safe driving environment. The following strategies and countermeasures are associated with this objective (Stutts et al. 2005):

- Improve access to safe stopping and resting areas (T)
- Improve rest area security and services (T)

2.3.10.3 Increase driver awareness of the risks of drowsy and distracted driving and promote driver focus. It is important to increase the general awareness of the safety issues and problems caused by drowsy and distracted driving. This objective focuses on the education of the general driving population. Through increased awareness the public opinion about drowsy and distracted driving can change to improve safety and reduce crashes. The following strategies and countermeasures are associated with this objective (Stutts et al. 2005):

- Conduct education and awareness campaigns targeting drowsy and distracted drivers (T)
- Visibly enforce existing statutes to deter distracted and drowsy drivers (E)

2.3.10.4 Implement programs that target populations at increased risk of drowsy or distracted driving crashes. This objective is to target specific high risk populations prone to drowsy or distracted driving. These strategies are specific to an individual group with a very specific solution that requires more individualized efforts. These groups include young drivers, nighttime workers, and commercial drivers. The following strategies and countermeasures are associated with this objective (Stutts et al. 2005):

- Strengthen graduated driver licensing requirements for young novice drivers (P/T)
- Implement targeted interventions for other high risk populations (T/E)

2.3.11 Work Zone Collisions

Volume 17 of the NCHRP Report 500 is titled: "A Guide for Reducing Work Zone Collisions" (Antonucci et al. 2005). Maintaining safe and efficient movement of traffic through work zones can be a major challenge. Work zones require that drivers pay careful attention because drivers are placed in special situations not normally encountered elsewhere on the roadway system. Also, the driving conditions in work zones typically differ from one another. This leads to factors that can result in violations in driver expectancy that can cause congestion, erratic maneuvers, and crashes. The nation's infrastructure is constantly in need of repair, which causes drivers to experience increased exposure to work zones. As exposure to work zones increases, the opportunity for crashes to occur also increases. There are many objectives to help in the reduction of work zone crashes. These objectives and a sample of their countermeasures are listed in the following subsections (Antonucci et al. 2005). A complete list of objectives and countermeasures is found in Appendix A, Table A-11.

2.3.11.1 Reduce the number, duration, and impact of work zones. Opportunities for crashes to occur can be decreased by reducing the exposure of travelers to work zones and of workers to traffic. Reduced exposure can be accomplished by using maintenance and construction practices that increase the life of the roadway system, accelerating construction and maintenance activities, and scheduling roadway work to avoid peak periods of traffic volume. The following strategies and countermeasures are associated with this objective (Antonucci et al. 2005):

- Improve maintenance and construction practices (P)
- Use nighttime road work (P)
- Use demand management programs to reduce volumes through work zones (P)

2.3.11.2 Improve work zone traffic control devices. A key to safety in work zones is the proper use of traffic control devices. These devices are used to convey needed information to drivers to alert them of the presence of potential roadway hazards. The following strategies and countermeasures are associated with this objective (Antonucci et al. 2005):

- Reduce flaggers' exposure to traffic (T)
- Improve visibility of work zone traffic control devices (T)

2.3.11.3 Improve work zone design practices. Safety needs to be addressed in the planning stages of the project to reduce the potential for crashes related to work zones. Part of the work zone design practices should be established design guidelines and common features across a jurisdiction so that the work zones are consistent and better meet driver expectations.

The following strategies and countermeasures are associated with this objective (Antonucci et al. 2005):

- Establish work zone design guidance (T)
- Implement measures to reduce work space intrusions (T)

2.3.11.4 Improve driver compliance with work zone traffic controls. Many work zone crashes are caused by the failure of drivers to comply with traffic control devices and traffic laws. To protect both drivers and workers it is important that strategies be implemented to enforce all traffic control devices and traffic laws. The following strategies and countermeasures are associated with this objective (Antonucci et al. 2005):

- Enhance enforcement of traffic laws in work zones (T)
- Improve credibility of signs (E)

2.3.11.5 Increase knowledge and awareness of work zones. The training and education of roadway users, highway designers, and construction workers is key to improving safety within a work zone. This education and training can be accomplished through public information, educational campaigns, and agency training programs. The following strategies and countermeasures are associated with this objective (Antonucci et al. 2005):

- Disseminate work zone safety information to road users (T)
- Provide work zone training programs and manuals for designers and field staff (T)

2.3.11.6 Develop procedures to effectively manage work zones. Work zone management practices help to bring about improvements in work zone safety. These practices can include crash data system improvements, safety awards, interagency coordination, and inspection. The following strategies and countermeasures are associated with this objective (Antonucci et al. 2005):

- Develop or enhance agency level work zone crash data systems (T)
- Use incentives to create and operate safer work zones (T)

2.3.12 Head-On Crashes on Freeways

Volume 20 of the NCHRP Report 500 is titled: "A Guide for Reducing Head-On Crashes on Freeways" (Neuman et al. 2008). Head-on crashes that occur on freeways are generally severe. These crashes typically happen when a vehicle crosses the median and crashes into another vehicle traveling in the opposite direction. These are normally called cross median crashes or median crossover crashes. These crashes may also occur when a vehicle inadvertently travels in the wrong direction in the opposing traffic lanes. NHTSA defines a head-on collision as a collision where the front end of one vehicle collides with the front end of another vehicle (Neuman et al. 2008). From 1994 to 2002 the number of fatalities for median crossover and wrong way crashes on divided highways increased by 17 percent from 581 to 680 fatalities per year (Ostensen 2004). Because of the increased number of crashes in this area many DOTs have focused on countermeasures to mitigate the problem. There are many objectives to help in the reduction of head-on collisions on freeways. These objectives and a sample of their countermeasures are listed in the following subsections (Neuman et al. 2008). A complete list of objectives and countermeasures is found in Appendix A, Table A-12.

2.3.12.1 Keeping vehicles from departing the travel way. This objective assumes that the vehicle has not left the road and is in its proper travel lane but is about to stray out of its lane and into the median. The strategies presented are to help keep the vehicle in its proper travel lane through the use of traffic control devices or to reduce the potential of leaving the roadway by improved pavement capability. The following strategies and countermeasures are associated with this objective (Neuman et al. 2008):

- Install left shoulder rumble strips (T)
- Provide enhanced pavement markings and median delineation (T)

2.3.12.2 Minimize the likelihood of head-on crashes with an oncoming vehicle. This objective considers the situation in which the vehicle has left the travel lane and is in, or on, the median. The strategies used here are to prevent the vehicle from crossing over the median and entering the opposite travel lanes. The central idea for this objective is to utilize the median in helping to prevent head-on crashes. The following strategies and countermeasures are associated with this objective (Neuman et al. 2008):

- Provide wider medians (P)
- Improve median design for vehicle recovery (T)

2.3.12.3 Reduce the severity of median barrier crashes that occur. When a crash occurs it is important to try to reduce the severity of the crash. A strategy associated with this objective aimed at improving roadside design and roadside hardware includes (Neuman et al. 2008):

- Improve design and application of barrier and attenuation systems (T)

2.3.12.4 Enhanced enforcement and awareness of traffic regulations. This objective aims at identifying sections of freeway considered to be high risk locations due to any number of circumstances. When these unsafe corridors have been pinpointed it is then suggested that enhanced traffic enforcement efforts along with education efforts to enhance safety along the corridor be implemented. The following strategies and countermeasures are associated with this objective (Neuman et al. 2008):

- Designate "highway safety corridors" (T)
- Conduct public information and education campaigns (T)

2.3.12.5 Improve coordination of agency safety initiatives. Data are key to safety planning. Accurate crash data along with the periodic updating of that data are required to be proactive in safety planning. Improving the methods of collection, distribution, and updating of crash data will help in the improvement of safety related to head-on collisions on the freeway system. The following strategy is associated with this objective (Neuman et al. 2008):

- Enhance agency crash data systems (T)

2.3.13 Speeding Related Crashes

Volume 23 of the NCHRP Report 500 is titled: "A Guide for Reducing Speeding-Related Crashes" (Neuman et al. 2009). NHTSA defines a speeding related crashes as a crash in which "the driver was charged with a speeding-related offense or if an officer indicated that racing, driving too fast for conditions, or exceeding the posted speed limit was a contributing factor in the crash" (NHTSA 2013). Speeding related crashes are the result of excessive or inappropriate speeds that can be directly related to a driver's behavior or a driver's response to the environment. This can also be stated as a driver who consciously chooses an inappropriate speed or a driver that inadvertently chooses a speed that is inappropriate for the driving environment. There are many objectives to help in the reduction of speeding related crashes. These objectives and a sample of their countermeasures are listed in the following subsections (Neuman et al. 2009). A complete list of objectives and countermeasures is found in Appendix A, Table A-13.

2.3.13.1 Set appropriate speed limits. Speed limits need to reflect the surrounding context of the roadway and meet the expectations of the driver. By doing this drivers are more likely to respect the posted speed limit. Speed limits that appear inconsistent may be ignored by drivers and lead to a lack of respect for speed limits in general. The following strategies and countermeasures are associated with this objective (Neuman et al. 2009):

- Set speed limits which account for roadway design, traffic, and environment (T)
- Implement variable speed limits (T)
- Implement differential speed limits for heavy vehicles (T)

2.3.13.2 Heighten driver awareness of speeding related safety issues. Drivers need to know the risk associated with speeding both to themselves and to others that use the roads. Informing drivers of these risks may encourage drivers to obey the speed limit and drive at safe speeds for the roadway environment that they encounter. The following strategies and countermeasures are associated with this objective (Neuman et al. 2009):

- Increase public awareness of the risk of driving at unsafe speeds (T)
- Increase public awareness of potential penalties for speeding (T)
- Implement "safe community" programs (T)

2.3.13.3 Improve the effectiveness of speed enforcement efforts. Many crashes are caused by the failure of the drivers to follow traffic control devices and traffic laws. The effectiveness of enforcement can increase if drivers believe there is a significant chance they may be cited for speeding and be given a fine. The goal of this objective is to increase driver perception of enforcement-related risk of speeding. The following strategies and countermeasures are associated with this objective (Neuman et al. 2009):

- Use targeted speed enforcement programs at locations with speed related problems (P)
- Implement automated speed enforcement (T)
- Increase fines in special areas (T)

2.3.13.4 Communicate appropriate speeds through the use of traffic control devices. Information about appropriate speeds needs to be conveyed clearly to drivers at the appropriate locations. This includes permanent speed limits, variable speed limits, and warning speeds. Even though drivers are ultimately responsible to drive at a safe speed, they need to be able to receive cues from the roadway environment to help them determine what that safe speed is. The following strategies and countermeasures are associated with this objective (Neuman et al. 2009):

- Improve speed limit signage (T)
- Implement active speed warning signs (T)
- Implement variable message signs (T)

2.3.13.5 Ensure that roadway design and traffic control elements support appropriate and safe speeds. The geometric design features of roadway sections and intersections need to reflect the speeds at which a driver would expect to travel. These design features, such as horizontal curves, can be designed to encourage appropriate speeds. The following strategies and countermeasures are associated with this objective (Neuman et al. 2009):

- Provide adequate change and clearance intervals at signalized intersections (P)
- Provide adequate sight distance for expected speeds (P)
- Effect safe speed transitions through design elements (T)

2.4 **Chapter Summary**

Roadway safety can be defined subjectively based on the perception or feel of the roadway or objectively based on a quantitative measure of safety. This quantitative measure of safety is generally in relation to the crashes that occur on the roadway. To understand safety it is important to understand crashes and the techniques used to analyze crash data. Crash analysis techniques are grouped into one of two categories: traditional descriptive analysis and predictive analysis. A traditional descriptive analysis focuses on summarizing, quantifying, and analyzing the historical crash data, while predictive analysis focuses on providing quantitative predictions based on advanced statistical models. Both of these analysis methods are used to find problematic roadway segments where countermeasures should be implemented to improve safety.

NCHRP developed the Report 500 series as guidance for implementation of the AASHTO Strategic Highway Safety Plan. The NCHRP Report 500 series includes multiple volumes each based on a specific type of highway crash. This series was developed to assist state and local agencies in reducing injuries and fatalities in specific target areas. Each volume includes an introduction, a description of the problem being addressed, the strategies and countermeasures to address that problem, and a model implementation process. It is important to understand that this report is not a comprehensive list of all possible strategies and countermeasures that can be used to improve safety for a given crash type. In most areas a combination of strategies is the most effective way to reduce injuries and fatalities for a specific crash type. Some of the crash types involve strategies that are discussed in multiple volumes, which makes it important to look at all volumes pertaining to the specific crash type.

The ability to select appropriate safety countermeasures is heavily dependent on the available data that can be used in safety analysis. The next chapter covers some of the data needs for this project.

3 DATA

Oftentimes the availability and quality of data is the limiting factor in determining the type of crash analysis that can be done. The accuracy of the data will determine how valid and accurate the results are. In this chapter general data considerations along with the different datasets that were utilized in this project and the need for uniformity in these datasets is presented. A discussion is also provided on the different ways that data were used in this project. For additional information not provided in this chapter about data the reader is referred to the report titled "Traffic and Safety Statewide Model and GIS Modeling" in the literature (Schultz et al. 2012).

3.1 General Data Considerations

Some of the general considerations with any dataset are accuracy, availability, coverage, and usability. Accuracy deals with the correctness and precision of the data, which is important to allow for a valid analysis that leads to real safety improvement. Quality checks need to be in place to ensure the accuracy of the data being used. Availability is the second data consideration. When data are available it encourages analysis and the sharing of results. Data that are not available for use and analysis are of little or no use. Not only is availability important at the present, but how available the data will be in the future is also important. The third data consideration is coverage, which deals with the extent of the data. The data need to cover the entire scope of the project to produce reliable analysis results. The last data consideration is usability. It is important to understand the data and how the data can be used for analysis. Data that are in a non-usable format can also be of little or no help in the analysis process (Schultz et al. 2012). All of these general considerations for data were evaluated in determining which datasets to utilize for this safety analysis project.

3.2 Utilized Datasets

This section provides an overview of the datasets utilized in 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. Additional information about these datasets and others, along with how they were prepared for use in GIS models and crash analysis, can be found in the literature (Schultz et al. 2012).

Table 3-1: Data Source Summary

Dataset	Source	Format	Future Availability
State Routes	Utah AGRC	LRS Feature Class	Updated Regularly
Crash Data	Scott Jones (UDOT)	CSV Tables (Excel)	Updated at least Annually
AADT	Frank Pisani, Lee Theobald (UDOT)	Excel Spreadsheet	Updated Annually
Truck AADT	Frank Pisani, Lee Theobald (UDOT)	Excel Spreadsheet	Updated Annually
Speed Limit	Larry Montoya (UDOT)	Shapefile	TBD
Functional Class	Charles Allen (Interplan)	Excel Spreadsheet	TBD
Through Lanes	UGATE	KML file	TBD
Urban Code	UGATE	Shapefile	TBD

3.3 Data Uniformity

Uniformity of data is critical to ensure accuracy and to allow for additional data to be added to the model with ease. Having an agency-wide standard for data uniformity can be difficult because the data are collected in different departments with different standards. For the use of data in GIS the only elements that need to be consistent and uniform are the column headings. Uniform column headings allow the data to be inserted into the model for analysis without having to manually prepare the dataset. The following list contains five data fields that are recommended for use in all datasets. These fields correspond with the State Routes Linear Referencing System (LRS) dataset that is required for use in the model that was developed for this research project. The "P" direction code indicates that route milepoint measures increase in the positive direction. The "N" direction code indicates that mileposts increase in the negative direction. Finally, the "X" direction is used as a surrogate measure for the "N" direction. The "X" Direction follows the same geometry as the "N" direction but has milepoints that match the "P" direction. Additional information about data uniformity can be found in the literature (Schultz et al. 2012).

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

3.4 Project Data Task

There are three distinct tasks for which the datasets mentioned in Table 3-1 are used. These tasks are: 1) the roadway segmentation process, 2) use as a variable in the model, and

3) for micro analysis of hot spots. The following sections will describe these tasks and how the data are used in each one.

3.4.1 Roadway Segmentation Process

The purpose of the segmentation process is to use roadway data and characteristics to identify homogeneous roadway segments to use in the statistical model for crash analysis. This is done so that each segment has consistent attributes throughout the entire segment. For this project the state roadway system was segmented with the following datasets: functional class, annual average daily traffic (AADT), speed limit, number of thru lanes, and urban code. This process is done using a GIS tool called "Overlay." It is important that the dataset used in the segmentation process has the five fields discussed in section 3.3 so that the GIS tool will be able to properly segment the roadway network. For more information concerning considerations about the segmentation process and a more in-depth description refer to the literature (Schultz et al. 2012).

3.4.2 Model Variables

To run the model developed for this project, input variables are required. These variables come from the same datasets mentioned in Table 3-1. The input variables can be changed based on the data to be used in the crash analysis. The variables can also be manipulated within the model based on how the code is written in the model. Each segment in the roadway network must have the model variables directly linked to it.

An important aspect of using the model is to determine the crash severities to analyze. Different crash severity combinations will give different hot spot locations. The differences arise because some segments tend to experience one severity more frequently than another. This project is focused primarily on severities K and A in the KABCO system of ranking crash severity or high severity crashes. 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. Excel and ArcMap can be used to remove crash severity types that are not wanted for a specific model run from the dataset.

The processes mentioned in this section can also be used to change the roadway types that can be analyzed or to make many different subsets of the data that the model will use. Even though this was not done in this project, an example would be to make a subset of the data so that only rural roadways were analyzed to determine rural hot spots. For more information about data preparation for use in the model refer to the literature (Schultz et al. 2012).

3.4.3 Hot Spot Analysis

The statistical model is used to determine the roadway segments that are considered to be hot spots. After using the model to develop a list of problematic segments, the data can then be used to perform a micro analysis on each hot spot segment to determine if the hot spots truly are problematic and have characteristics that can be addressed through the use of countermeasures. The main dataset that is used in the micro analysis is the crash dataset to look for common traits or characteristics associated with the crashes on the segment. There are four crash datasets provided by UDOT for each year that were utilized in the hot spot analysis. These datasets deal with the crash itself, vehicles involved in the crash, possible contributing factors to the crash, and officer comments on the crash. More information about the crash datasets can be found in Chapter 5 and Chapter 6. Other datasets should also be considered in the micro analysis of hot spots such as roadway geometry and speed limits. The methodology associated with the analysis of hot spots is described in greater detail in Chapter 5 and Chapter 6.

3.5 Chapter Summary

The availability and quality of data may be the limiting factor in determining what type of crash analysis can be done and will determine how valid and accurate the results are. Accuracy, availability, coverage, and usability are general data considerations that need to always be considered when performing crash analysis. The datasets used in this project are summarized in this chapter along with a suggested method of providing uniformity to all datasets so that future data can be easily added for use in the developed model. In this project there are three tasks for which data are used. These tasks are to segment the current roadway system into uniform segments, to prepare data to be used as a variable in the model, and to use the data to perform a micro analysis of all determined hot spots.

4 STATISTICAL MODEL

A hierarchical Bayesian model was developed to analyze crashes on all state roads in Utah. This chapter discusses the theoretical basis for the hierarchical Bayesian model, a summary of the components used to develop the model, and the resulting output of the model.

4.1 Theoretical Basis – Hierarchical Bayesian Poisson Mixture 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 number of crashes per mile, 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 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.

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

where: Y_{ijk} = number of crashes,

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

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

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

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

Using the canonical log link function, which is standard for Poisson regression, models are formed in Equations 4-2a and 4-2b to model both λ_{ijk} and p_{ijk}.

$$\log(\lambda_{ijk}) = \beta_{0jk} + \beta_{1jk}VMT_{ijk} + \beta_{2jk}SpeedLim_{ijk} + \beta_{3jk}NumLanes_{ijk} + \beta_{4jk}\%Trucks_{ijk} + \beta_{5jk}VMT_{ijk}^2 + \beta_{6jk}SpeedLim * NumLanes_{ijk} \quad (4\text{-}2a)$$

$$\log(\frac{p_{ijk}}{1-p_{ijk}}) = \gamma_{0jk} + \gamma_{1jk}VMT_{ijk} + \gamma_{2jk}SpeedLim_{ijk} + \gamma_{3jk}NumLanes_{ijk} + \gamma_{4jk}\%Trucks_{ijk} + \gamma_{5jk}VMT_{ijk}^2 + \gamma_{6jk}SpeedLim * NumLanes_{ijk} \quad (4\text{-}2b)$$

Using the deviance information criterion (DIC), a best-fit model is selected which includes the predictor variables which were introduced above to model λ_{ijk}. They are VMT, speed limit (*SpeedLim*), number of lanes (*NumLanes*), percentage of trucks (*%Trucks*), VMT^2, and the interaction between speed limit and number of lanes (*SpeedLim*NumLanes*), as shown in Equation 4-2a. In order to assess the effects of these six variables on λ_{ijk}, the variables β_{0jk}, β_{1jk}, β_{2jk}, β_{3jk}, β_{4jk}, β_{5jk}, and β_{6jk} are introduced. Similarly, to model p_{ijk} in Equation 4-2b, the same covariates as above are used and the variables γ_{0jk}, γ_{1jk}, γ_{2jk}, γ_{3jk}, γ_{4jk}, γ_{5jk}, and γ_{6jk} are introduced to measure the corresponding effects.

Non-informative normal and 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.

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

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

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

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

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_{1jk}, which is specific to the j^{th} route of the k^{th} functional classification. However, 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 seven parameters in the linear models, seven hyperparameters, and 304 routes nested within seven functional classifications, yielding a total of 2,177 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 $\vec{\beta}_{jk}$ and $\vec{\gamma}_{jk}$ 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.

4.2 **Model Development**

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

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

4.3 **Model Output**

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

An example posterior predictive distribution produced by the model is shown in Figure 4-1. The bars represent the distribution of the number of crashes that would be expected on this segment based on analysis of all segments in the same functional classification and route, having the same covariate characteristics; such as the same VMT, speed limit, etc. 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 4-1, the percentile is equal to 0.965, thus indicating that the actual number of crashes on this road segment was higher than predicted.

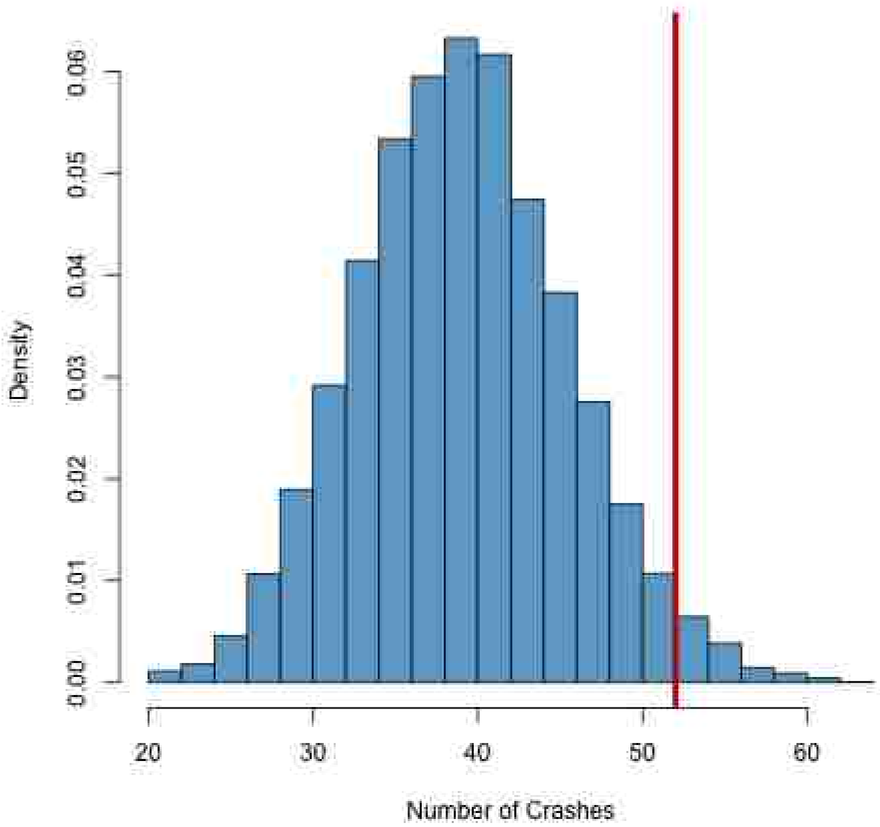

Figure 4-1: Example of a posterior predictive distribution for a single road segment.

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

4.4 **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 overdispersed. Posterior predictive distributions for each roadway segment are developed using MCMC and Gibbs sampling methods. By comparing the posterior predictive distribution with the actual number of crashes for a given segment it can be determined if more crashes have occurred on that segment than would normally be expected.

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5 HOT SPOT IDENTIFICATION AND ANALYSIS METHODOLOGY

A hot spot identification and analysis methodology has been developed for this project. This methodology is the way through which problematic segments are identified, analyzed, defined, and feasible countermeasures are evaluated and selected. This chapter will focus on the hot spot identification and analysis methodology steps. These steps are: 1) identify problematic segments with safety concern, 2) identify problem spots within the segments, 3) micro analysis of problematic segments and spots, 4) defining the segment, 5) defining the problem, 6) evaluation of possible countermeasures, and 7) selection and recommendation of feasible countermeasures, as illustrated in the flowchart in Figure 5-1. The general purpose and definition of each of the steps is given in this chapter. A more in-depth discussion with examples of these methodology steps is provided in Chapter 6.

5.1 Step 1: Identify Problematic Segments with Safety Concerns

Chapter 4 provides the details on the statistical model developed to identify problematic segments or hot spots. Using the results of the statistical model for hot spot identification, the analyst is then able to determine the number of segments to continue with for further analysis.

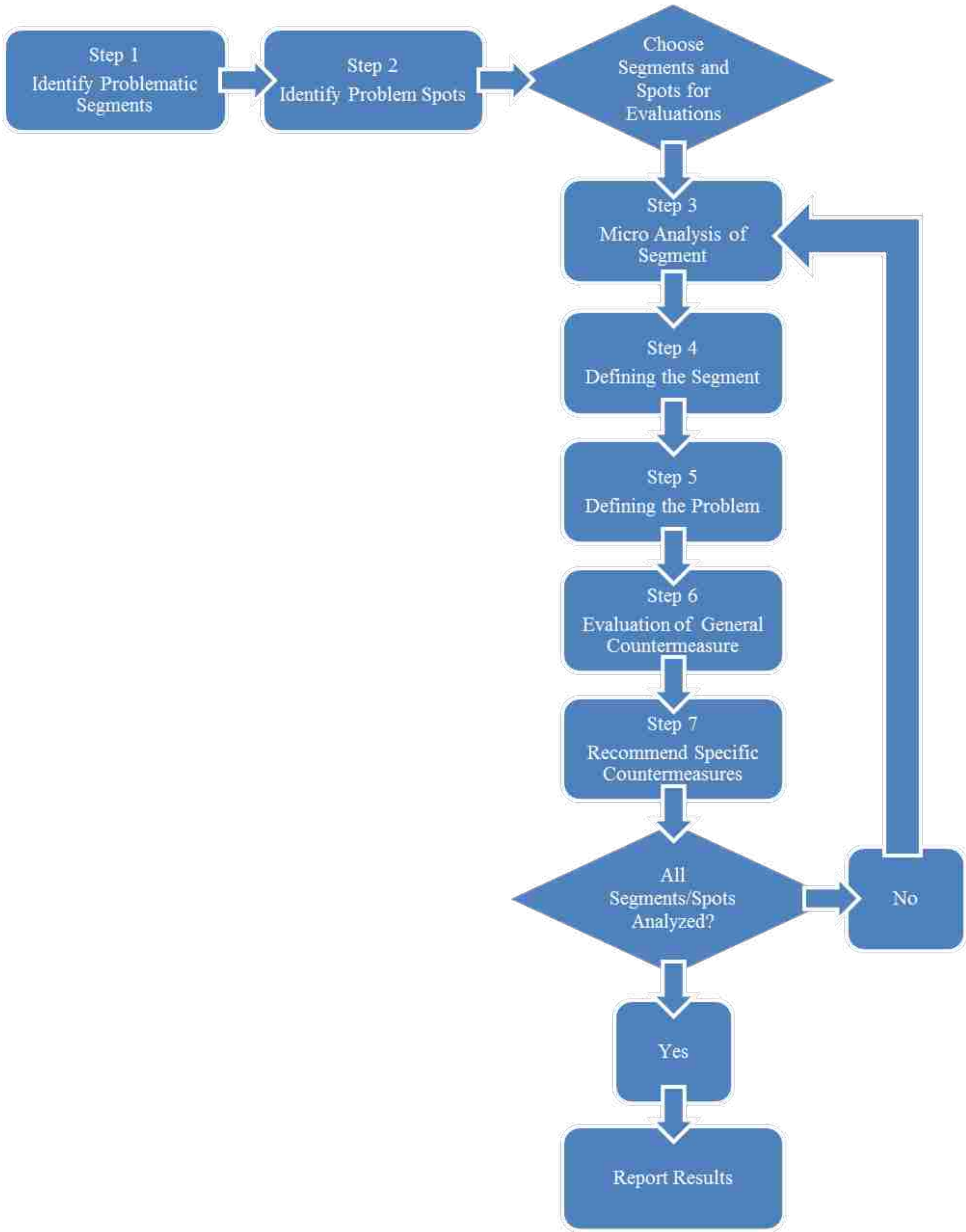

Figure 5-1: Methodology flowchart.

5.2 Step 2: Identify Problem Spots within the Segments

Within each segment that has been identified as a hot spot it is necessary to determine whether there are problem spots within the segment that may be causing the entire segment to be considered a hot spot. Problem spots are identified primarily with the use of ArcMap crash analysis tools. The purpose of the ArcMap crash analysis tools is to help identify problem spots within the predetermined hot spot segment. The statistical model is used to determine the segments that are considered to be hot spots. The process by which the roadway network is broken up into segments is described in section 3.4.1. These segments can have a wide range of lengths so it is necessary to determine if the safety problem is found along the entire length of the segment or if it is confined to a particular spot along the segment.

Esri has developed two tools for crash analysis in ArcMap; the strip analysis tool and the sliding scale analysis tool. The following subsections will briefly explain each tool and how it can be used for micro analysis of an identified hot spot (Esri 2013). For additional information not provided in this chapter about GIS tools see the previous report titled "Traffic and Safety Statewide Model and GIS Modeling" (Schultz et al. 2012).

5.2.1 Strip Analysis Tool

The strip analysis tool helps analyze a roadway system by breaking the inputted roadway network into segments that contain a specific number of crashes. The length of these segments is selected by the user along with a minimum crash threshold. The tool works by laying windows over the roadway end-to-end and counting the number of crashes within each window. Any window that has the minimum number of crashes is copied into an output file. The segments in the output file are called "High Accident Locations" or HALs (Esri 2013).

5.2.2 *Sliding Scale Analysis Tool*

The sliding scale tool is very similar to the strip analysis tool. The difference is that the window in the sliding scale tool moves or slides along the route in an incremental manner, rather than end-to-end. The user must also define how far the window will slide down the route before analyzing the next segment. This is beneficial because it eliminates the chance that a HAL becomes split in half (Esri 2013). Figure 5-2 is an example of the output in ArcMap of both the strip analysis tool and the sliding scale analysis tool. The output for each of these tools provided identical results for this analysis.

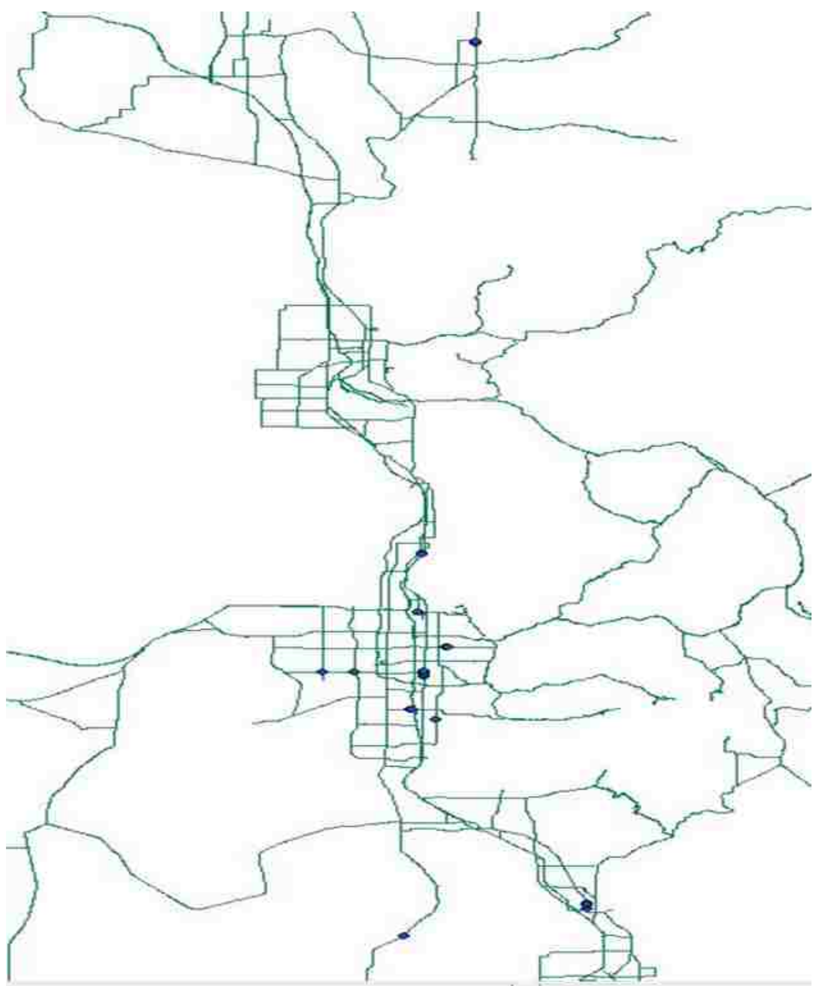

Figure 5-2: ArcMap analysis tools output.

Because the user can determine the input values for length and number of crashes used in the strip and sliding scale analysis tools they are able to customize the output HALs that are considered to be problem spots in the segment. This allows the user to change the problem spot definition based on individualized needs and situations. If no HAL is output on a segment then the problem is assumed to be along the entire length of the segment. After using these ArcMap crash analysis tools the analyst is able to generate a list of possible problem spots that exist within the hot spot segments that need further micro analysis.

5.3 Step 3: Micro Analysis of Problematic Segments and Spots

Once the statistical and GIS models have been used to determine the top hot spot segments and problem spots on the roadway network, a micro analysis needs to be performed on each of the individual segments or spots. The purpose of the micro analysis is to determine the cause of the problem, location of the problem, and any factors that may be contributing to the problem. The following sections provide a more in depth discussion on several tools used in the micro analysis of problematic roadway segments including: 1) crash data, 2) internet tools, 3) site visits, and 4) communicating with experts.

5.3.1 Crash Data

The purpose of using crash data in the micro analysis is to help identify common traits and characteristics for each of the hot spot segments and problem spots. Crash data received from state DOTs can come in many different forms. These files are typically very large and contain more information than is needed for a crash analysis. With a list of hot spot segments and problem spots it becomes important to sort through all of the crash data files and compile the data that are needed and considered important for a given segment or spot. Chapter 6 discusses the specific crash files used for this purpose in Utah. When the crash data are compiled into one location it becomes easier to look for common traits and characteristics in the crash data that could be contributing to the safety problem. The most important crash data to consider is dependent on the type of data that are available and the type of analysis that is being performed. Possible considerations for crash data to compile are: crash sequence of events, vehicle maneuvers, manner of collision, speed related, roadway geometry related, and intersection-related.

5.3.2 Internet Tools

Internet tools can help with the micro analysis of hot spot segments and problem spots by allowing the analyst to quickly view the hot spot segments and problem spots. The main tools that can be used in Utah are Google Earth (Google, Inc. 2013a), Google Maps (Google, Inc. 2013b), and UDOT's Roadview Explorer (UDOT 2013). If other tools are available they could also be considered for usefulness in helping to analyze hot spots. By using these internet tools, the analyst is able to become familiar with the segment or problem spot before doing an actual site visit. The tools also allow the analyst to view the segment over different years so that it is possible to see what changes to the roadway have occurred. It becomes possible to make a list of information to verify while performing an actual site visit so that nothing is overlooked or forgotten. By viewing the site with internet tools it is also possible to get a perspective, such as a bird's eye view, that could not be possible when actually visiting the site. It is important that any information retrieved by using internet tools be verified with a site visit to ensure its accuracy.

If possible, the internet should also be used to identify future, current, and past construction at the site. Many state DOTs keep track of their future, current, and past construction projects online.

5.3.3 Site Visits

After analyzing the roadway using the internet tools, the next step is to conduct a site visit. A site visit is critical to the analysis of a roadway when safety issues are of concern. The main purpose of a site visit is to get a firsthand feel or understanding of how the roadway segment functions. Much can be gained from the use of statistical models, GIS, roadway data, crash data, ArcMAP tools, and the use of other internet tools, but none of these can replace firsthand knowledge about a roadway segment gained from a site visit. A site visit allows the analyst to verify or dismiss conclusions drawn from other analysis methods. It is also an excellent way for information to be gathered that is otherwise not found in the collected data. With the understanding of a segment gained through a site visit, the analyst is able to more fully understand the associated problems causing the safety concerns and the possible countermeasures that can be used to mitigate the problem.

5.3.4 Communicating with Experts

Another micro analysis tool is to communicate with experts familiar with the site such as law enforcement agencies, local and state government officials, traffic engineers in the area, and local DOT employees. The purpose of communicating with an expert is to gain knowledge from one who has a specific understanding and interest in the site. These experts can provide necessary information that could not be found in any other way. It can also be informative to contact stakeholders, such as local residents or business owners, who are affected by the roadway segment of interest. Stakeholders are able to provide opinions, observations, and concerns that could aid in defining the problem and evaluating possible countermeasures. This communication is used to help gain a greater understanding of the site so no information is overlooked that could help in the selection of feasible countermeasures.

5.4 Step 4: Defining the Segment

After a careful micro analysis has been performed on a hot spot segment it is important to define the problem area of the segment. The purpose of this step in the methodology is to help gain a better understanding of the segment and the characteristics found within the segment. When defining the problem area of a segment it is important to clearly define the milepoint locations at which the safety problem occurs. It is possible for the safety problem to occur on the entire length of the segment or at a localized spot. Along with a clear definition of the location where the problem occurs, the roadway characteristics of the location should also be defined. These characteristics include the roadway geometry, number of through lanes, speed limit, intersection types if present, and any other characteristics that are deemed necessary to fully understand the segment.

5.5 Step 5: Defining the Problem

After a thorough micro analysis of the hot spot segment or spot has been performed and the segment or spot has been clearly defined it is then possible to provide a clear definition of the problem that is causing the segment to be considered a hot spot. With a clear definition of the problem it becomes easier to select possible countermeasures for evaluation. Along with defining the safety problem it is also important to define the cause of the problem and any known contributing factors if at all possible. By clearly defining the segment, along with having the problem defined it is possible to make a list of all possible countermeasures and to thoroughly evaluate the feasibility of each one. If a clear problem cannot be defined after completing the previous steps in the methodology, the process should be repeated to see if any information was overlooked. Without a clearly defined problem it becomes difficult, if not impossible, to find a solution.

5.6 Step 6: Evaluation of Possible Countermeasures

The purpose of the micro analysis, defining the segment, and defining the safety problem is to provide the information necessary for the analyst to make a comprehensive list of all possible known countermeasures for evaluation. 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. The following is a list of possible questions to ask when evaluating possible countermeasures:

- Are there any quick solutions?
- Are there any inexpensive solutions?
- What are the implementation times of the possible countermeasures?
- Will the implementation of one countermeasure mitigate the problem?
- Will the implementation of multiple countermeasures be the most effective?
- Does this countermeasure relate directly to the defined safety problem?
- Is there a CMF related to this countermeasure?
- Is this countermeasure considered to be a proven countermeasure?
- What countermeasures listed are already being used at this site?
- Is it possible to implement this countermeasure at the site?
- Are there any other countermeasures not being considered?

After the list of possible countermeasures has been evaluated and the right questions have been asked about the specific countermeasures the next step is to eliminate all countermeasures that are not considered feasible at the specific hot spot. Only countermeasures considered to be viable and feasible solutions to help mitigate the safety issue at the specific hot spot should be considered for implementation in the next step of the methodology.

5.7 Step 7: Selection and Recommendation of Feasible Countermeasures

The last step in the hot spot identification and analysis methodology is to select countermeasures that will have the greatest impact for safety improvement. With a more focused list of feasible countermeasures, the next step is to determine which countermeasure, or combination of countermeasures, to select for implementation. This countermeasure, or combination of countermeasures, should then be recommended for implementation to mitigate the safety problem. It is possible that there may not be a feasible countermeasure for implementation. If this is the case it is recommended that the methodology steps be repeated to see if any information was overlooked that would help in the selection of a feasible countermeasure. Recommendations should only be made if countermeasures can be shown to improve the safety at a site with a known problem.

5.8 Chapter Summary

A hot spot identification and analysis methodology has been developed to aid in the identification of feasible countermeasures to improve safety and reduce crashes along roadways. This methodology is the process through which safety hot spots are identified and analyzed. This micro analysis is done through a number of different steps. These steps include the use of ArcMAP and internet tools, crash data, site visits, and communicating with experts. After a problematic segment is analyzed the segment and problem are clearly defined so that possible countermeasures can be listed and evaluated. Each possible countermeasure is then evaluated to find the best possible solution to mitigate the defined safety problem. Only feasible countermeasures are recommended for implementation if they directly relate to the defined problem. Figure 5-1 (shown previously) summarizes the methodology steps into a flow chart.

6 METHODOLOGY EXAMPLES AND RESULTS

The purpose of this chapter is to illustrate how to follow the methodology steps outlined in Chapter 5 in improving roadway safety on a specific hot spot segment or problem spot. With specific examples provided for each of the steps, the reader will better understand the importance of each step in improving safety along with an increased understanding of why the analysis is performed in this manner. This chapter follows the seven steps in the hot spot identification and analysis methodology: 1) identify problematic segments with safety concern, 2) identify problem spots within the segments, 3) micro analysis of problematic segments and spots, 4) defining the segment, 5) defining the problem, 6) evaluation of possible countermeasures, and 7) selection and recommendation of feasible countermeasures.

6.1 Step 1: Identification of Problematic Segments with Safety Concern

The first step in the methodology is to run the statistical model to identify the problematic segments or hot spots. For the analysis completed in this research, data used in the statistical model included all crashes from the years 2006 to 2011. To complete the modeling task 100,000 iterations were performed on each segment to obtain posterior predictive distributions on the number of crashes expected to occur. The actual number of crashes were compared to the posterior predictive distribution to assign a percentile to each segment. The percentile was determined by where the actual number of crashes fell on the distribution and was assigned a number between 0 and 1. The higher the percentile, the greater chance the segment is a hot spot that needs to be analyzed for safety improvements. Table 6-1 shows the top 20 segments hot spots from the model based on the percentile calculated. These segments are ordered from highest percentile descending downward to the lowest percentile. The column labeled “Post Med” represents the median of the posterior predictive distribution. Refer to Chapter 4 for more information on the statistical model.

Table 6-1: Top 20 Model Hot Spots

Route	Beg Milepoint	End Milepoint	Location Description	Crash Count	Post Med	Difference	Percentile
89	334.855	335.59	SR 114 Center Street Provo via 500 West	19	4	15	1.00000
91	29.008	29.819	1400 North Logan	11	2	9	0.99984
154	15.72	15.93	6200 South	8	1	7	0.99886
71	8.843	9.212	10600 South	7	1	6	0.99831
80	139.43	141.84	Parleys Summit	10	3	7	0.99802
68	11.638	23.934	SR 6 Elberta	12	3	9	0.99771
65	8.441	14.158	Road to Great Western Trail	7	1	6	0.99702
209	6.947	7.154	700 West	9	2	7	0.99666
89	370.298	371.216	5900 South	24	12	12	0.99639
15	303.193	303.44	SR 266 4500 South Murray	4	0	4	0.99613
89	386.801	388.04	SR 93 (2600 South) Bountiful	14	5	9	0.99563
6	205.649	210.71	Sheep Creek Road Left	13	5	8	0.99500
15	58.85	62.5	SR 56 200 North Cedar City	9	3	6	0.99394
186	6.708	6.937	1300 South Foothill Village Shopping Center	5	0	5	0.99323
171	11.93	12.533	900 East	9	3	6	0.99319
12	92.77	106.644	Burr Trail road	8	2	6	0.99317
89	378.701	379.145	Main Street via 400 South	9	3	6	0.99224
191	253.09	258.999	Road to Power Plant	5	1	4	0.99163
15	295.999	297.703	SR 209 9000 South Sandy	11	4	7	0.99143
172	0	0.993	6200 South via 5600 West (SR 172)	13	5	8	0.99112

6.2 Step 2: Identify Problem Spots within the Segments

The next step in the analysis methodology was to identify possible problem spots within the hot spot segments from step 1. Section 5.2 provided an overview of the different types of ArcMap tools that can be used in this micro analysis of the roadway segment; specifically the strip analysis tool and the sliding scale analysis tool. Because of the similarities between the two tools, only the sliding scale analysis tool was used in this analysis because it doesn't have the chance of a HAL being split in half as explained in section 5.2.2.

The sliding scale analysis tool was run on the top 20 hot spot segments to determine if there were any problem spots within the hot spot segments. Parameters asked for when using the tool are the window length, length that the window will slide, and the minimum number of crashes per window to be considered a HAL. For this analysis a window length of 1/20 of a mile was used with the window sliding half that distance. A minimum of 6 crashes per window was also used to be considered a HAL or problem spot. With 6 years of crash data, a minimum of 6 crashes was used so that a spot would average one high severity crash per year to be considered a problem spot. After running the sliding scale analysis tool it was determined that there were a total of five problem spots in the top 20 hot spot segments. Table 6-2 shows where these problem spots are located along with the severity of each crash.

Table 6-2: Segment Problem Spots

Route	Segment Milepoint	# of Crashes	Problem Spot	# of Crashes	# Severity K	# Severity A	Segment Rank
89	334.885-335.59	19	335.31-335.32	7	0	7	1
89	370.298-371.216	24	371.21	8	0	8	9
171	11.93-12.533	9	12.23-12.29	6	1	5	15
89	378.701-379.145	9	379.1-379.145	6	0	6	17
172	0.0-0.993	13	0.98-0.99	7	0	7	20

For the purposes of this study, only the top five hot spot segments and the problem spots on the number one and number nine ranked segments were chosen for further analysis. The analysis will continue to follow the remaining steps as shown previously in the methodology flowchart in Figure 5-1. Even though five hot spot segments and two problem spots will be analyzed further, only one hot spot and one problem spot will be presented in this chapter as examples of how to follow the methodology. These examples are the hot spot on I-80 from milepoint 139.43 to milepoint 141.84 and the problem spot on U.S. 89 at milepoint 371.21. The methodology results from the other hot spots and problem spot can be found in Appendix B.

6.3 Step 3: Micro Analysis of Problematic Segments and Spots

A general description of the micro analysis step can be found in Section 5.3 along with an overview of the different tools (i.e., crash data, internet tools, site visit, and communicating with experts) that can be used to help in the micro analysis of a problem spot. This section will focus on how these tools were used to analyze a hot spot and a problem spot.

6.3.1 Crash Data

The first step in the micro analysis process is to identify common traits and characteristics in the crash data that could be causing a safety problem. Up to this point the statistical model and ArcMap tools were used to determine the hot spot and problem spots that should be evaluated using the crash data provided by UDOT. Now the crash data will be used more proactively to aid in the overall safety analysis process.

Crash data were provided in a total of eight different excel files for the years 2006 to 2011. Only four of these files were used while analyzing the crash data for a particular segment or spot. None of these crash data files were modified in any way. The four excel files used are labeled with the year followed by the name. Using the 2011 crash data as an example, the four files are labeled 2011_crash, 2011_crash_comments, 2011_vehicle, and 2006-2011 Crash Rollup #1. These different files are linked together with a unique crash ID number that is assigned to each individual crash in the database. These files are also directly related to the DI-9 forms that law enforcement officers fill out at the scene of a crash.

The crash file was used to pull information about the crash itself. In the crash file data about the crash conditions, road conditions, light conditions, horizontal alignment, weather conditions, and harmful events can be found. Only data pertaining to the first harmful event collision type and manner of collision was used for this study. In this file only one line of data will be found for each crash ID.

The vehicle file contains all information pertaining to the vehicles involved in the crash. Because there can be more than one vehicle involved in a crash it is possible to have multiple lines of data in this file for the same crash ID. Data about the vehicle collision event sequence, most harmful event, body type, most damaged area, trailing units, travel direction, and vehicle maneuver can be found in the vehicle file. Only data pertaining to event sequence, most harmful event, and vehicle maneuver were used for this study.

The crash rollup file is a quick reference file to help determine the contributing factors in a crash. For every crash ID there is a list of possible contributing factors that could have led to the crash. If the possible contributing factor was involved in the crash then it is marked with a "Y" for "yes," but if it is not involved then it is marked with an "N" for "no". For this study only data pertaining to driving under the influence (DUI), aggressive driving, speed related, intersection-related, roadway geometry related, and teenage driver were used. When all of the data are compiled into one file for the hot spot being analyzed it becomes easy to see common traits and characteristics that could be contributing to the safety problem.

The crash comments file contains comments from the law enforcement officer about the crash. There is only one set of comments for every crash ID. Most of the crash IDs do not have officer comments but it is still important to consider them when present. A table was created if there were comments but this information will not be added to this report. It is suggested that the compiled crash comments file be referred to when defining the problem at the segment and also when evaluating possible countermeasures.

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 micro analysis. It is important for the analyst to pull all data that are relevant to the segment for analysis. Other data that weren't used but could be considered include weather conditions, time of year, and direction of travel.

As noted previously, one hot spot and one problem spot will be presented in this chapter as examples of how to follow the methodology. These locations, I-80 and U.S. 89, are presented in the following subsections, and as subsections in the remaining sections of this chapter.

6.3.1.1 Crash data for hot spot on Interstate 80. A compilation of the crash data from the crash file, vehicle file, and crash rollup files for I-80, milepoint 139.43 to 141.84, can be found in Tables 6-3 through 6-5. Table 6-3 provides the crash file data, Table 6-4 provides the vehicle file data, and Table 6-5 provides the crash rollup file data (all information not available is represented with an NA in the table).

Table 6-3: Crash File - I-80 (Milepoint 139.43-141.84)

Crash ID	First Harmful Event	Manner of Collision
10104093	Motor Vehicle	Front to Rear
10075463	Motor Vehicle	Front to Rear
10284229	Motor Vehicle	NA
10421947	Motor Vehicle	Front to Rear
10080777	NA	NA
10070796	Motor Vehicle	Head-On
10368724	NA	NA
10108839	Motor Vehicle	Parked Vehicle
10345683	Rollover	NA
10361258	Motor Vehicle	Sideswipe
10348565	Rollover	NA
10353894	Rollover	NA
10182559	Rollover	NA
10381755	Crash Cushion	Sideswipe

Table 6-4: Vehicle File - I-80 (Milepoint 139.43-141.84)

Crash ID	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
10104093	Motor Vehicle, ROR, Ditch	Motor Vehicle	Straight Ahead/Straight Ahead
10075463	Motor Vehicle	Motor Vehicle	Stopped in Lane/Straight Ahead
10284229	ROR, Embankment, Rollover	Rollover	Straight Ahead
10421947	Motor Vehicle, ROR, Embankment, Light Pole	Motor Vehicle/Utility Pole	Straight Ahead/Passing
10080777	ROR, Delineator Post, Culvert, Post	Delineator Post	Changing Lanes
10070796	Motor Vehicle, ROR	Motor Vehicle	Straight Ahead/Straight Ahead
10368724	Equipment Failure, ROR, Fence, Rollover	Rollover	Straight Ahead
10108839	ROR, Embankment/Equipment Failure, Downhill Runaway/Motor Vehicle	Embankment/Motor Vehicle	Straight Ahead/Parked/Straight Ahead
10345683	Motor Vehicle, ROR, Rollover	Rollover	Straight Ahead
10361258	Motor Vehicle, ROR, Fence, Rollover	Rollover	Straight Ahead/Crossed Median
10348565	ROR, Rollover	Rollover	Straight Ahead
10353894	Motor Vehicle, Rollover, Non-Fixed Object	Rollover	Straight Ahead
10182559	ROR, Rollover, Delineator Post	Rollover	Straight Ahead
10381755	ROR, Crash Cushion, Motor Vehicle	Motor Vehicle	Straight Ahead/Straight Ahead

Table 6-5: Rollup File - I-80 (Milepoint 139.43-141.84)

Crash ID	DUI	Aggressive Driving	Speed Related	Intersection Related	Roadway Geometry	Teenage Driver
10104093	N	N	Y	N	Y	N
10075463	N	N	N	N	Y	N
10284229	N	N	Y	N	Y	Y
10421947	Y	N	Y	N	Y	N
10080777	N	N	Y	N	Y	Y
10070796	N	N	N	N	Y	N
10368724	N	N	Y	N	Y	N
10108839	N	N	N	N	Y	N
10345683	N	N	N	N	Y	N
10361258	N	N	N	N	Y	N
10348565	N	N	N	N	Y	N
10353894	N	N	Y	N	Y	N
10182559	N	N	N	N	Y	Y
10381755	N	N	Y	N	Y	N
Total	1/14	0/14	7/14	0/14	14/14	3/14

Upon review of the crash data tables for the hot spot on I-80 it was determined that the common trend was an excess of rollovers and ROR collisions. These types of collisions happened while the vehicle was traveling straight or passing. The possible contributing factors are speeding, roadway geometry, and rear end collisions.

6.3.1.2 Crash data for problem spot on U.S. 89. A compilation of the crash data from the crash file, vehicle file, and crash rollup files for U.S. 89, milepoint 371.21, can be found in Tables 6-6 through 6-8. Table 6-6 provides the crash file data, Table 6-7 provides the vehicle file data, and Table 6-8 provides the crash rollup file data (all information not available is represented with an NA in the table).

Table 6-6: Crash File - U.S. 89 (Milepoint 371.21)

Crash ID	First Harmful Event	Manner of Collision
574477	Motor Vehicle	Head-On
10037371	Motor Vehicle	Angle
10051383	Motor Vehicle	Angle
10072159	NA	Front to Rear
10156790	Motor Vehicle	Angle
10225638	Motor Vehicle	Angle
10313381	Motor Vehicle	Front to Rear
10427803	Motor Vehicle	Angle

Table 6-7: Vehicle File - U.S. 89 (Milepoint 371.21)

Crash ID	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
574477	Motor Vehicle, ROR, Fixed Object	NA	Straight Ahead/Overtaking-Passing
10037371	Motor Vehicle, Traffic Signal, Utility Pole, Fixed Object	Motor Vehicle	Straight Ahead/Straight Ahead
10051383	Motor Vehicle	Motor Vehicle	Turning Left/Straight Ahead
10072159	NA	NA	Turning Left/Straight Ahead
10156790	Motor Vehicle	Motor Vehicle	Turning Left/Straight Ahead
10225638	Motor Vehicle, Motor Vehicle	Motor Vehicle	Straight Ahead
10313381	Motor Vehicle	Motor Vehicle	Stopped in Lane/Straight Ahead
10427803	Motor Vehicle	Motor Vehicle	Turning Left/Straight Ahead

Table 6-8: Rollup File - U.S. 89 (Milepoint 371.21)

Crash ID	DUI	Aggressive Driving	Speed Related	Intersection Related	Roadway Geometry	Teenage Driver
574477	N	N	N	Y	Y	Y
10037371	N	N	N	Y	N	Y
10051383	N	N	N	Y	N	Y
10072159	N	N	N	Y	Y	Y
10156790	N	N	N	Y	N	N
10225638	N	N	N	Y	Y	Y
10313381	N	N	N	Y	N	N
10427803	N	N	N	Y	N	N
Total	0/8	0/8	0/8	8/8	3/8	5/8

Upon review of the crash data tables for the problem spot on U.S. 89 it was determined that the majority of the collisions are angled crashes that happened while one vehicle was traveling straight and the other vehicle was turning left. All of these collisions are intersection-related with a majority of them being teenage driver related.

6.3.2 Internet Tools

The internet can be a very useful tool when analyzing roadway segments with safety concerns. For this study, Google Maps was used to verify the current conditions at the segment in question and its roadway features (Google, Inc. 2013b). In addition to Google Maps, UDOT has a website call Roadview Explorer that can be used to observe the current conditions of the roadway and to gain a historical perspective of the roadway (UDOT 2013). This tool was used to identify changes that have happened to the roadway over the years. Both of these internet tools can also be used to evaluate factors that are unusual and could possibly be causing a safety problem. While using the tools it is important to make a list of information to verify while performing a site visit.

In the following subsections, examples of how internet tools were used on the hot spot and problem spot will be presented. These examples are located on I-80 and U.S. 89.

6.3.2.1 Internet tools for hot spot on Interstate 80. Using Google Maps it was observed that I-80 from milepoints 139.43-141.84 is an interstate highway through Parleys Canyon with three lanes of travel in each direction divided by a sloped center median. The median is unpaved with a small concrete ditch in the center. For almost the entire length of the segment there are no barriers in the median or the shoulder. The shoulder has both a paved and unpaved portion. On both sides of the road there are rumble strips. Figure 6-1 is a Google Map image of the segment that helps to visualize the curvature of the roadway through Parleys Canyon.

Figure 6-1: Birds eye view of Interstate 80 (Google, Inc. 2013b).

Using the UDOT Roadview Explorer tool the analyst can see that there have been few changes to the segment from the years 2009 to 2012. The only noticeable change that could be seen was that the segment was repaved sometime between the years 2011 and 2012. Figure 6-2 shows a portion of the segment in 2009 while Figure 6-3 shows the same portion of the segment in 2012.

Figure 6-2: Interstate 80 in 2009 (UDOT 2013).

Figure 6-3: Interstate 80 in 2012 (UDOT 2013).

6.3.2.2 Internet tools for problem spot on U.S. 89. Using Google Maps it was observed that the U.S. 89 milepoint 371.21 problem spot is at the intersection of 5300 South and State Street in Murray, Utah. There are three through lanes in the northbound and southbound directions at the intersection. One of the three through lanes for the northbound traffic is a shared right turn lane while southbound traffic has a dedicated right turn pocket. For northbound traffic there are two left turn lanes and only one left turn lane is striped for southbound traffic. There is also a raised median barrier down the center of the roadway. Figure 6-4 is a Google Map image of the intersection that helps to visualize the geometry of the intersection.

Figure 6-4: U.S. 89 problem spot intersection (Google, Inc. 2013b).

Using UDOT Roadview Explorer it was determined that at some point before 2010 a second left turn lane was added for the northbound traffic as illustrated in Figure 6-5 and Figure 6-6. It is unclear whether the changes were made to address the safety issue at the intersection or if they were done to expedite traffic flow. It appears that the road had to be widened to accommodate this change (the exact date of the change could not be determined). There are not enough data to determine if this change addressed the problem of angled crashes but from the crash data it was noted that there have been collisions since the change was made.

Figure 6-5: U.S. 89 before 2010 (UDOT 2013).

Figure 6-6: U.S. 89 in 2012 (UDOT 2013).

6.3.3 Site Visit

After analyzing the roadway using the internet tools, the next step was to conduct a site visit to better understand how the roadway geometry and posted speed interact with one another. Also, it was important to verify that the median was how it appeared in the internet tools. A site visit is critical to the analysis of a roadway when safety issues are of concern. The main purpose of a site visit is to get a firsthand feel or understanding of how the roadway segments function. It is imperative that all assumptions be verified with a site visit before any countermeasures are implemented.

In the following subsections, examples of how a site visit was used on the hot spot and problem spot will be presented. These examples are located on I-80 and U.S. 89.

6.3.3.1 Site visit at hot spot on Interstate 80. On the site visit to the hot spot on I-80 measurements were taken of the geometric features. Along with taking measurements, assumptions about median barriers and shoulder slopes were verified. Figure 6-7 shows the typical median found along the hot spot. It was observed on the site that for most of the segment the roadway elevation for eastbound traffic is higher than that for westbound traffic. This higher elevation causes a steeper median slope for traffic traveling eastbound. The average measured distance across the center median was 50 feet. No median barrier was found on the segment. One observation from the site visit was that leading up to the hot spot segment there was generally a median barrier found alongside the eastbound lanes. Figure 6-8 shows the typical right side shoulder found along the segment. There is on average 10 feet of paved shoulder.

Figure 6-7: Typical center median on Interstate 80.

Figure 6-8: Typical shoulder on Interstate 80.

6.3.3.2 Site visit at problem spot on U.S. 89. On the site visit to the problem spot on U.S. 89 measurements were taken of the geometric features. Along with taking measurements the left hand turns were driven several times in both directions to get a feel for the turning movement. After this was done the intersection was observed for a time to help understand how it operates. It was noted that the signal at this intersection seems to be operating properly with no particular problems observed. What was observed was the raised median barrier just south of the intersection. This barrier was at different heights and one portion even had a fence. These led the analyst to believe that there may be a problem with pedestrian traffic created by presence of the high school and an abundance of teenagers. Figure 6-9 shows this raised median barrier.

Figure 6-9: Raised median barrier on U.S. 89.

6.3.4 *Communicating with Experts*

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. There is no exact place where this analysis tool must or should be used when using the analysis methodology. Based on a meeting with UDOT, the analyst was able to gain further insight into how to perform a more thorough micro analysis and was able to identify an additional internet tool that could aid in the micro analysis process. This internet tool allows the analyst to be able to see future, current, and past construction projects at the site being analyzed.

6.4 **Step 4: Defining the Segment**

After a careful micro analysis has been performed on the hot spot segment or problem spot it is important to define the problem area of the segment. This step in the methodology is to help gain a better understanding of the segment and the characteristics found within the segment. The following subsections provide the results of this step in the methodology for I-80 and U.S. 89, respectively.

6.4.1 *Interstate 80*

The hot spot on I-80 is located between the milepoints of 139.43 and 141.84. The roadway segment is a divided canyon interstate highway with three travel lanes in each direction. The posted speed limit for this stretch of roadway is 65 mph. There are rumble strips on both sides of the road for both travel directions. The center median dividing opposing traffic is sloped and unpaved with a small ditch in the middle. The width of the sloped median and ditch is an average of 50 feet. The shoulder in the middle is 7 feet. The shoulder next to the outside lane is large with both paved and unpaved sections. The paved section of the shoulder is 10 feet wide. The lanes are 12 feet wide and seem adequate. The problem appears to be along the entire length of the segment.

6.4.2 U.S. 89

The problem spot on U.S. 89 is located at milepoint 371.21. This spot is part of a larger hot spot segment on U.S. 89 between milepoints 370.298 and 371.216. The problem spot is located at the signalized intersection of 5300 South and State Street 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 40 mph. The problem spot occurs for traffic traveling on State Street, which has three lanes in each direction. For the northbound traffic there are two left turn lanes with a storage length of approximately 335 feet. For the southbound traffic there is only one left turn lane with a storage length of approximately 230 feet. At the intersection there is no shoulder but there is a gutter, curb, and sidewalk. A raised median separates opposing traffic at the intersection. Lane widths are slightly larger than 11 feet. There are pedestrian crosswalks on all legs of the intersection.

6.5 **Step 5: Defining the Problem**

The next step in the methodology process is to provide a clear definition of the problem that is causing the spot to be a safety concern. With a clear definition of the problem it becomes easier to select possible countermeasures for evaluation. It is also important to clearly understand possible contributing factors to the problem at the hot spot or problem spot being analyzed. The following subsections provide the results of this step in the methodology for I-80 and U.S. 89, respectively.

6.5.1 Interstate 80

The safety problem occurring at the hot spot on I-80 between the milepoints of 139.43 and 141.84 is an excess of ROR and rollover collisions resulting in high severity crashes. Based on the crash data in Table 6-3, Table 6-4, and Table 6-5 possible contributing factors to the problem are speeding, poor roadway geometry, and rear end collisions.

6.5.2 U.S. 89

The safety problem occurring at the problem spot on U.S. 89 at milepoint 371.21 is an excessive number of angled collisions between a vehicle turning left and a vehicle driving straight in the opposite travel direction resulting in high severity collisions. Based on the crash data in Table 6-6, Table 6-7, and Table 6-8 possible contributing factors to this problem are intersection geometry and layout and a high number of teenage drivers. It should also be noted that Murray High School is located near this intersection, which could be the cause of the teenage driver related collisions. It is believed that teenage drivers may be one of the main contributing factors to the safety problem at this problem spot.

6.6 **Step 6: Evaluation of Possible Countermeasures**

The purpose of the micro analysis, defining of the segment, and the defining of the safety problem is to make a comprehensive list for evaluation of all possible known countermeasures that could improve safety. This list is to be evaluated to eliminate all unfeasible countermeasures at the segment that is being analyzed. The following subsections provide the results of this step in the methodology for I-80 and U.S. 89, respectively.

6.6.1 Interstate 80

The following provides a list of possible countermeasures for implementation at the hot spot segment located on I-80. This list was evaluated based on the criteria and questions found in section 5.6. The countermeasures listed are specific to the problem and not the site, and were compiled using the countermeasure matrices found in Appendix A based on ROR collisions, head-on collisions, and horizontal curve collisions. Only countermeasures related to ROR and rollover collisions were added to the list for evaluation.

- Install midlane rumble strips
- Eliminate shoulder drop off
- Provide enhanced shoulder or in lane delineation and marking for sharp curve
- Provide improved highway geometry for horizontal curves
- 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
- Enhance delineation along the curve
- Add or improve roadside hardware
- Widen left shoulder

6.6.2 U.S. 89

The following provides a list of possible countermeasures for implementation at the problem spot located on U.S. 89. This list was evaluated based on the criteria and questions found in section 5.6. The countermeasures listed are specific to the problem and not the site, and were compiled using the countermeasure matrices found in Appendix A based on signalized intersection collisions. Only countermeasures related to left turns were added to the list 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

6.7 Step 7: Selection and Recommendation of Feasible Countermeasures

The final step in the methodology is to select countermeasures to be recommended for implementation at the specific site. After considering the list of all possible countermeasures for implementation, and taking into consideration the feasibility of each one, the following lists of possible countermeasures were considered as feasible solutions at each of the example sites (I-80 and U.S. 89). Each of the countermeasures listed are specific to the site and were selected without economic consideration as this was beyond the scope of this project. The following subsections provide the results of this step in the methodology for I-80 and U.S. 89, respectively.

6.7.1 Interstate 80

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 – focus on eastbound traffic
- Install shoulder barriers
- Widen the left shoulder – focus on eastbound traffic

6.7.2 U.S. 89

The following provides a list of suggested countermeasures for implementation at the problem spot on U.S. 89 based on the hot spot identification and analysis methodology. The countermeasures dealing with teenage drivers are based on the site visit observations and not from the lists of countermeasures found in Appendix A.

- Reduce approach speeds
- Optimize clearance intervals for left turn movements
- Improve signal coordination along the corridor
- Increased law enforcement presence during school hours
- Provide educational opportunities to the local high school students

6.8 Chapter Summary

A more in-depth discussion of the hot spot identification and analysis methodology steps was evaluated in this chapter with two specific examples and results for each of the individual steps from Utah's roadway network. Along with the examples, a detailed discussion on how to follow the methodology steps was provided. The 5th ranked hot spot segment located on I-80 between milepoints 139.43 and 141.84 and the highest crash count problem spot located on U.S. 89 at milepoint 371.21 were the examples used throughout the chapter to show how the methodology steps work. For both of these examples, limited recommendations are provided on possible countermeasures for implementation. Although limited recommendations are provided, the main purpose of this chapter was to show how to follow the methodology steps in improving roadway safety by the selection of feasible countermeasures for implementation at known hot spots. More example results for the other selected hot spots for analysis can be found in Appendix B.

7 CONCLUSIONS

The purpose of this research was to advance the level of safety research in the state of Utah by developing a methodology for accomplishing the first three steps in the framework for highway safety mitigation, illustrated in Figure 7-1. The developed methodology covers the steps of network screening, diagnosis, and countermeasure selection.

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

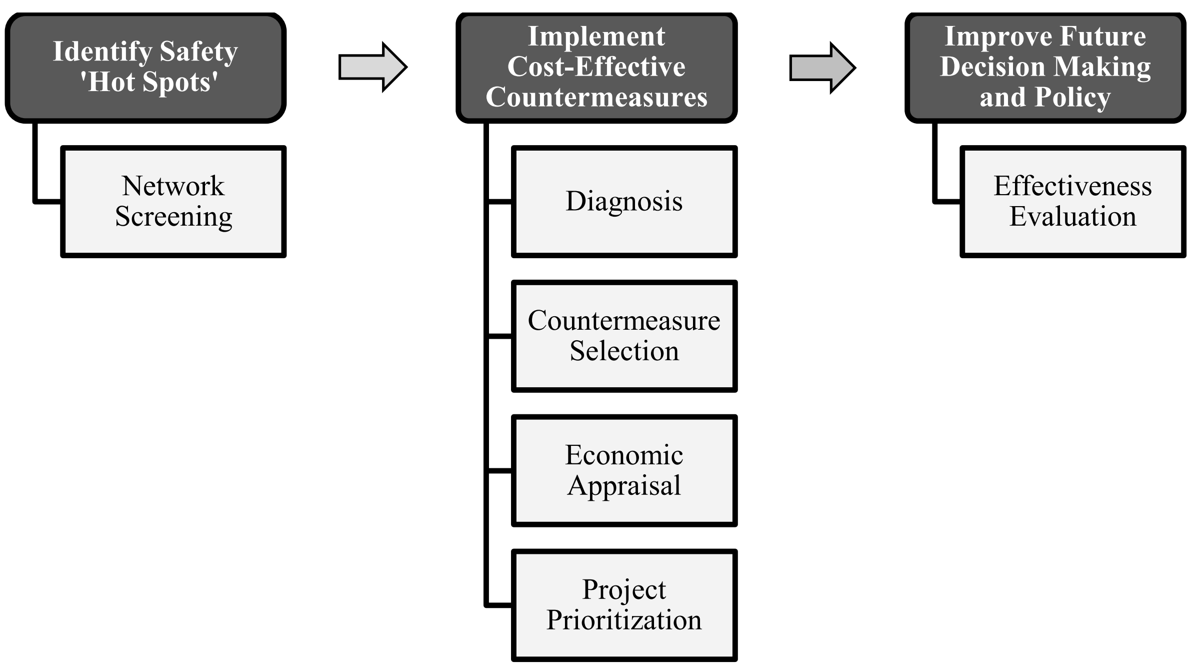

Figure 7-1: Framework for highway safety mitigation (Schultz et al. 2011).

7.1 Methodology Summary

Because safety continues to be a high priority for UDOT a methodology was developed to accomplish the first three steps in the framework for highway safety mitigation. This methodology is titled, "Hot Spot Identification and Analysis," and covers the steps of network screening, diagnosis, and countermeasure selection. As illustrated in Figure 7-2 the hot spot identification and analysis methodology consists of seven steps: 1) identify problematic segments with safety concern, 2) identify problem spots within the segments, 3) micro analysis of problematic segments and spots, 4) defining the segment, 5) defining the problem, 6) evaluation of possible countermeasures, and 7) selection and recommendation of feasible countermeasures. By using this methodology a systematic approach can be taken to identify safety issues in the roadway network and to select feasible countermeasures to mitigate the problem.

7.2 Future Research

In a continuation of research related to the analysis methodology and the framework for highway safety mitigation, three areas for future research were identified. These areas of future research would be consistent with past research and continue to aid UDOT in meeting their goal of advancing safety of throughout the state. These areas of research are: 1) determining acceptable methods of including geometric data in the statistical model, 2) the development of a methodology on how to accomplish the next two steps of the framework for highway safety mitigation (i.e., economic appraisal and project prioritization), and 3) the implementation of the hot spot identification and analysis methodology on Utah's roadway network.

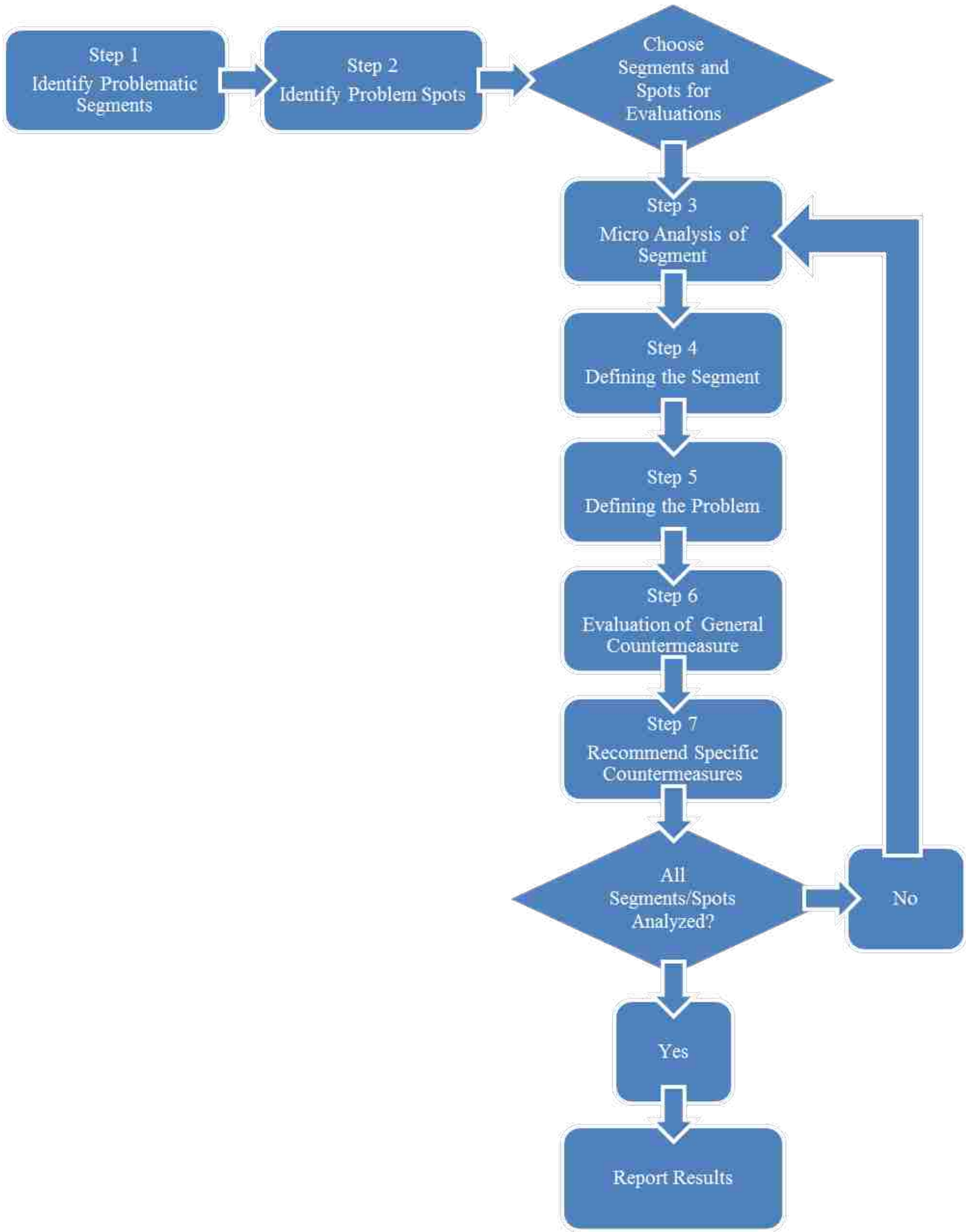

Figure 7-2: Hot spot identification and analysis methodology.

7.2.1 Methods for Including Geometric Data

Up to this point, trying to include roadway geometry data has created accuracy issues and a large number of very short analysis segments. These short segments complicate the statistical analysis used to identify hot spots. Methods to incorporate geometric data without causing accuracy issues and excessive numbers of segments should be explored using the new LiDAR data that UDOT has collected.

7.2.2 Continued Methodology Development

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

7.2.3 Implementation of Hot Spot Identification and Analysis Methodology

The next step after developing the hot spot identification and analysis methodology is to put the methodology into practice. This methodology could be implemented in the form of a project. The project could include the identification and analysis of a specified number of hot spots to be submitted to UDOT with suggestion on countermeasures for consideration to mitigate the safety problem.

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LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
BYU	Brigham Young University
CDL	Commercial Drivers License
CMF	Crash Modification Factor
CRF	Crash Reduction Factor
DIC	Deviance Information Criterion
DUI	Driving Under the Influence
EB	Empirical Bayesian
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
GIS	Geographic Information System
GVWR	Gross Vehicle Weight Rating
HAL	High Accident Location
HSM	Highway Safety Manual
LRS	Linear Referencing System
MCMC	Markov Chain Monte Carlo
MVN	Multivariate Normal
NB	Negative Binomial

NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
PDO	Property Damage Only
PMM	Poisson Mixture Model
ROR	Run-Off-Road
RTM	Regression to the Mean
SPF	Safety Performance Function
TRB	Transportation Research Board
UDOH	Utah Department of Health
UDOT	Utah Department of Transportation
UDPS	Utah Department of Public Safety
UTA	Utah Transit Authority
VMT	Vehicle Miles Traveled

APPENDIX A. COUNTERMEASURE MATRICES

Appendix A is a complete list of compiled countermeasure matrices based of the NCHRP Report 500 series. Each of the tables corresponds with a particular volume within the NCHRP Report 500 series. The tables found in this appendix include all objectives and associated countermeasure to those objectives. More detail can be found in chapter 2 of this report.

Table A-1: Collision with Trees Mitigation Objectives and Countermeasures (Neuman et al. 2003a)

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Prevent Trees From Growing in Hazardous Locations	Develop, Revise, and Implement Planting Guidelines to Prevent Placing Trees in Hazardous Locations		✓		
	Mowing and Vegetation Control Guidelines	✓			
Eliminate the Hazardous Condition and/or Reduce the Severity of the Crash	Remove Trees in Hazardous Locations	✓			
	Shield Motorists from Striking Trees	✓			
	Modify Roadside Clear Zone in the Vicinity of Trees	✓			
	Delineate Trees in Hazardous Locations			✓	

Table A-2: Head-On Collision Mitigation Objectives and Countermeasures (Neuman et al. 2003b)

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Keep vehicles from encroaching into opposite lane	Install centerline rumble strips for two lane roads		✓		
	Install profiled thermoplastic strips for centerlines		✓		
	Provide wider cross sections on two lane roads			✓	
	Provide center two way left turn lanes for four and two lane road		✓		
	Reallocate total two lane roadway width (lane and shoulder) to include a narrow "buffer median"		✓		
Minimize the likelihood of crashes into an oncoming vehicle	Use alternating passing lanes or four lane sections at key locations		✓		
	Install median barriers for narrow width medians on multilane roads		✓		

Table A-3: Unsignalized Intersection Collision Mitigation Objectives and Countermeasures (Neuman et al. 2003c)

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Improve management of access near unsignalized intersections	Implement driveway closures/relocations		✓		
	Implement driveway turn restrictions		✓		
Reduce the frequency and severity of intersection conflicts through geometric design improvements	Provide left turn lanes at intersections	✓			
	Provide longer left turn lanes at intersections		✓		
	Provide offset left turn lanes at intersections		✓		
	Provide bypass lanes on shoulders at T-intersections		✓		
	Provide left turn acceleration lanes at divided highway intersections		✓		
	Provide right turn lanes at intersections	✓			
	Provide longer right turn lanes at intersections		✓		
	Provide offset right turn lanes at intersections		✓		
	Provide right turn acceleration lanes at intersections		✓		
	Provide full width paved shoulders in intersection areas		✓		
	Restrict or eliminate turning maneuvers by signing		✓		
	Restrict or eliminate turning maneuvers by providing channelization or closing median openings		✓		
	Close or relocate "high risk" intersection		✓		
	Convert four legged intersections to two T-intersections		✓		
	Convert offset T-intersection to four legged intersection		✓		
	Realign intersection approaches to reduce or eliminate intersection skew	✓			
	Use indirect left turn treatments to minimize conflicts at divided highway intersections		✓		
	Improve pedestrian and bicycle facilities to reduce conflicts between motorists and nonmotorists				✓

Table A-3: Continued

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Improve sight distance at unsignalized intersections	Clear sight triangles on stop or yield controlled approaches to intersections		✓		
	Clear sight triangles in the medians of divided highways near intersections		✓		
	Change horizontal and/or vertical alignment of approaches to provide more sight distance		✓		
	Eliminate parking that restricts sight distance		✓		
Improve availability of gaps in traffic and assist drivers in judging gap sizes at unsignalized intersections	Provide an automated real time system to inform drivers of the suitability of available gaps for making turning and crossing maneuvers			✓	
	Provide roadside markers or pavement markings to assist drivers in judging the suitability of available gaps for making turning and crossing maneuvers			✓	
	Re-time adjacent signal to create gaps at stop controlled intersections		✓		
Improve driver awareness of intersection as viewed from the intersection approach	Improve visibility of intersections by providing enhanced signing and delineation		✓		
	Improve visibility of the intersection by providing lighting	✓			
	Install splitter islands on the minor road approach to an intersection		✓		
	Provide a stop bar (or provide a wider stop bar) on minor road approaches		✓		
	Install larger regulatory and warning signs at intersections		✓		
	Call attention to the intersection by installing rumble strips on intersection approaches		✓		
	Provide dashed marking (extended left edgelines) for major road continuity across the median opening at divided highway intersections		✓		
	Provide supplementary stop signs mounted over the roadway		✓		
	Provide pavement markings with supplementary messages such as STOP AHEAD		✓		
	Provide improved maintenance of stop signs		✓		
	Install flashing beacons at stop controlled intersections		✓		

Table A-3: Continued

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Choose appropriate intersection traffic control to minimize crash frequency and severity	Avoid signalizing through roads		✓		
	Provide all way stop control at appropriate intersections	✓			
	Provide roundabouts at appropriate locations	✓			
Improve driver compliance with traffic control devices and traffic laws at intersections	Provide targeted enforcement to reduce stop sign violations		✓		
	Provide targeted public information and education on safety problems at specific intersections		✓		
Reduce operating speeds on specific intersection approaches	Provide targeted speed enforcement	✓			
	Provide traffic calming on intersection approaches through a combination of geometrics and traffic control devices	✓			
	Post appropriate speed limit on intersection approaches		✓		
Guide motorists more effectively through complex intersections	Provide turn path marking		✓		
	Provide a double yellow centerline on the median opening of a divided highway at intersections		✓		
	Provide lane assignment signing or marking at complex intersections		✓		

Table A-4: Run-Off-Road Collision Mitigation Objectives and Countermeasures (Neuman et al. 2003d)

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Keep vehicles from encroaching on the roadside	Install shoulder rumble strips		✓		
	Install edgeline "profile marking," edgeline rumble strips or modified shoulder rumble strips on sections with narrow or no paved shoulders			✓	
	Install midlane rumble strips			✓	
	Provide enhanced shoulder or in lane delineation and marking for sharp curve	✓	✓	✓	
	Provide improved highway geometry for horizontal curves	✓			
	Provide enhanced pavement markings		✓		
	Provide skid resistant pavement surfaces				✓
	Apply shoulder treatments like eliminating shoulder drop off or widening shoulders	✓		✓	
Minimize the likelihood of crashing into an object or overturning if the vehicle travels beyond the edge of the shoulder	Design safer slopes and ditches to prevent rollovers	✓			
	Remove/relocate objects in hazardous locations	✓			
	Delineate trees or utility poles with retroreflective tape			✓	
Reduce the severity of the crash	Improve design of roadside hardware		✓		
	Improve design and application of barrier and attenuation systems		✓		

Table A-5: Horizontal Curve Collision Mitigation Objectives and Countermeasures (Torbic et al. 2004)

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Reduce the likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway at a horizontal curve	Provide advance warning of unexpected changes in horizontal alignments		✓		
	Enhance delineation along the curve		✓		
	Provide adequate sight distance		✓		
	Install shoulder rumble strips	✓			
	Install centerline rumble strips		✓		
	Prevent edge dropoffs		✓		
	Provide skid resistant pavement surfaces		✓		
	Provide grooved pavement		✓		
	Provide lighting of the curve		✓		
	Provide dynamic curve warning system		✓		
	Widen the roadway	✓			
	Improve or restore superelevation	✓			
	Modify horizontal alignment	✓			
	Install automated anti-icing system		✓		
	Prohibit/restrict trucks with very long semitrailers on roads with horizontal curves that cannot accommodate truck offtracking		✓		
Minimize the adverse consequences of leaving the roadway at a horizontal curve	Design safer slopes and ditches to prevent rollovers	✓			
	Remove/relocate object in hazardous locations	✓			
	Delineate roadside objects			✓	
	Add or improve roadside hardware		✓		
	Improve design and application of barrier and attenuation systems		✓		

Table A-6: Utility Pole Collision Mitigation Objectives and Countermeasures (Lacy et al. 2004)

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Treat specific utility poles in high crash and high risk spot locations	Remove poles in high crash location	✓			
	Relocate poles in high crash locations farther from the roadway and/or to less vulnerable locations	✓			
	Use breakaway devices		✓		
	Shield drivers from poles in high crash locations	✓			
	Improve the drivers' ability to see poles in high crash locations			✓	
	Apply traffic calming measures to reduce speeds on high risk sections		✓		
Prevent placing utility poles in high risk locations	Develop, revise, and implement policies to prevent placing or replacing poles with the recovery area		✓		
Treat several utility poles along a corridor to minimize the likelihood of crashing into a utility pole if a vehicle runs off the road	Place utilities underground	✓			
	Relocate poles along the corridor farther from the roadway and/or to less vulnerable locations	✓			
	Decrease the number of poles along the corridor	✓			

Table A-7: Collisions Involving Pedestrians Mitigation Objectives and Countermeasures (Zegeer et al. 2004)

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Reduce pedestrian exposure to vehicular traffic	Provide sidewalks/walkways and curb ramps	✓			
	Install or upgrade traffic and pedestrian signals	✓	✓	✓	
	Construct pedestrian refuge island and raised medians	✓			
	Provide vehicle restriction/diversion measures	✓	✓		
	Install overpasses/underpasses	✓			
Improve sight distance and/or visibility between motor vehicles and pedestrians	Provide crosswalk enhancements	✓	✓		
	Implement lighting/crosswalk illumination measures	✓			
	Eliminate screening by physical objects		✓		
	Signals to alert motorists that pedestrians are crossing		✓	✓	
	Improve reflectorization/conspicuity of pedestrians		✓		
Reduce vehicle speed	Implement road narrowing measures		✓		
	Install traffic calming-road sections	✓	✓		
	Install traffic calming-intersections	✓	✓		
	Provide school route improvements		✓		
Improve pedestrian and motorist safety awareness and behavior	Provide education, outreach, and training	✓			
	Implement enforcement campaigns		✓		

Table A-8: Signalized Intersection Collision Mitigation Objectives and Countermeasures (Antonucci et al. 2004)

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Reduce frequency and severity of intersection conflicts through traffic control and operational improvements	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	✓			
	Employ emergency vehicle preemption	✓			
	Improve operation of pedestrian and bicycle facilities at signalized intersections	✓	✓		
	Remove unwarranted signal	✓			
Reduce frequency and severity of intersection conflicts through geometric improvements	Provide/improve left turn channelization	✓			
	Provide/improve right turn channelization	✓			
	Improve geometry of pedestrian and bicycle facilities	✓	✓		
	Revise geometry of complex intersections	✓	✓		
	Construct special solutions		✓		
Improve sight distance at signalized intersections	Clear sight triangles		✓		
	Redesign intersection approaches	✓			
Improve driver awareness of intersections and signal control	Improve visibility of intersections on approaches		✓		
	Improve visibility of signals and signs at intersections		✓		
Improve driver compliance with traffic control devices	Provide public information and education		✓		
	Provide targeted conventional enforcement of traffic laws		✓		
	Implement automated enforcement of red light running	✓			
	Implement automated enforcement of approach speeds		✓		
	Control speed on approaches			✓	
Improve access management near signalized intersections	Restrict access to properties using driveways closures or turn restrictions		✓		
	Restrict cross median access near intersections		✓		

Table A-8: Continued

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Improve safety through other infrastructure treatments	Improve drainage in intersection and on approaches		✓		
	Provide skid resistance in intersection and on approaches		✓		
	Coordinate closely spaced signals near at-grade railroad crossings		✓		
	Relocate signal hardware out of clear zone		✓		
	Restrict or eliminate parking on intersection approaches	✓			

Table A-9: Collisions Involving Heavy Truck Mitigation Objectives and Countermeasures (Knipling et al. 2004)

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Reduce fatigue related crashes	Increase efficiency of use of existing parking spaces			✓	
	Create additional parking spaces		✓		
	Incorporate rumble strips into new and existing roadways				✓
Strengthen CDL Program	Improve test administration for the CDL		✓		
	Increase fraud detection of state and third party testers		✓	✓	
Increase public knowledge about sharing of the road	Incorporate "Share the Road" information into driver materials		✓		
	Promulgate "Share the Road" information through print and electronic media		✓		
Improve maintenance of heavy trucks	Increase and strengthen truck maintenance programs and inspection performance				✓
	Conduct postcrash inspections to identify major problems and problem conditions			✓	
Identify and correct unsafe roadways infrastructure and operational characteristics	Identify and treat truck crash roadway segments-signing			✓	
	Install interactive truck rollover signing	✓			
	Modify speed limits and increase enforcement to reduce truck and other vehicle speeds		✓		
Improve and enhance truck safety data	Increase the timeliness, accuracy, and completeness of truck safety data				✓
Promote industry safety initiatives	Perform safety consultations with carrier safety management	✓			
	Promote development and deployment of truck safety technologies			✓	

Table A-10: Drowsy and Distracted Driving Mitigation Objectives and Countermeasures (Stutts et al. 2005)

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Make roadways safer for drowsy and distracted drivers	Install shoulder and/or centerline rumble strips	✓	✓		
	Implement other roadway improvements to reduce the likelihood and severity of run-off-road and/or head-on collisions	✓	✓		
	Implement roadway improvements to reduce the likelihood and severity of other types of distracted and drowsy driving crashes		✓	✓	
Provide safe stopping and resting areas	Improve access to safe stopping and resting areas		✓		
	Improve rest area security and services		✓		
Increase driver awareness of the risk of drowsy and distracted driving and promote driver focus	Conduct education and awareness campaigns targeting the general driving public		✓		
	Visibly enforce existing statutes to deter distracted and drowsy driving			✓	
Implement programs that target populations at increased risk of drowsy or distracted driving crashes	Strengthen graduated driver licensing requirements for young drivers	✓	✓		
	Incorporate information on distracted/fatigued driving into education programs and materials for young drivers		✓		
	Encourage employers to offer fatigue management programs to employees working nighttime or rotating shifts	✓			
	Enhance enforcement of commercial motor vehicle hours of service regulations	✓			
	Encourage trucking companies and other fleet operators to implement fatigue management programs		✓		
	Implement targeted interventions for other high risk populations		✓	✓	

Table A-11: Work Zone Collision Mitigation Objectives and Countermeasures (Antonucci et al. 2005)

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Reduce the number, duration, and impact of work zones	Improve maintenance and construction practices	✓			
	Utilize full time roadway closure for construction operations		✓		
	Utilize time related contract provisions	✓			
	Use nighttime road work	✓			
	Use demand management programs to reduce volume through work zones	✓			
	Design future work zone capacity into new or reconstructed highways		✓		
Improve work zone traffic control devices	Implement ITS strategies to improve safety			✓	
	Improve visibility of work zone traffic control devices		✓		
	Improve visibility of work zone personnel and vehicles				✓
	Reduce flaggers' exposure to traffic		✓		
Improve work zone design practices	Establish work zone design guidance		✓		
	Implement measures to reduce work space intrusions (and limit consequences of intrusions)		✓		
	Improve work zone safety for pedestrians, bicyclists, motorcyclists, and heavy truck drivers.		✓		
Improve driver compliance with work zone traffic controls	Enhance enforcement of traffic laws in work zones		✓		
	Improve credibility of signs			✓	
	Improve application of increased driver penalties in work zones		✓		
Increase knowledge and awareness of work zones	Disseminate work zone safety information to road users		✓		
	Provide work zone training programs and manuals for designers and field staff		✓		
Develop procedures to effectively manage work zones	Develop or enhance agency level work zone crash data systems		✓		
	Improve coordination, planning, and scheduling of work activities		✓		
	Use incentives to create and operate safer work zones		✓		
	Implement work zone quality assurance procedures		✓		

Table A-12: Head-On Crashes on Freeways Mitigation Objectives and Countermeasures (Neuman et al. 2008)

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Keep vehicles from departing the traveled way	Install left shoulder rumble strips		✓		
	Provide enhanced pavement markings and median delineation		✓		
	Provide improved pavement surfaces		✓		
Minimize the likelihood of head-on crashes with an oncoming vehicle	Provide wider medians	✓			
	Improve median design for vehicle recovery (i.e. pavement edge drop off, install paved median shoulders, and design safer slopes)		✓		
	Install median barriers for narrow width medians	✓			
	Implement channelization, signing and striping improvements at interchanges susceptible to wrong way movements		✓	✓	
Reduce the severity of median barrier crashes that occur	Improve design and application of barrier and attenuation systems		✓		
Enhance enforcement and awareness of traffic regulations	Designate "Highway Safety Corridors"		✓		
	Conduct public information and education campaigns		✓		
Improve coordination of agency safety initiatives	Enhance agency crash data system		✓		

Table A-13: Speed Related Crash Mitigation Objectives and Countermeasures (Neuman et al. 2009)

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Set appropriate speed limits	Set speed limits which account for roadway design, traffic, and environment		✓		
	Implement variable speed limits		✓		
	Implement differential speed limits for heavy vehicles if appropriate (high speeds only)		✓		
Heighten driver awareness of speeding related safety issues	Increase public awareness of the risk of driving at unsafe speeds		✓		
	Increase public awareness of potential penalties for speeding		✓		
	Increase public awareness of risks of not wearing seatbelts		✓		
	Implement neighborhood speed watch/traffic management programs (low speeds only)		✓		
	Implement "Safe Community" programs		✓		
Improve efficiency and effectiveness of speed enforcement efforts	Use targeted conventional speed enforcement programs at locations known to have speeding related crashes	✓			
	Implement automated speed enforcement		✓		
	Increase penalties for repeat and excessive speeding offenders		✓		
	Strengthen the adjudication of speeding citations to enhance the deterrent effects of fines		✓		
	Increase fines in special areas		✓		
Communicate appropriate speeds through use of traffic control devices	Improve speed limit signage		✓		
	Implement active speed warning signs		✓		
	Use in-pavement measures to communicate the need to reduce speeds		✓		
	Implement variable message signs (high speeds only)		✓		

Table A-13: Continued

Objective	Countermeasures	Category			
		Proven	Tried	Experimental	Not Available
Ensure that roadway design and traffic control elements support appropriate and safe speeds	Use combinations of geometric elements to control speeds (horizontal and vertical curves, cross sections), including providing design consistency along an alignment		✓		
	Effect safe speed transitions through design elements and on approaches to lower speed areas		✓		
	Provide appropriate intersection design for speed of roadway		✓		
	Provide adequate change and clearance intervals at signalized intersections	✓			
	Operate traffic signals appropriately for intersections and corridors (signal progression)		✓		
	Provide adequate sight distance for expected speeds	✓			
	Implement protected only signal phasing for left turns at high speed signalized intersections (high speeds only)		✓		
	Install lighting at high speed intersections (high speeds only)		✓		
	Reduce speeds and/or volume on both neighborhood and downtown streets with the use of traffic calming and other related countermeasures (low speeds only)		✓		

APPENDIX B. RESULTS

This appendix provides the results from the other hot spot segments and problem spots analyzed for this project. Results are provided for the number one through four ranked hot spot segments and the problem spot on the number one ranked segment.

B.1 Number One Ranked Hot Spot Segment

The number one ranked hot spot segment is located on U.S. 89 from milepoint 334.885 to milepoint 335.59. Table B-1 provides the crash file data. Table B-2 provides the vehicle file data. Table B-3 provides the crash rollup file.

Table B-1: Crash File - U.S. 89 (Milepoint 334.885-335.59)

Crash ID	First Harmful Event	Manner of Collision
574667	Motor Vehicle	Angle
10025158	Motor Vehicle	Front to Rear
10044647	Traffic Signal Support	NA
10460546	Motor Vehicle	Front to Rear
10034974	Motor Vehicle	Front to Rear
10346491	Pedal cycle	NA
10318023	Motor Vehicle	Angle
576660	Motor Vehicle	Angle
10059193	Parked Motor Vehicle	Parked Vehicle
10354229	Motor Vehicle	Angle
10360271	Motor Vehicle	Angle
10063304	Motor Vehicle	Front to Rear
10214894	Motor Vehicle	Sideswipe Same Direction
10319970	Tree/Shrubbery	NA
10159046	Motor Vehicle	Angle
10388830	Culvert	NA
10347135	Motor Vehicle	Front to Rear
573963	Motor Vehicle	Head On
10336402	Motor Vehicle	Angle

Table B-2: Vehicle File - U.S. 89 (Milepoint 334.885-335.59)

Crash ID	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
574667	Motor Vehicle	NA	Straight Ahead/Straight Ahead
10025158	Motor Vehicle	NA	Slowing in lane/Slowing in lane
10044647	Motor Vehicle, Traffic Signal	Traffic Signal	Turing Left
10460546	Motor Vehicle, Motor Vehicle	Motor Vehicle	Stopped in Lane/Straight Ahead
10034974	Motor Vehicle, Motor Vehicle	Motor Vehicle	Slowing in Lane/Stopped in Lane
10346491	Pedal cycle	Pedal cycle	Straight Ahead
10318023	Motor Vehicle, Motor Vehicle	Motor Vehicle	Turing Left/Straight Ahead
576660	Motor Vehicle, Motor Vehicle	NA	Straight Ahead/Straight Ahead
10059193	Parked Vehicle, Parked Vehicle	Parked Vehicle	Parked/Parked/Straight Ahead
10354229	Motor Vehicle, Motor Vehicle	Motor Vehicle	Turning Left/Stopped in Lane/Straight Ahead
10360271	Motor Vehicle, Motor Vehicle	Motor Vehicle	Straight Ahead/Straight Ahead/Straight Ahead
10063304	Motor Vehicle, Motor Vehicle	Motor Vehicle	Stopped in Lane/Straight Ahead
10214894	Motor Vehicle, Motor Vehicle	Motor Vehicle	Making U-turn/Straight Ahead
10319970	Run off Road Right, Tree/Shrubbery	Tree/Shrubbery	Straight Ahead
10159046	Motor Vehicle, Motor Vehicle	Motor Vehicle	Turning Left/Straight Ahead
10388830	Run off Road Left, Ditch, Culvert, Overturn/Rollover	Culvert	Straight Ahead
10347135	Motor Vehicle, Motor Vehicle	Motor Vehicle	Straight Ahead/ Sopped in Lane
573963	Motor Vehicle, Motor Vehicle	NA	Overtaking/Passing/Straight Ahead
10336402	Motor Vehicle, Motor Vehicle	Motor Vehicle	Straight Ahead/Straight Ahead

Table B-3: Rollup File - U.S. 89 (Milepoint 334.885-335.59)

Crash ID	DUI	Aggressive Driving	Speed Related	Intersection Related	Roadway Geometry	Teenage Driver
574667	N	N	N	Y	N	N
10025158	N	N	N	Y	N	N
10044647	N	N	Y	Y	N	N
10460546	N	N	N	Y	N	N
10034974	N	N	N	Y	N	N
10346491	N	N	N	Y	N	N
10318023	N	N	N	Y	N	N
576660	N	N	N	Y	N	N
10059193	Y	N	N	N	N	N
10354229	N	N	Y	Y	N	N
10360271	N	N	N	Y	N	N
10063304	N	N	N	Y	N	Y
10214894	N	N	N	N	N	Y
10319970	Y	N	N	N	N	N
10159046	N	Y	Y	Y	N	Y
10388830	N	N	N	N	N	N
10347135	N	N	N	Y	N	N
573963	N	N	N	N	N	N
10336402	N	N	N	Y	N	N
Total	2/19	1/19	3/19	14/19	0/19	3/19

Based on the analysis of this segment the safety problem deals with an excess of rear end collisions and collisions involving left turns at intersections. Possible contributing factors to this problem are signal timing, signal coordination, and intersection design and operations. The following is a list of suggested countermeasures for consideration:

- Employ multiphase signal operation
- Optimize clearance intervals
- Install signals at unsignalized intersections
- Improve signal coordination on the corridor

B.2 Number Two Ranked Hot Spot Segment

The number two ranked hot spot segment is located on U.S. 91 from milepoint 29.008 to milepoint 29.819. Table B-4 provides the crash file data. Table B-5 provides the vehicle file data. Table B-6 provides the crash rollup file.

Table B-4: Crash File - U.S. 91 (Milepoint 29.008-29.819)

Crash ID	First Harmful Event	Manner of Collision
10397588	Fell/Jumped From Vehicle	NA
10460652	Motor Vehicle	Front to Rear
10347225	Motor Vehicle	Front to Rear
10319669	Motor Vehicle	Front to Rear
10034404	Motor Vehicle	Angle
10439136	Motor Vehicle	Angle
10175294	Motor Vehicle	Angle
10220605	Motor Vehicle	Angle
10261729	Motor Vehicle	Angle
10315986	Motor Vehicle	Angle
10352148	Motor Vehicle	Angle

Table B-5: Vehicle File - U.S. 91 (Milepoint 29.008-29.819)

Crash ID	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
10397588	Other, Fell/Jumped From Vehicle	Fell/Jumped From Vehicle	Straight Ahead
10460652	Motor Vehicle	Motor Vehicle	Straight Ahead
10347225	Motor Vehicle, Motor Vehicle	Motor Vehicle	Turning Left/Straight Ahead
10319669	Motor Vehicle, Motor Vehicle	Motor Vehicle	Straight Ahead/Straight Ahead
10034404	Motor Vehicle, Motor Vehicle	Motor Vehicle	Turning Left/Straight Ahead
10439136	Motor Vehicle, Overturn/Rollover, Motor Vehicle	Overturn/Rollover, Motor Vehicle	Turning Left/Straight Ahead/Slowing in Traffic
10175294	Motor Vehicle, Motor Vehicle, Motor Vehicle	Motor Vehicle	Straight Ahead/Straight Ahead/Turning Left
10220605	Motor Vehicle, Motor Vehicle	Motor Vehicle	Turning Left/Straight Ahead
10261729	Motor Vehicle, Motor Vehicle	Motor Vehicle	Straight Ahead/Turning Left
10315986	Motor Vehicle, Motor Vehicle	Motor Vehicle	Straight Ahead/Turning Left
10352148	Motor Vehicle, Motor Vehicle	Motor Vehicle	Turning Left/Straight Ahead

Table B-6: Rollup File - U.S. 91 (Milepoint 29.008-29.819)

Crash ID	DUI	Aggressive Driving	Speed Related	Intersection Related	Roadway Geometry	Teenage Driver
10397588	N	N	N	N	N	Y
10460652	N	N	Y	N	N	Y
10347225	N	N	N	N	N	N
10319669	N	N	N	Y	N	N
10034404	N	N	N	Y	N	N
10439136	N	N	N	Y	N	N
10175294	N	N	N	Y	N	N
10220605	N	N	N	Y	N	N
10261729	N	N	N	Y	N	N
10315986	N	N	N	Y	N	Y
10352148	N	N	Y	Y	N	Y
Total	0/11	0/11	2/11	8/11	0/11	4/11

Based on the analysis of this segment the safety problem is mainly focused at the two signalized intersections on this hot spot segment. These two intersections are located at 2200 North and 2500 North on Main Street in Logan, Utah. The problem deals with an excess of collisions involving vehicles making left turns at these intersections. Possible contributing factors to this problem are signal timing, signal coordination, clearance interval issues, and intersection design and operations. The following is a list of suggested countermeasures for consideration:

- Employ multiphase signal operation
- Optimize clearance intervals
- Improve signal coordination
- Allow permitted/protected left turns
- Change signal head types

B.3 Number Three Ranked Hot Spot Segment

The number three ranked hot spot segment is located on S.R. 154 from milepoint 15.72 to milepoint 15.93. Table B-7 provides the crash file data. Table B-8 provides the vehicle file data. Table B-9 provides the crash rollup file.

Table B-7: Crash File – S.R. 154 (Milepoint 15.72-15.93)

Crash ID	First Harmful Event	Manner of Collision
10363308	Guardrail	NA
10402218	Motor Vehicle	Front to Rear
10321116	Motor Vehicle	Angle
10025831	Motor Vehicle	Front to Rear
10171889	Motor Vehicle	Angle
10325066	Motor Vehicle	Front to Rear

Table B-8: Vehicle File – S.R. 154 (Milepoint 15.72-15.93)

Crash ID	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
10363308	Guardrail	Guardrail	Straight Ahead
10402218	Motor Vehicle	Motor Vehicle	Stopped in lane/Straight Ahead
10321116	Motor Vehicle	Motor Vehicle	Changing Lanes/Stopped in lane
10025831	Motor Vehicle	Motor Vehicle	Straight Ahead/Straight Ahead
10171889	Motor Vehicle	Motor Vehicle	Turning Left/Turning Left
10325066	Motor Vehicle	Motor Vehicle	Stopped in Lane/Straight Ahead

Table B-9: Rollup File – S.R. 154 (Milepoint 15.72-15.93)

Crash ID	DUI	Aggressive Driving	Speed Related	Intersection Related	Roadway Geometry	Teenage Driver
10363308	Y	Y	N	N	N	N
10402218	N	N	N	N	N	N
10321116	N	N	N	N	N	Y
10025831	N	N	N	Y	N	Y
10171889	Y	Y	N	Y	N	Y
10325066	N	N	Y	Y	N	Y
Total	2/6	2/6	1/6	3/6	0/6	4/6

Based on the analysis of this segment the safety problem is focused mainly on the intersection at Bangerter Highway and 5400 South. The problem deals with an excess of rear end collisions and angled collisions involving left turns at intersections. Possible contributing factors to this problem are teenage drivers, signal timing, signal coordination, and intersection design and operations. It should be noted that in year 2010 the intersection was converted to a Continuous Flow Intersection. The following year there were no recorded high severity crashes on this hot spot segment. It is suggested that the hot spot segment be further analyzed when the 2012 crash data becomes available before any countermeasures are suggested.

B.4 Number Four Ranked Hot Spot Segment

The number four ranked hot spot segment is located on S.R. 71 from milepoint 8.843 to milepoint 9.212. Table B-10 provides the crash file data. Table B-11 provides the vehicle file data. Table B-12 provides the crash rollup file.

Table B-10: Crash File - S.R. 71 (Milepoint 8.843-9.212)

Crash ID	First Harmful Event	Manner of Collision
10350897	Motor Vehicle	Angle
10465007	Rollover	NA
10054950	Motor Vehicle	Angle
10383800	Concrete Barrier	NA
10271754	Motor Vehicle	Front to Rear
10054001	Motor Vehicle	Angle
10229032	Motor Vehicle	Angle

Table B-11: Vehicle File - S.R. 71 (Milepoint 8.843-9.212)

Crash ID	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
10350897	Motor Vehicle, Rollover	Motor Vehicle	Turning Right/Straight Ahead
10465007	Rollover	Rollover	Left Turn
10054950	Motor Vehicle	Motor Vehicle	Left Turn/Backing
10383800	Other Non-fixed Object, ROR, Concrete Barrier	Concrete Barrier	Left Turn
10271754	Motor Vehicle, Motor Vehicle	Motor Vehicle	Stopped in Lane/Straight Ahead
10054001	Motor Vehicle	Motor Vehicle	Straight Ahead/Straight Ahead
10229032	Motor Vehicle	Motor Vehicle	Left Turn/Straight Ahead

Table B-12: Rollup File – S.R. 71 (Milepoint 8.843-9.212)

Crash ID	DUI	Aggressive Driving	Speed Related	Intersection Related	Roadway Geometry	Teenage Driver
10350897	N	N	N	Y	N	N
10465007	N	N	N	Y	N	N
10054950	N	N	N	N	N	N
10383800	Y	N	N	N	N	N
10271754	N	N	N	Y	N	N
10054001	N	N	N	Y	N	Y
10229032	N	N	N	Y	N	N
Total	1/7	0/7	0/7	5/7	0/7	1/7

Based on the analysis of this segment the safety problem is focused mainly on a segment of road surrounding two unsignalized T-intersections. The problem deals with an excess of rear end collisions and angled collisions involving left turns at the intersections. Possible contributing factors to this segment are intersection design and operations, lack of right turn lanes, and insufficient storage length. The following is a list of suggested countermeasures for consideration:

- Increase left turn channelization storage length
- Install right turn channelization

B.5 Number One Ranked Segment's Problem Spot

The number one ranked hot spot segment's problem is located on U.S. 89 from milepoint 335.31 to milepoint 335.32. Table B-13 provides the crash file data. Table B-14 provides the vehicle file data. Table B-15 provides the crash rollup file.

Table B-13: Crash File - U.S. 89 (Milepoint 335.31-335.32)

Crash ID	First Harmful Event	Manner of Collision
576660	Motor Vehicle	Angle
10059193	Parked Vehicle	Parked Vehicle
10354229	Motor Vehicle	Angle
10360271	Motor Vehicle	Angle
10063304	Motor Vehicle	Front to Rear
10214894	Motor Vehicle	Sideway Same Direction

Table B-14: Vehicle File - U.S. 89 (Milepoint 335.31-335.32)

Crash ID	Event Sequence (1-4)	Most Harmful Event	Vehicle Maneuver
576660	Motor Vehicle, Motor Vehicle	NA	Straight Ahead/Straight Ahead
10059193	Parked Vehicle, Parked Vehicle, Parked Vehicle	Parked Vehicle	Parked/Parked/Parked
10354229	Motor Vehicle, Motor Vehicle, Motor Vehicle	Motor Vehicle	Stopped in Lane/ Sopped in Lane/ Straight Ahead
10360271	Motor Vehicle, Motor Vehicle, Motor Vehicle	Motor Vehicle	Stopped in Lane/Straight Ahead/ Straight Ahead
10063304	Motor Vehicle, Motor Vehicle	Motor Vehicle	Stopped in Lane/Straight Ahead
10214894	Motor Vehicle, Motor Vehicle	Motor Vehicle	Making U-turn/Straight Ahead

Table B-15: Rollup File - U.S. 89 (Milepoint 335.31-335.32)

Crash ID	DUI	Aggressive Driving	Speed Related	Intersection Related	Roadway Geometry	Teenage Driver
576660	N	N	N	Y	N	N
10059193	Y	N	N	N	N	N
10354229	N	N	Y	Y	N	N
10360271	N	N	N	Y	N	N
10063304	N	N	N	Y	N	Y
10214894	N	N	N	N	N	Y
Total	1/6	0/6	1/6	4/6	0/6	2/6

Based on the analysis of this segment the safety problem identified is an excess of collisions involving vehicles stopped in the travel lane and vehicles traveling straight at the intersection of 500 North and 500 West in Provo, Utah. Possible contributing factors to this problem are signal timing, signal coordination, and intersection design and operations. The following is a list of suggested countermeasures for consideration:

- Employ multiphase signal operation
- Optimize clearance intervals
- Improve signal coordination on the corridor