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Effectiveness of Various Safety Improvements in Reducing Crashes on Wyoming Roadways

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EFFECTIVENESS OF VARIOUS SAFETY IMPROVEMENTS IN REDUCING CRASHES ON WYOMING ROADWAYS

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Disclaimer

ABSTRACT

The high societal cost of roadway crashes nationwide makes improving highway safety an important objective of transportation agencies. Recognizing this, Safety Management Systems (SMS) have been required by the Federal Highway Administration (FHWA) to encourage states to pursue and promote safety and accident investigations. In 2006, the Wyoming Department of Transportation (WYDOT) SMS Committee organized an effort to reduce the number of fatal and serious injury crashes on Wyoming roadways. A plan was published in a formal document known as the Wyoming State Highway Safety Plan (WSHSP). When developing the WSHSP, the WYDOT SMS Committee recognized four main emphasis areas: roadway departure crashes, use of safety restraints, impaired driving, and speeding. While each one of the four emphasis areas plays an important role in the overall reduction of fatal and serious injury crashes statewide, this research focuses primarily on roadway departure crashes. This research study summarizes the effectiveness of the WSHSP on crash severity statewide. This is done by analyzing crash severity on geometric conditions statewide, as well as the effectiveness of two types of safety devices installed on selected roadway sections: shoulder rumble strips and cable median barriers.

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EXECUTIVE SUMMARY

The high societal cost of roadway crashes nationwide makes improving highway safety an important objective of transportation agencies. Recognizing this, Safety Management Systems (SMS) have been established by the Federal Highway Administration (FHWA) to encourage states to pursue and promote safety and accident investigations (Karlaftis & Golias 2002). One of the primary goals of the FHWA is to reduce the number and, more importantly, the severity of roadway departure crashes. The main roadway departure crash types include run-off-road (ROR) and cross-median (FHWA 2011B). According to the Fatality Analysis Reporting System (FARS), 31.5% of fatal crashes nationwide in 2005 were single-vehicle crashes occurring off the roadway (Torbic, D.J. et al. 2009).

In 2006, the Wyoming Department of Transportation (WYDOT) SMS Committee organized an effort to reduce the number of fatal and serious injury crashes on Wyoming roadways. A plan was published in a formal document known as the Wyoming State Highway Safety Plan (WSHSP). When developing the WSHSP, the WYDOT SMS Committee recognized four main emphasis areas: roadway departure crashes, use of safety restraints, impaired driving, and speeding (WYDOT 2006). While each one of the four emphasis areas plays an important role in the overall reduction of fatal and serious injury crashes statewide, this report primarily focuses on roadway departure crashes.

The first objective of this report is determining the impact of various geometric conditions on the severity of roadway departure crashes on Wyoming's rural roads. The overall effectiveness of the 2006 WSHSP in reducing crash severity on Wyoming rural roadways is evaluated as well. The second objective is determining the effectiveness of the installed shoulder rumble strips in reducing the number and severity of roadway departure crashes. The third objective consists of determining the effectiveness of installed cable median barriers in reducing fatal and serious injury crashes.

After the implementation of the WSHSP, fatal and serious injury crashes were considerably reduced statewide, implying that it contributed to these reductions. The geometric study was conducted on the Wyoming rural interstates, state highways, and local roadways and included eight combinations of geometric conditions. Curve-downhill and curve-level crashes on both the rural state highways and local roadways were found to be the most severe geometric combinations. Further analysis indicated that rollover crashes occurred most often and were the most severe roadway departure crash type by far.

For the shoulder rumble strips, a before-after period was established for each project analyzed. The crash data were analyzed statistically using a one-tailed t-test on the severity and ROR crash types by crashes per mile. These analyses were performed for interstate and state highway separately due to the typical difference in traffic volumes. The results of the analyses suggest that crash severity was reduced on both the interstate and state highway sections due to SRS installation.

The third study analyzed five cable median barrier projects between 2007 and 2008 on various interstate sections statewide. Although Wyoming's interstates have relatively low traffic volumes, the Wyoming Legislature made the installation of cable barriers in narrow medians a top priority. The analysis was performed using only the crash numbers obtained for a two year before-after period. The results indicated a large reduction in fatal and serious injury crashes, which amounted to an overall estimated annual savings of about $322,000 per mile of installed cable median barrier.

This report primarily focuses on roadway departure crashes on Wyoming's rural roadways. The analysis results indicated an overall reduction in crash severity statewide since the implementation of the WSHSP. Cost effective safety improvements installed due to the WSHSP, such as shoulder rumble strips and cable median barriers, are contributing to the reduction roadway departure crash severity statewide.

1. INTRODUCTION

1.1 Background

The high societal cost of roadway crashes nationwide makes improving highway safety an important objective of transportation agencies. Recognizing this, Safety Management Systems (SMS) have been established by the Federal Highway Administration (FHWA) to encourage states to pursue and promote safety and accident investigations (Karlaftis & Golias 2002). One of the primary goals of the FHWA is to reduce the number and, more importantly, the severity of roadway departure crashes. The main roadway departure crash types include run-off-road (ROR), cross-median, and cross center line crashes (FHWA 2011B).

The FHWA was justified in making an effort to reduce roadway departure crashes. According to the Fatality Analysis Reporting System (FARS), 31.5^% of fatal crashes nationwide in 2005 were single-vehicle crashes occurring off the roadway (Torbic, D.J. et al. 2009). When including single-vehicle fatal crashes that occurred in the median and on the shoulder, the value increased to 40.3%. It has also been found that twice as many single-vehicle ROR (SVROR) crashes occur on rural roads than on urban roads. This is partially due to the higher speeds and greater miles on rural roads.

Highway safety professionals can address reducing roadway departure crashes through multiple means. Some of the options include making geometric improvements, eliminating roadside hazards, enhancing warning signs, and adding safety features such as rumble strips and median barriers. Unfortunately, there is not one solution that will fix every problem. This is because the primary causes for roadway departure crashes are drivers that are fatigued, drowsy, or inattentive (FHWA, Rumble Strip Website). Drivers become fatigued by driving on long, monotonous stretches of roadway, which can reduce the driver's concentration and reaction time. Speeding, alcohol, and drugs have also been found to contribute to reduced reactions times, which can compound crash severity (FHWA, Rumble Strip Website).

Geometric features on roadways play a major role in driver expectancy, especially when it comes to rural roads. Many factors can result in a crash involving even a regular user of a local roadway. Although the somewhat random nature of roadway departure crashes can be related to the driver becoming drowsy or distracted, geometric conditions still have an impact on these crashes. According to FARS, for two-lane rural roads, the distribution of SVROR crashes was found to be nearly equally distributed on tangent and curve sections (Torbic, D.J. et al. 2009). Since tangent sections encompass a majority of most roadways length, the reason for the higher percent of crashes on curves needs to be analyzed.

When vehicles depart the travel lane without warning, the crashes are usually severe due to higher speeds. Shoulder rumble strips (SRS) improve the chances for a vehicle to safely recover when departing the travel lane by providing motorists with an audible and vibrational warning that their vehicle has partially or completely departed from the roadway (FHWA 2011B; Harwood 1993). Rumble strips also aid in alerting drivers to the lane limits in reduced visibility situations where there are environmental factors such as rain, fog, or snow (FHWA, Rumble Strip Website).

When the vehicles go through the median and crash with a vehicle in the opposing travel lane, the crash severity is even higher. Cable median barriers contain or redirect errant vehicles that enter the median by keeping them from encountering terrain features and roadside objects or entering opposing travel lanes, which may cause severe crashes (FHWA, Cable Median Barrier Website).

1.2 Problem Statement

Local and state transportation agencies are continually faced with decisions concerning the safe operation of roadways. Most safety related improvements have been, more often than not, reactive. This means that the safety countermeasures are applied to roadways only after high crash frequencies have been observed (WYDOT 2006). Predicting where crashes are likely to happen is a very useful proactive tool for reducing the number and severity of crashes. Roadway sections found to be the most potentially hazardous would become high priority candidates for safety improvements. Identifying the locations for needed safety improvement is a vital aspect of any safety improvement program due to the limited resources available for such programs (Labi & CATS 2005).

In 2006, the Wyoming Department of Transportation (WYDOT) SMS Committee organized an effort to reduce the number of fatal and serious injury crashes on Wyoming roadways. A plan was published in a formal document known as the Wyoming State Highway Safety Plan (WSHSP). When developing the WSHSP, the WYDOT SMS Committee recognized four main emphasis areas: roadway departure crashes, use of safety restraints, impaired driving, and speeding (WYDOT 2006).

While each one of the four emphasis areas plays an important role in the overall reduction of fatal and serious injury crashes statewide, this report primarily focuses on roadway departure crashes. Also, all the analyses in this report were performed using crash numbers or frequencies instead of crash rates, which is consistent with the WSHSP. Also, the million vehicle miles traveled (MVMT) data on Wyoming local roads can be unreliable.

According to the WSHSP report, roadway departures accounted for 37% of all serious injury and fatal crashes in Wyoming in 2004. In order to reduce the crash severity of roadway departure crashes, the main causes of the crashes need to be determined. The first step would be to identify the severity of crashes associated with each type of geometric conditions. This would enable local and state agencies to proactively use preventive measures to increase the safety of areas identified to have higher severity crashes instead of waiting for crashes to occur to determine if a roadway section warrants a countermeasure (WYDOT 2006).

Following the implementation of the WSHSP, numerous safety implementations were installed around Wyoming. Cable median barriers and SRS are the two main safety devices WYDOT installed on various roadway sections statewide specifically designed to reduce the severity of roadway departure crashes. Projects implemented early enough to be analyzed using before-after analyses were selected for inquiry. The purpose of theses analyses are to find the effectiveness of these safety devices on Wyoming's relatively low volume interstates and state highways.

1.3 Research Objectives

This report has the following objectives:

- Determine the impact of various geometric conditions on the severity of roadway departure crashes of Wyoming's rural roads
- Evaluate the overall effectiveness of the 2006 WSHSP in reducing crash severity on Wyoming rural roadways.

- Determine the effectiveness of the installed shoulder rumble strips in reducing the number and severity of roadway departure crashes on Wyoming's relatively low volume interstate and state highways
- Determine the effectiveness of installed cable median barriers in reducing fatal and serious injury crashes on Wyoming's relatively low volume interstates

1.4 Report Organization

There are six sections in this report. The Literature Review (Section 2) contains a description of the background research of the current practices of geometric alignment safety, SRS, and cable median barriers. Section 3 contains a description of the data collection and the methods of analyzing the high severity geometric conditions on Wyoming's rural roads. Section 4 details the data collection and methods for analyzing the effectiveness of installed SRS on Wyoming's interstate and state highway sections. Section 5 has the data collection and methods for analyzing the effectiveness of installed cable median barriers on Wyoming interstate sections. Section 6 is a summary of the research effort, including the results from Sections 3 through 5, with an evaluation of the overall conclusions that should be drawn from the results and a list of recommendations for future tasks.

2. LITERATURE REVIEW

This section summarizes current methodologies and practices for identifying potentially hazardous geometric conditions, and assessing effectiveness of SRS and cable median barriers. The underlying assumption is that by finding potentially hazardous geometric conditions, as well as installing safety devices statewide, the WSHSP goal of reducing crash severity will be reached. The first section is a brief summary explaining how geometric conditions affect crashes and potential safety improvements. The second section explains aspects of rumble strips and their benefits. The third section provides details about cable median barriers and their benefits. The fourth and final section of the literature review is a summary of how the combination of all three aspects has the potential to make roadways safer by reducing the severity of roadway departure crashes.

2.1 Geometrics Conditions

2.1.1 Geometric Causative Crash Factors

There are many different factors that cause crashes. Some of the factors, such as animal related crashes, have little to do with the geometrics of the roadway. Other crashes, such as roadway departure and rollovers, have been found to be impacted by geometric characteristics of roadways. Horizontal and vertical alignments are the two major geometric characteristics of every roadway. Horizontal curves are measured by their radius, while vertical alignments by their slopes.

Roadway curves are a necessary and important element of nearly all highways, but they are also one of the most complex features. Initially, their shape was a result of what seemed reasonable to the designer's eye. Now, roadway curves are geometrically designed using computer programs to form perfect circular curves. Despite a long standing design procedure based on sound principles, roadway curves often tend to be high-crash locations.

The geometric variable that most significantly affects operating speeds and crash experience on horizontal curves is the radius. Horizontal curves having lager curve radii are found to be associated with fewer crashes. By having a large curve radii the lateral forces on the vehicle are reduced, allowing drivers to negotiate the curve more smoothly, reducing the risk of overturning or departing the roadway. When vertical grades are combined with horizontal curves, it has been found that safety is adversely impacted. Also, vertical alignments with a lower average grade have been found to be safer. The lower average vertical grade improves driver's sight distance and allows vehicles to decelerate faster, which results in a reduction in the number and severity of crashes (Aram 2010; Labi & CATS 2005).

Although several studies over the years have indicated that roadway curves exhibit higher accident rates than straight roadway sections, and that accident rates increase as curve radii decrease, one of the most comprehensive analyses was done by Glennon et al. in 1983. This study had some very significant conclusions about roadway curve safety. One significant conclusion was the average single-vehicle ran-off-road (SVROR) crash rate for roadway curves is about four times the average SVROR crash rate for straight roadway segments. Also, roadway curves were found to have a higher proportion of fatal and injury accidents than straight segments. Some reasons for this were roadside character, substandard roadway curves, and roadside slope traversal.

Roadside character (roadside slope, clear-zone width, coverage of fixed objects) appears to be the largest contributor to high accident rates on curves. Most curves with high accident rates, however, usually have multiple contributing factors (i.e., sharper curvature, longer curve lengths, narrower shoulders, and lower pavement skid resistance). Substandard roadway curves are dangerous when drivers do not decrease speeds to match the safe speed of the curve. Roadside slopes on roadway curves need to be flatter than those on straight segments. This is because higher vertical deceleration rates result in a higher potential for rollover crashes (Glennon, J.C. et al. 1983).

Other studies resulted in somewhat different conclusions regarding the effects of radius, length of curve, etc. They all concluded, however, that roadway curves are significantly more dangerous than straight segments and that SVROR crashes are a predominant aspect of curves, and which tend to have a higher severity than multi-vehicle crashes.

2.1.2 Safety Improvements

The low traffic volumes on some rural roads make major improvements appear not to be cost effective and usually do not warrant an increased level of law enforcement effort. Persuading local authorities to spend time and money directly on safety improvements is an important step towards a proactive safety approach. Large financial commitments and complex safety analyses are not always necessary. Historically, liability issues have deterred local agencies from identifying safety concerns, because they fear that they would be exposed to tort liability simply by admitting that safety deficiencies exist on their roadways (Wilson 2003). Many agencies implement safety ideas at local levels without utilizing a specific safety program due to lack of funding, resources, or training to allow safety improvements to be made quickly and effectively (Calvert & Wilson 1999).

A solution to this is incremental safety improvements, which have been found to be an effective strategy in enhancing roadway safety. In order to effectively implement a safety program, the functional classification safety improvement guidelines for each classification need to be established (Calvert & Wilson 1999).

Factors that help to reduce the number of crashes are recommended by the American Association of State Highway and Transportation Officials (AASHTO) and can be found in the 2010 Highway Safety Manual (HSM). The HSM uses crash modification factors (CMF) for geometric design features to adjust the crash frequencies predicted by safety performance functions (SPF). The effectiveness of an improvement is based on the functional class and current design of a road section. The CMFs that are suggested for rural two-lane road segments are: lane width, shoulder width and type, horizontal curve length, radius and superelevation, vertical grades, centerline rumble strips, passing lanes, roadside design, lighting, advanced warning signs, and automated speed enforcement. When implemented appropriately, each of these safety improvements has the potential to effectively reduce the number and severity of crashes (AASHTO 2010). Figure 2.1 shows two CMF’s on a horizontal curve: shoulder widening and advanced warning signs.

Figure 2.1 Shoulder Widening and Advanced Warning Signs on Horizontal Curves

2.2 Shoulder Rumble Strips (SRS)

A rumble strip is defined as a raised or grooved pattern that is placed on a paved surface of a roadway or shoulder (Harwood 1993). More specifically, the FHWA defines an SRS as a longitudinal design feature that is installed on the shoulder of a paved roadway outside the edge of the traveled lane (FHWA 2011B). The purpose is to provide motorists with an audible and vibrational warning that their vehicle has partially or completely departed from the roadway.

In 1955, New Jersey's Garden State Parkway installed 25 miles of singing shoulders, the first set of shoulder rumble strips (SRS). The singing shoulder was a strip of corrugated concrete that produced an actual song when driven on. From the 1960s on, a variety of SRS forms have been utilized by different states. Rumble strips really took off in the1980s when a milled-in rumble strip was designed by the Pennsylvania Turnpike Commission. The milled-in design allowed the application of rumble strips within existing pavement for the first time. Due to the growing documentation of studies on the success of rumble strips over the past few decades, an increase in SRS installation occurred primarily on high volume rural freeways (FHWA 2011A). Shoulder rumble strips have a proven ability to reduce single-vehicle run-off-the-road (SVROR) crashes. This has motivated many agencies nationwide to install them on two-lane rural roadways (Torbic, D.J. et al. 2009). The FHWA has reported that more than 85% of states use shoulder rumble strips to improve the safety of their roads (FHWA, Rumble Strip Website).

2.2.1 Rumble Strip Design

The four most common types of rumble strips are milled, rolled, formed, and raised (FHWA 2011B). Each type is installed for different roadway situations. Various rumble strip dimensions have been tested nationwide, and many states have established their own practice.

2.2.1.1 Types and Installation

Milled rumble strips are made by a machine with a rotary cutting head, which creates a smooth, uniform, and consistent groove into the asphalt or Portland cement concrete (PCC). When the tires from a vehicle pass over the milled rumble strips, they drop into the groove causing tire noise and vehicle vibrations (FHWA 2011A). Studies have shown that noise and vibrations inside a vehicle greatly increase when milled rumbles are used instead of rolled rumbles. Milled rumble strips are used by most road agencies in North America since they can be installed at any time, and at whatever distance is needed (FHWA 2011B).

Rolled rumble strips are depressed into hot asphalt during the construction or reconstruction of a roadway. They form rounded or V-shaped grooves and are made by a roller with steel pipes welded to drums as it passes over the pavement (FHWA 2011A; Torbic, D.J. et al. 2009). There are numerous problems that can occur if the pavement temperature isn't in the correct range when pressed. These problems include premature pavement deterioration, lack of stabilization, or inability to reach adequate depth.

Formed rumble strips, similar to rolled, are made by pressing forms into PCC shoulders as they are being constructed. They have dimensions similar to milled rumbles, but, like rolled rumbles, lack consistency and have some installation limitations during paving operations (FHWA 2011B).

Unlike the other three types of rumble strips, raised rumbles are usually rounded, rectangular markers, or strips that adhere to new or existing pavements. Some agencies elect to use asphalt bars or raised buttons (Torbic, D.J. et al. 2009). Due to their height, the use of raised rumble strips is usually restricted to warmer climates that don't require snow removal. If used by agencies in colder climates, they are only kept on the road during the warmer seasons. Another use is placing them on surfaces where milling could compromise the integrity of the pavement (FHWA 2011B).

2.2.1.2 Dimensions

Rumble strips can be cut in several different dimensions. Milled rumble strips can be cut into different dimensions that provide correlating amounts of sound and vibration. There are mathematical models used to predict the noise generation based on the dimensions of the rumble strip configuration. It has been generally found, however, that deeper and wider rumble strips supply a more intense vibration. Typical rumble strips are 5" to 7" wide, approximately 1/2" deep, and have 12" to 16" intermittent spacing. States are currently experimenting with 4" edge line rumble strips, but a 6" length has been found to be the preferred dimension used by most agencies (FHWA, Rumble Strip Website).

Rolled and formed rumble strips are rounded or V-shaped grooves usually 32 mm (1.2") deep, and vary between 40 mm (1.57") to 2 feet wide. Raised rumbles strip markers can be rounded or rectangular in shape and can be adhered to new or existing pavements. Their dimensions can vary from 50 mm (1.97") to 305 mm (12") wide and 6 mm (0.24") to 13 mm (0.51") in height (FHWA, Rumble Strip Website).

2.2.2 Shoulder Rumble Strip Application Considerations

Rumble strips fall into four basic categories: SRS, centerline rumble strips (CLRS), transverse rumble strips (TRS), and mid-lane rumble strips (MLRS). CLRS are placed on or near the centerline of the road to prevent head-on collisions as well as opposite-direction sideswipe crashes. TRS are placed across the full width of a traveled lane to alert motorist of upcoming conditions such as intersections, toll plazas, and horizontal curves (Harwood 1993). MLRS are a concept where rumbles would be placed in the center of the traveled lane, which theoretically has the potential to mitigate both SVROR and crossover type crashes, but no installations are documented (Torbic, D.J. et al. 2009).

Even though there are several types of rumble strips, shoulder rumble strips are the primary focus of this study. Shoulder rumble strips are an effective means of preventing run-off-the-road (ROR) crashes and, as previously mentioned, they are primarily used to warn drivers they have drifted right and are leaving the travel lane. There are numerous considerations and a variety of ways and places that SRS can be utilized.

2.2.2.1 Continuous vs. Intermittent

New research suggests the continuous length of the rumble strip is not as critical as once assumed (Harwood 1993). A positive feature of intermittent rumble strips is that they leave gaps for bicyclists or motorcyclist to maneuver through as needed (FHWA, Rumble Strip Website), as shown in Figure 2.2. The application of continuous versus intermittent rumble strips, however, usually comes down to the preference and/or policy of each individual agency.

Figure 2.2 Intermittent Rumble Strips on 3 ft. Shoulders

2.2.2.2 Section Lengths and Overuse

The unpredictability of ROR crashes makes it hard to select specific locations for rumble strip implementation. The random nature of ROR crashes is more related to the driver becoming drowsy or distracted than the location of the vehicle on the road. The traditional recommendation is to install rumble strips on corridors or long roadway sections and prioritize installation by the crash frequencies. Because these crashes cannot be easily pinpointed, spot installations of SRS are estimated to be less effective (FHWA 2011B).

It is important for agencies to refrain from using rumble strips on sections where they are not needed. The effectiveness of rumble strips relies on motorists being surprised upon encountering them. If they are overused, a driver becomes accustomed to the feeling, which negates the point of the rumble strip. Potential adverse effects of overusing rumble strips can be mitigated by limiting their placement in the travel lane, which should reduce the frequency of motorists encountering them. Shoulder rumble strips are appropriate for frequent use on freeways and highways since they are not in the travel lane and are encountered only by errant vehicles (Harwood 1993).

2.2.2.3 Area Utilization

Rumble strips have been used extensively in rural areas with great effectiveness. The use of SRS in urban areas has also been found to be an effective way to increase safety. The use of rumble strips in urban areas can sometimes be limited due to low speeds, noise, or other common issues (FHWA 2011B).

2.2.2.4 Combining Uses

There are cases where it becomes necessary to use more than one type of rumble strip on the same stretch of road. The most common example is combining SRS and CLRS on the same segment of undivided highways. It has been found that SRS on divided highways should be placed on the median shoulder as well as on the right shoulder because cars have just as much a chance of drifting to the left as to the right. The practice of installing both SRS and CLRS along the same segments of road is becoming more common with no noted detrimental effects. In fact, a Missouri study showed that when both center line and edge line rumble strips were installed together, there was a greater reduction in serious injury crashes (FHWA 2011B).

2.2.2.5 Bicycle Considerations

Since bicyclists are prohibited from riding on freeways in nearly every state, considerations for them are less of a concern as they would be on rural highway sections. On most roadways the shoulder is the preferred travel area for bicyclists, making SRS policies a large concern. Some bicyclists are concerned that there is not enough room between the SRS and the shoulder edge and too much debris collects on the shoulders. These problems may cause bicyclists to ride in the travel lane (Harwood 1993), as shown in Figure 2.2.

In order to accommodate bicyclists, rumble strips and shoulders should be designed consistently and implemented system-wide. According to a 1997 FHWA survey, 68% of states utilizing SRS had accommodations for bicyclists. Each agency uses different combinations of policies, but some policies are more common than others. A policy for providing a minimum clear shoulder width for bicyclists is always applied. Different considerations for situations such as bicycle corridors, high ROR crash areas, reconstruction sites, and lack of funding for shoulder width improvements are generally included. Most importantly, areas not meeting the AASHTO bicycle standards are not designated or signed as a bike route (FHWA 2011B).

2.2.3 Wyoming's Rumble Design and Application

A system-wide effort to gain public acceptance has been initiated for SRS. Certain design practices have evolved through numerous national effectiveness studies, which have enhanced SRS performance and promoted public acceptance. WYDOT has used these findings to create and implement an SRS policy (FHWA, Rumble Strip Website).

Wyoming installs rumble strips on rural roads with either asphalt or concrete shoulders. Milled SRS are the preferred method for both new and existing shoulders on asphalt and concrete shoulders. WYDOT prefers to wait until they have a backlog of new pavement sections so they can let a statewide contract to install the milled rumble strips.

To promote public acceptance, WYDOT policy has restricted SRS use in residential areas to prevent offensive noise to nearby residents and keep the shoulders free of debris on designated bike routes and areas with high bicycle volumes (FHWA 2011A). Rumble strips are also not placed in urban areas, curb and gutter sections, bridge structures, intersections, driveway entrances, or on/off ramps (FHWA, Rumble Strip Website). Advance warning signs, along with public service announcements, will be provided to educate the public about SRS use, benefits, and limitations (FHWA 2011A). WYDOT policy incorporates SRS on any rural highway or freeway with a high number of ROR crashes. Continuous rumble strips are preferred over intermittent for interstate sections and intermittent rumbles strips are preferred on non-interstate highways (FHWA, Rumble Strip Website).

The contract plans for rumble strip projects considered in this research contained WYDOT standard designs for rumble strips. For intermittent rumble strips, WYDOT specifies 48’ of continuous rumbles with 12’ gaps with no rumbles in between. Specific dimensions for SRS are 16” wide for shoulders 8’ or wider. This also applies to all SRS on rural interstate and divided highway medians. Shoulders 6’ to 8’ wide should have 12”-wide SRS. Placing rumble strips on shoulders less than 6’ wide are not suggested to keep a 4’ clear width from the rumble edge to the shoulder break line for bicycle traffic. Unless otherwise specified, rumble strips will be 7” wide with 5” spaces between. Depths can vary from ½” to 5/8” on interstates and 3/8” to ½” on non-interstate shoulders. The acceptable design features can be found in the WYDOT Standard Plan 401.02A for asphalt SRS and 414-01B for concrete SRS (FHWA, Rumble Strip Website).

2.2.4 Effectiveness

2.2.4.1 Crash Statistics

The primary intention of SRS is to reduce SVROR crashes. The SVROR crash situations that are targeted by SRS include drowsy, fatigued, inattentive, and distracted drivers, which account for 40% to 60% of these crashes (FHWA, Rumble Strip Website). Crashes due to other situations, however, should not be expected to be significantly reduced by SRS. Torbic et al. (2009) noted several recent studies that identified between 17% and 20% of drivers and 25% of truck drivers in the United States and Canada admitted to falling asleep while driving. Drowsy driving has been predicted to cause up to 20% of serious crashes in the United States annually.

The 2005 SVROR crash statistics from the Fatality Analysis Reporting System (FARS) and the General Estimates System (GES) were summarized by Torbic et al. (2009). The reports indicated that 16.5% of single-vehicle property damage only (PDO) crashes, 21% of single-vehicle injury crashes, and 40.3% of all fatal crashes occurred off the roadway, on the shoulder, or within the median. A notable statistic showed that 31.7% of the fatal crashes were single-vehicle collisions with fixed objects (Torbic, D.J. et al. 2009). Also, about two-thirds of roadway departure crashes occur in rural areas (FHWA, Rumble Strip Website).

2.2.4.2 Safety Studies

There have been numerous studies completed to determine the effectiveness of SRS in reducing SVROR crashes on different roadway types. Through these evaluations, rumble strips have been confirmed to be an effective countermeasure for preventing roadway departure crashes. Documentation has shown SRS to reduce SVROR crashes by 7% to 41% (FHWA, Rumble Strip Website). The most recent evaluations were analyzed by Torbic et al. (1995) and compared against other previous evaluations (Torbic, D.J. et al. 2009).

The two types of roadways considered were rural freeways and rural two-lane roads (Torbic, D.J. et al. 2009). The analysis data were collected in Minnesota, Missouri, and Pennsylvania (Torbic, D.J. et al. 1995). The data were analyzed by combining all of the data from the three states. The two statistical approaches used were a before-after empirical Bayes (EB) comparison and a cross-sectional analysis using a generalized linear model (GLM). Torbic et al. (1995) showed the average effects of SVROR total (TOT) and fatal plus injury (FI) crash results, along with their standard error (SE) at a 95% confidence level.

The resulting average safety effects for SVROR TOT crashes showed a 5% to 15% reduction for rural freeways, and an 8% to 24% reduction for rural two-lane roads. These estimates were not proven to be statistically reliable. The average safety effects for SVROR FI crashes were proven, however, to be statistically significant. These results indicated a 10% to 24% reduction on rural freeways, and a 26% to 46% reduction on rural two-lane roads (Torbic, D.J. et al. 1995; Torbic, D.J. et al. 2009).

Other significant studies have been completed on the effectiveness of SRS on rural locations as well. A combination of interstate sections in Arizona, Mississippi, Nevada, and North Carolina showed a 6% reduction in crashes. The study produced a wide variation of crash reduction percentages attributed to the SRS results (FHWA, Rumble Strip Website). Harwood (1993) concluded his study by noting that a 20% reduction in ROR crashes could be expected system-wide with the incorporation of SRS. Reduction rates on long, isolated, monotonous stretches of rural highways were found to potentially achieve up to a 70% reduction in crashes (Harwood 1993).

2.2.5 Economic Feasibility

2.2.5.1 Costs and Benefits of Rumble Strips

Each rumble strip project will vary in cost per linear foot depending on a variety of factors. A major factor that influences the expense is the type of rumble strip installed. The mobilization cost of installing milled rumble strips is higher due to it being its own separate project. There is also a noticeable difference in price between rumble strips placed on PCC and those placed on asphalt, as well as temporary and raised rumble strips (Harwood 1993).

The price for rumble strips was found for asphalt and PCC projects that occurred in 2008. The sum was obtained from the WYDOT weighted average bid prices. For asphalt sections, the cost was $345 per mile for contract quantities of 665 miles. For PCC sections, the price was $1,500 per mile for 18 miles. This indicates that PCC rumbles strips cost over $1,100 more per mile than asphalt sections. The unit price was not taken from the full contract bid, which means other costs such as mobilization, traffic control, and fog seal, were not included. Thus, the total cost of installing rumble strips is higher than the bid prices shown on both asphalt and PCC roadway sections.

There have been many benefits realized when implementing SRS. As previously mentioned, SRS have been shown to effectively reduce ROR crashes caused by driver inattention, visibility issues, and fatigue. Also, SRS can be inexpensively installed on new or existing pavements while causing no noticeable pavement degradation and requiring minimal maintenance. SRS have aided vehicles in navigation during bad weather, and even snow plow drivers utilized them for finding the edge of the traveled lane during heavy snow and low visibility situations. In mountainous areas, SRS have been known to be utilized by motorists to provide traction for their vehicles traveling up or down long slopes (FHWA, Rumble Strip Website).

A study from Khan and Bacchus (1995) demonstrated that the benefit/cost ratio (B/C) of implementing rumble strips was greater than four in numerous instances. A Nevada study recently found SRS to have B/C ratios ranging from around 30:1 to over 60:1, in some cases. A survey of 50 state departments of transportation (DOTs) performed by the Maine DOT identified a B/C ratio of 50:1 for milled rumble strips on rural interstates nationwide. These high B/C ratios make SRS among the most cost-effective safety features in reducing ROR crashes available, including guardrails, culvert-end treatments, and slope flattening (FHWA, Rumble Strip Website).

2.2.5.2 Maintenance Issues

Asphalt deterioration is one of the primary maintenance considerations when implementing rumble strips. Some early concerns were that heavy traffic would cause shoulder pavements with rumble strips to crumble faster, or that the freeze-thaw cycle of water collecting in the grooves would crack the pavement. These concerns have since been proved to be unfounded (FHWA 2011B). In fact, field tests have refuted those concerns by finding that vibrations and the wheels passing over the rumble strips will knock debris, ice, and water out of the grooves. Thus, rumble strips have been found to have a minimal effect on the rate of deterioration on new pavements due to weather related issues (FHWA, Rumble Strip Website). These are results from DOTs that have performed studies and may not be applicable in every state.

Several tests nationwide have shown that rumble strips on older pavement shoulders continue to make noise and create vehicle vibration effectively, but the shoulders tend to degrade more quickly than on newer pavements (FHWA, Rumble Strip Website). To reduce or mitigate accelerated pavement degradation, locating rumble strips at least a few inches from the joints has become common practice (FHWA 2011B). To preserve shoulders from oxidation and moisture, asphalt fog seal can be placed over milled-in strips to help prevent corrosion (Khan & Bacchus 1995).

Shoulder rumble strips can limit the ability for the shoulder to be used as a traveled lane during maintenance activities (Harwood 1993). To solve this problem, road agencies tend to fill in the rumble strips with asphalt during long-term rehabilitation projects on asphalt pavements, and then mill in rumble strips to the resurfaced shoulder once construction is complete (FHWA, Rumble Strip Website).

There are a few situations where rumble strips are not advised for maintenance reasons. Shoulder pavements that have high degrees of deformation and/or cracking distress should have maintenance performed prior to implementation of rumble strips. In addition, raised rumble strips should be restricted to use in areas that don't deal with snow removal on a regular basis as they tend to get scraped off the road by snow plow blades passing over them (Harwood 1993).

2.3 Cable Median Barriers

A cable median barrier is a longitudinal barrier used to contain or redirect errant vehicles that leave the roadway by keeping them from encountering terrain features and roadside objects or entering opposing travel lanes, which may cause severe crashes. The most typical cable median barrier is a three-strand steel cable barrier system that is connected to a series of weak posts (FHWA, Cable Median Barrier Website). The three-strand cable barrier system has two cables on one side of the post and one cable on the other side to be able to withstand a collision from either side. Cable median barriers minimize the lateral force on the vehicle and its occupants by absorbing most of the energy of a crash laterally by breaking and bending the posts and stretching the cables (Marzougui, D. et al. 2007).

California was one of the first states to begin implementing and studying the effects of cable median barriers on crashes in the 1950s. These studies led to the first guidelines for the implementation of median barriers. Due to low crash frequency, the data were insufficient and DOTs didn't start using modified tensioned cables barrier, which greatly reduced barrier deflection under impact, until the 1980s (Sicking, D.L. et al. 2009). In 1989, after research and modification, the AASHTO *Roadside Design Guide* (RDG) added information pertaining to cable median barrier design which has been nearly unchanged ever since (Strasburg & Crawley 2005). These barriers are beginning to be deployed with regularity by state DOTs trying to address the risks of cross-median crashes on divided highways and interstates (Marzougui, D. et al. 2007).

2.3.1 Crash Statistics

One crash type that causes millions of dollars of damage and claims the lives of numerous people every year is cross-median crashes (Strasburg & Crawley 2005). A cross-median crash occurs when a vehicle leaves the traveled lane, completely crosses the median dividing the highway's directional lanes, and collides with a vehicle traveling in the opposite direction (Marzougui, D. et al. 2007). Vehicle speeds at collisions in cross-median crashes are typically high, usually resulting in violent crashes, which cause multiple injuries and fatalities (Miaou, S. et al. 2005). In fact, North Carolina reported that while fewer than 3% of all interstate crashes are cross-median crashes, they account for nearly 33% of all interstate fatalities. North Carolina also found cross-median crashes to be three times more deadly than all other freeway crashes (Hunter, W.W., et al., 2001).

These tragedies can be prevented by keeping vehicles on the right side of the road. Solving this problem is difficult since there is no identified pattern for time, conditions, or geometrics of cross-median crashes (Miaou, S. et al. 2005; Strasburg & Crawley 2005). One of the solutions to improve roadway safety by reducing cross-median crashes is the installation of median barriers. Median barriers are protective devices positioned between two opposing traffic streams with the purpose of keeping an errant vehicle from reaching the other side of the traffic lanes (Marzougui, D. et al. 2007). One cost effective type of median barrier being implemented almost nationwide is flexible barriers, also known as cable median barriers (FHWA, Cable Median Barrier Website). The primary purpose of cable median barriers is to eliminate severe, cross-median, head-on crashes (Marzougui, D. et al. 2007; Hunter, W.W. et al. 2001).

2.3.2 Effectiveness

There have been numerous studies completed to determine the effectiveness of cable median barriers in the reduction of cross-median crashes and crash severity on interstates and divided highways. Seven

DOTs that performed in-service cable median barrier studies, summarized by Sheikh et al. (2008), included Oregon, Washington, Missouri, Ohio, Utah, Colorado, and North Carolina. Through these evaluations, cable median barriers have been confirmed to be an effective countermeasure by preventing up to 90% of cross-median crashes (FHWA, Cable Median Barrier Website).

Other benefits from implementing cable median barriers include being more economically efficient to install than other barrier systems, as well as yielding considerable societal savings. An analysis conducted by the Washington DOT found that there was a societal savings of $10.26 million annually following its cable median barrier installation. That amounts to an estimated savings of $420,000 per mile of installed cable median barrier annually (McClannahan, D. et al. 2004). North Carolina's cable median barrier program has reportedly already paid for itself in saved lives (about 20 per year) with an estimated crash cost savings of $58 million per year (Strasburg & Crawley 2005).

Although it was found that crash severity is reduced by cable median barrier installation, property damage crash rates with fixed objects have been found to increase by up to five times. This happens because vehicles that previously could have recovered in the median undamaged now strike the cable barrier, resulting in damage to the vehicle and the cable barrier. It should also be noted that once a cable median barrier section has been compromised by a crash, if another crash happens in the same location before it's repaired, there is a much larger risk of barrier penetration (Hunter, W.W. et al. 2001; McClannahan, D. et al. 2004). However, it was found in North Carolina that 90% of crashes penetrating the cable median barrier were due to vehicles under-riding the cables (Sheikh, N.M., et al., 2008).

2.3.3 Costs and Maintenance

2.3.3.1 Installation Costs

The cable median barrier installation costs for 2008 were obtained from the WYDOT weighted average bid prices. The average price for installing 37,399 feet of cable barrier was $10.54 per foot or about $55,650 per mile in 2008. The unit price for installing cable median barrier gating terminals was $3,260.47 each. The bids included other built-in items such as mobilization and traffic control costs. Because 2008 was one of the first years WYDOT installed cable median barriers, the unit costs should decrease somewhat as local contractors become more familiar with installation practices. Similarly, North Carolina reported a $55,000 per mile total installation cost for cable median barriers (Strasburg & Crawley 2005).

Washington, which has been utilizing cable median barriers for almost two decades, reported installation costs of $8.33 per foot or $44,000 per mile for cable median barriers. Cable median barrier installation was found to be nearly half the cost of W-beam guardrail and almost one-tenth the cost of cast-in-place concrete barriers (McClannahan, D. et al. 2004). According to Sheikh et al. (2008), the Oregon DOT determined that installing cable median barriers cost 70% less than a concrete barrier system. Installing cable barriers has also been proven to be a better option than W-beam guardrail in cases where both are viable options (FHWA, Cable Median Barrier Website; Tarko, A.P. et al. 2008).

2.3.3.2 Repair Costs

The maintenance reports in Washington showed an average total repair cost of $733 per collision. An average of 6.7 posts were hit per crash, resulting in an average repair time of 9.4 hours for maintenance crews. The annual maintenance cost for cable median barriers in the State of Washington at the time of the study was $2,570 per mile (McClannahan, D. et al. 2004). A maintenance repair is not always associated with a crash report. In most cases, only 50% to 55% of all cable barrier crashes were reported and/or matched to a crash report. Fewer posts were hit on average for unreported crashes, which resulted in less repair time, fewer parts, and less overall cost.

Most agencies reported only needing to replace four to six posts on average following a crash, which usually requires about two hours to repair (Sheikh, N.M. et al. 2008). Agencies have found that pre-stretched cables have significantly greater cable tension, which means less re-tensioning of cables is needed and cable deflection is reduced during a crash. In many instances this leads to fewer repairs and faster repair times when damaged by a collision (Strasburg & Crawley 2005).

2.3.3.3 Maintenance

The maintenance and repair of cable median barriers has received mixed reviews from maintenance crews when first implementing them. Most maintenance crews reported that after receiving proper training and gaining familiarity with the system, cable median barriers become relatively easy to maintain and repair.

An important factor in the performance of cable median barriers is the tension of the cables. A cable that is not pre-stretched loses about 77% of its initial tension in the first year of service. The temperature and cable length are the main factors in cable tension loss. In order to compensate for this, maintenance crews need to tighten the cables higher than the desired level initially. Each agency needs to develop its own re-tensioning methods based on the temperature variation in its area, as well as the length of each cable section (Sheikh, N.M. et al. 2008).

2.3.4 Guidelines

Hunter et al. (2001) noted that California initially utilized one-strand cable barriers, but stopped using them due to high rates of vehicle penetration. Today, the only designs tested and approved for use by the RDG are variations of three- and four-strand cable barriers. Research by the National Crash Analysis Center (NCAC) found that four-stand cable barriers increase the likelihood of retaining a broader spectrum of vehicles (FHWA, Cable Median Barrier Website). Some agencies have made approved modifications to the standard RDG cable median barrier design for implementation in their state, but most cable barrier designs nationwide are very similar. In accordance with *NCHRP Report 350*, guidelines for Test Level 3 safety performance, a three-strand cable barrier has been proven to withstand the impact of a 2,000-kg (4,400-lb) pickup truck at an angle of 25° with a collision velocity of 100 km/h (62 mph) (Ross, H.E. Jr. et al. 1993). According to Sheikh et al. (2008), some DOTs reported cable median barriers preventing penetration from much larger vehicles such as fire trucks and semi-trucks.

Besides the recent acceptance of high-tension cables, the RDG cable median barrier guidelines have changed minimally over the past two decades. The RDG recommends that divided roadway sections are built with median widths 50 feet or wider, so median barriers are not required. According to Hunter et al. (2001), crash rates in unobstructed medians have been found to decline with increasing median widths for medians 25 to 60 feet wide. Cable median barriers can still be an effective safety measure if justified through an analysis pertaining to operations and/or crash history (Miaou, S. et al. 2005). Unlike semi-rigid and rigid barriers, cable barriers should not be utilized when median widths are less than 25 feet to prevent them from deflecting into the opposing traveled lane (Hunter, W.W. et al. 2001). Some agencies have reported implementing cable barriers in medians with widths up to 75 feet wide (Miaou, S. et al. 2005).

The RDG justifies cable median barriers based on factors such as speed limits, median widths, and annual average daily traffic (AADT) volumes. Cable barrier installation is warranted when AADT volumes are over 20,000 vehicles and speed limits exceed 55 miles per hour (mph) (AASHTO 2002). Unlike semi-rigid and rigid median barriers, cable median barriers have been proven to retain their effectiveness when installed on sloping terrain as steep as 1V:6H (V=vertical, H=horizontal) (Miaou, S. et al. 2005; Sheikh, N.M. et al. 2008). Testing has shown that cable barriers should not be placed between 1 to 8 feet from the centerline of the median to prevent vehicles from under-riding the cables (Strasburg & Crawley 2005; Marzougui, D. et al. 2007). Overall, cable median barriers have been found to be a relatively cheap and effective cross-median crash solution on freeway and divided highway sections with narrow median widths, especially high volume roads and sections determined to be hazardous (Torbic, D.J. et al. 2009).

2.3.5 Wyoming's Cable Median Barrier Design and Application

Cable barrier implementation has gained national acceptance through numerous studies on their effectiveness. WYDOT has used these findings to create and implement a cable median barrier system. Wyoming was one of the last states to implement cable median barriers as a roadway safety measure when it installed its first section in 2007. Currently, there are 102.8 miles of cable median barriers installed on various interstate sections in Wyoming.

Figure 2.3 Trinity Cass TL-3 Cable Median Barrier System

WYDOT plans for cable median barrier projects include six sheets of details. These details cover the dimensions and requirements for employing cable median barriers in Wyoming. WYDOT uses the two approved systems: the Trinity Cass TL-3 Three-Cable High-Tension System, shown in Figure 2.3, and the Briffin three- or four-cable system.

Maximum lateral deflection of the system provided is not to exceed 9', and the post spacing is not to exceed 16'-6". WYDOT has been typically using the Cass System with a 16'-6" post spacing. WYDOT recognizes the optimum placement of cable median barriers as being 8 feet [2.4 m] or more from the bottom of the median ditch with slopes as steep as 1V:6H. This prevents the vehicle's suspension from compressing, resulting in under-riding the bottom cable and penetrating the barrier while traversing the ditch bottom.

According to the RDG, justification for implementing cable barriers in Wyoming is needed since roadways don't meet the 20,000 AADT minimum volume requirements (WYDOT 2011). The justification for WYDOT was the Wyoming Legislature making the installation of cable barriers in narrow medians on I-80 one of its top priorities. Thus, WYDOT installed most of the cable barriers in medians between 25 to 40 feet wide. This most likely would not have been possible if high tension cable barriers hadn't been developed. A major advantage of cable median barriers in Wyoming is that, unlike box beam or corrugated beam median barriers, it does not cause significant snow drifting. This makes it easier on maintenance crews, and decreases the risk of crashes that are associated with drifting snow.

2.4 Section Summary

This section contained a review of literature from various safety projects, which pertained to geometric conditions, SRS, and cable median barriers. The first section illustrated common causative crash statistics related to geometric features and identified proven safety improvements. The contributing crash statistics proved a need to make improvements to roads with an insufficient geometric design. There are several proven safety improvements identified that can be used to reduce crashes and/or crash severity. The best solution for each road is generally different, which means the causative crash factors need to be analyzed before determining the appropriate improvement.

The second section outlined SRS research. Rumble strips have various applications and have several approved designs nationwide. The B/C ratios from multiple studies indicated that SRS are among the most cost-effective safety features in reducing ROR crashes. Since this report focuses on the effectiveness of Wyoming's SRS, the WYDOT's standard designs for SRS were included.

The third and final section discussed cable median barrier research. The crash statistics emphasized a need to implement cable median barriers on divided interstate sections with narrow medians and high AADT. This is due to their effectiveness in reducing cross-median crashes. Cable median barriers were found to have a relative low installation cost compared with other barriers, while having relatively low maintenance and replacement costs. Wyoming's design and implementation practices were also discussed.

3. GEOMETRICS CONDITIONS

3.1 Introduction

Although the fairly random nature of roadway departure crashes can be related to the driver becoming drowsy or distracted, geometric alignments still have an impact on these crashes. Analyzing why a high percent of crashes are occurring on horizontal curve sections is important when attempting to reduce crash severity. This section includes the data collection and data analysis for determining the impact of various geometric conditions on the severity of roadway departure crashes on Wyoming's rural roads. Also included is an analysis of the overall impact of the WSHSP in reducing crash severity statewide.

3.2 Data Collection

All data utilized in this study were obtained from the Critical Analysis Reporting Environment (CARE) 9 crash database (WYDOT 2010). The CARE 9 crash database is a program that is updated quarterly with all available details of every crash in Wyoming since 1994. The data input screens are shown in Appendix A: CARE 9 Data Input Screens, which illustrates the process of obtaining the crash data from the CARE 9 database. Although the data available in the CARE 9 crash database are vast, the research in Section 3 concentrated primarily on the following categories: functional classification, crash type, and geometric conditions.

For the analysis, two time periods of four years were selected using the publication of the WSHSP in September 2006 as the end of the "before" period and the beginning of the "after" period. The "before" analysis is from September 2002 to August 2006. The "after" analysis is from September 2006 to August 2010. The data are filtered in three categories: crash severity, time period, and functional classification.

The crash data were summarized into three functional classifications for rural roadways: interstate, state highways, and local roads. The crash data for all roadways statewide were also analyzed. Eight combinations of possible geometric conditions were included in the analysis using two horizontal alignment types (straight and curved) and four vertical alignment types (uphill, downhill, curves, and level). These geometric combinations are summarized in Table 3.1

Table 3.1 Analyzed Geometric Combinations

Geometric Combinations	
Horizontal Alignment	**Vertical Alignment**
Straight	Level
Straight	Uphill
Straight	Downhill
Straight	Curve
Curve	Level
Curve	Uphill
Curve	Downhill
Curve	Curve

Although the data available in the CARE 9 crash database are vast, there are still limitations in the program. The main limitation is the information is only as accurate and complete as the officer reporting the crash records it. Although there are numerous classes every year which help officers develop and retain knowledge about reporting crashes, the reporting officers are not expected to be experts on every detail. Thus, detailed information that could be used to enhance safety is not always statistically reliable due to having a chance of either being unreported or reported incorrectly. For example, curve radii, vertical grades, and AADT values are not reported for 93%, 68%, and 52% of crashes, respectively. Also, the CARE 9 crash database has categories for posted speeds and vehicle speeds, but there is no category for speeding. Thus, each crash would have to be analyzed individually in order to determine the number of speeding vehicles, which can be extremely time-consuming.

The CARE 9 crash database identifies different roads by ML numbers. The road numbers in this system are divided into state highways, county roads, and city streets. In this system, the interstates are included in the state highway network. The three roadway categories in this report (interstates, state highways, and local roads) were developed by using this reporting style. The interstates were extracted out of the state highway category and the county road category was called local roads. This means the roads are not divided by true functional classifications (collectors, arterials, etc.), thus the state highway and county road categories both have a mix of arterials and collectors roads in their respective crash numbers. WYDOT currently has not merged roadway lengths into the CARE 9 crash database. This means that the proportionate length of each geometric combination compared with the entire road network is unknown.

3.3 Data Analysis

The analysis of the data was performed in two phases. The first phase determined the statewide impact of the WSHSP and concentrated on locating hazardous geometric conditions. The hazardous geometric conditions were analyzed for rural roads statewide, as well as on interstates, state highways, and local roadways in Wyoming. The purpose of the geometric conditions analysis was to determine if any of the functional classes have a significantly high proportion of severe crashes. The second phase analyzed the geometric combinations identified in the first phase of research as having high severity crashes. Only roadway departure crashes were analyzed in phase II since they are an emphasis area in the WSHSP.

The equivalent property damage only (EPDO) is a performance measure where weighting factors relative to property damage only (PDO) crashes are assigned by severity types to develop a single equivalent combined frequency. In this research, the EPDO values for the five main crash severity levels were based on the comprehensive crash costs, calculated in 2007 dollar values, from the 2010 Highway Safety Manual (AASHTO, 2010). Since Wyoming roadways typically have low crash numbers, crash performance measures are more sensitive to fatal crashes and potentially can be over-emphasized. To mitigate this, fatal crashes were combined with incapacitating injury crashes and designated as “critical” crashes, shown below in Equation 1. Also, the two less severe injury types (non-incapacitating and complaint of pain) were combined into a “serious” crash category.

Table 3.2 illustrates how the EPDO weight factors were established. The HSM comprehensive crash costs were averaged against the number of crashes in the critical and serious categories. This determined the weighted comprehensive costs for the critical and serious categories. The PDO value was not weighted. The EDPO weighting factors were calculated by dividing the weighted comprehensive crash costs by the PDO comprehensive cost. These values are valid for all crashes regardless of functional classification.

Table 3.2 EPDO Performance Measure Methodology

CRASH SEVERITY		WY Crashes (2000-09)	HSM Comprehensive Crash Costs (2007)	Weighted Comp. Crash Cost	EPDO Weighting Factors
CRITICAL	K	1428	$ 4,810,700.00	$ 976,667.93	110
	A	7631	$ 259,200.00		
SERIOUS	B	16847	$ 94,800.00	$ 75,386.24	8.5
	C	15222	$ 53,900.00		
PDO		118115	$ 8,900.00	$ 8,900.00	1

Equation 1 is the EPDO formula utilized in the data analysis.

$$EPDO = 110*(A+K) + 8.5*(B+C) + PDO \quad (1)$$

where:

EPDO: Equivalent Property Damage Only
K: Number of fatal crashes
A: Number of A injury crashes (incapacitating injuries that will prevent normal activities for more than 24 hours)
B: Number of B injury crashes (non-incapacitating injuries that will not prevent normal activities for more than 24 hours)
C: Number of C injury crashes (complaint of pain or momentary unconsciousness), and
PDO: Property Damage Only crashes

The EPDO value for each geometric combination and the corresponding total EPDO value were calculated for every functional classification. The total percentage of crashes and the corresponding percentage of the total EPDO value were calculated for every geometric combination in each functional classification. The EPDO performance measure methodology will also assist Wyoming in attaining the 2006 WSHSP goal of successfully reducing fatal and serious injury crashes by emphasizing the “critical” crash category. Table 3.3 shows an example from the interstate system of how the total crash numbers and EPDO values were converted into percentages.

Table 3.3 Total Crash and EPDO Percentages on the Interstate System

Wyoming Rural INTERSTATES Crashes (SEPT 2002-AUG 2006)								
Geometric Combinations		CRASH SEVERITY			Total Crashes	EPDO Values	% Total Crashes	% EPDO
Horizontal Alignment	Vertical Alignment	CRITICAL	SERIOUS	PDO				
Straight	Level	361	870	3298	4529	9592	44.5%	42.4%
Straight	Uphill	149	429	1344	1922	4186.5	18.9%	18.5%
Straight	Downhill	167	323	1245	1735	3878.5	17.1%	17.1%
Straight	Curve	8	25	91	124	250.5	1.2%	1.1%
Curve	Level	64	117	330	511	1315.5	5.0%	5.8%
Curve	Uphill	70	145	388	603	1525.5	5.9%	6.7%
Curve	Downhill	85	155	484	724	1791.5	7.1%	7.9%
Curve	Curve	9	3	14	26	105.5	0.3%	0.5%
TOTAL VALUES		**913**	**2067**	**7194**	**10174**	**22645.5**	**100%**	**100%**

The purpose of this research is to locate geometric sections in Wyoming that consistently result in a significantly higher proportion of severe crashes. A Weighted Severity Index (WSI) was formulated to eliminate having to analyze the data purely using crash numbers. The WSI identifies geometric conditions that have significantly higher EPDO percentages than percentages of total crashes. The WSI also emphasizes higher crash locations by giving more weight to geometric combinations with larger total crash percentages. Since the WSI multiplies two percentages together, it is multiplied by a factor of 10,000 to display a number instead of a decimal. Equation 2 illustrates how the WSI values are calculated.

$$WSI = (\%\ EPDO - \%\ Total\ Crash) * (\%\ EPDO) * 10{,}000 \quad (2)$$

where:
WSI: Weighted Severity Index
% EPDO: Percentage of total EPDO for each geometric combination
% Total Crash: Percentage of total crash for each geometric combination

Ranges of severity for the WSI are the following:

- Low, WSI < 0
- Average, WSI = 0
- Moderate, WSI = 0.1 to 15
- High, = 15.1 to 30
- Very High, WSI ≥ 30

The ranges of severity were established after the WSI values were calculated for all categories. The ranges were set on a linear scale, which was closely represented by the difference between the EPDO and total crash percentages. Geometric combinations with a positive WSI value indicate a higher than average risk. On the other hand, geometric combinations with a negative WSI value indicate a lower than average risk. The WSI values were calculated for every geometric combination reported in this report.

3.3.1 Phase I: WSHSP and Geometric Analysis

The WSHSP initiated a shift in policy which aimed at reducing the severity of crashes statewide. A direct result of the WSHSP was an increase in resources and funding allocated toward the selected safety emphasis areas. To evaluate the overall effectiveness of the 2006 WSHSP in reducing crash severity, the before-after crash severity numbers were obtained, as shown in Figure 3.1. The raw crash data for the statewide crashes are shown in Appendix B1.

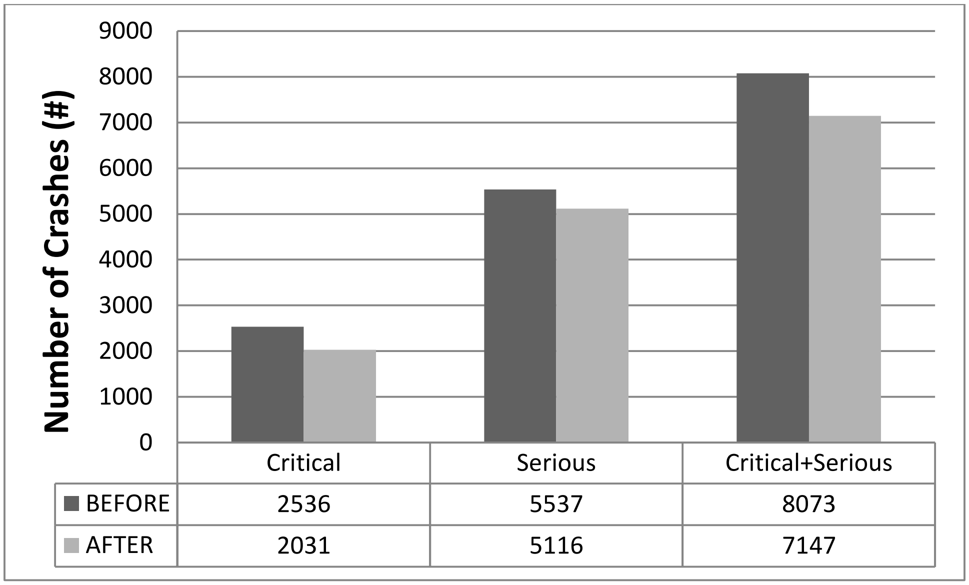

Figure 3.1 Effects of WSHSP on Crash Severity Statewide

The number of critical crashes was reduced by more than 500 in the four years following the implementation of the WSHSP. Similarly, over 400 serious crashes were reduced. Thus, within four years of the WSHSP implementation, there was a reduction of more than 900 critical and serious crashes statewide. It should be noted that Wyoming has had a continual, long lasting, safety effort prior to the WSHSP. However, the increase and focus of safety projects due to the WSHSP is a contributing factor to the significant reduction in the number of critical and serious crashes statewide.

The first phase also concentrated on the total crash percentage for each geometric combination and compared them against their respective EPDO percentage. Table 3.4 shows the statewide rural WSI values for the before-after analysis periods. This analysis shows a problem statewide with the severity of curve-level and curve-downhill crash. The analysis also shows crash severity improvement on three geometric combinations. An increase in severity was apparent on curve-level sections. The straight-level WSI value also increased, but remained negative, indicating there is still a very low frequency of severe crashes on those sections.

Table 3.4 Statewide Analysis before-after WSHSP

STATEWIDE Rural Weighted Severity Index (SEPT 2002 - AUG 2006)					STATEWIDE Rural Weighted Severity Index (SEPT 2006 - AUG 2010)					
Geometric Combinations		TOTAL	EPDO	Weighted Severity Index	Geometric Combinations		TOTAL	EPDO	Weighted Severity Index	Change in WSI After WSHSP
Horizontal Alignment	Vertical Alignment				Horizontal Alignment	Vertical Alignment				
Straight	Level	48.83%	40.42%	-340.1	Straight	Level	48.7%	43.7%	-219.1	121.0
Straight	Uphill	12.50%	11.96%	-6.5	Straight	Uphill	12.3%	9.4%	-26.9	-20.4
Straight	Downhill	13.15%	13.92%	10.7	Straight	Downhill	11.8%	11.5%	-4.1	-14.8
Straight	Curve	1.21%	1.10%	-0.1	Straight	Curve	2.1%	2.2%	0.2	0.3
Curve	Level	9.24%	12.34%	38.2	Curve	Level	10.2%	13.6%	46.6	8.4
Curve	Uphill	5.23%	6.85%	11.1	Curve	Uphill	5.3%	7.0%	11.7	0.6
Curve	Downhill	9.45%	12.67%	40.8	Curve	Downhill	8.5%	11.2%	30.6	-10.3
Curve	Curve	0.38%	0.74%	0.3	Curve	Curve	1.1%	1.4%	0.4	0.2

To help indicate which functional classification(s) contributed to the high severity geometric combinations in Table 3.4, additional analyses were performed on the interstate, state highways, and local roadways as described in the following sections. Appendix B2 shows the overall number and percentage of crashes obtained for each functional classification.

3.1.1.1 Interstate

The before-after analysis on the rural interstate sections is shown in Table 3.5. Interstates are typically known for their conservative geometric designs since they regularly carry high traffic volumes at higher speeds. For this reason the geometrics of interstates usually adhere to driver expectancy to help prevent high speed crashes from happening. The before-after results indicate that the crash severity was low to moderate for all the geometric combinations except curve-downhill sections, which were found to be high severity. Straight-downhill was initially almost considered high severity also, but was reduced to low following the WSHSP implementation.

Table 3.5 Interstate Before-After Analysis

INTERSTATE Rural Weighted Severity Index (SEPT 2002 - AUG 2006)					INTERSTATE Rural Weighted Severity Index (SEPT 2006 - AUG 2010)					
Geometric Combinations		TOTAL	EPDO	Weighted Severity Index	Geometric Combinations		TOTAL	EPDO	Weighted Severity Index	Change in WSI After WSHSP
Horizontal Alignment	Vertical Alignment				Horizontal Alignment	Vertical Alignment				
Straight	Level	44.52%	40.26%	-171.3	Straight	Level	45.8%	43.1%	-116.6	54.7
Straight	Uphill	18.89%	17.08%	-31.0	Straight	Uphill	17.8%	15.5%	-36.8	-5.8
Straight	Downhill	17.05%	17.86%	14.4	Straight	Downhill	14.8%	14.2%	-8.3	-22.7
Straight	Curve	1.22%	0.95%	-0.3	Straight	Curve	2.6%	2.8%	0.6	0.8
Curve	Level	5.02%	6.68%	11.1	Curve	Level	6.1%	7.5%	10.2	-0.9
Curve	Uphill	5.93%	7.44%	11.3	Curve	Uphill	5.5%	7.0%	11.1	-0.2
Curve	Downhill	7.12%	8.91%	16.0	Curve	Downhill	6.3%	8.6%	19.3	3.4
Curve	Curve	0.26%	0.82%	0.5	Curve	Curve	1.0%	1.3%	0.4	-0.1

3.3.1.2 State Highway

Table 3.6 shows the before-after analysis results performed on rural state highway geometric combinations. The results before the WSHSP implementation illustrate that the curve-level and curve-downhill sections had very-high severity crashes. Although the curve-downhill sections improved following the WSHSP implementation, they are still considered to be producing high severity crashes. The curve-uphill and straight-uphill sections also have a slightly improved crash severity index. Curve-level sections indicated very high severity crashes in both the before and after analyses.

Table 3.6 State Highway Before-After Analysis

STATE HIGHWAY Rural Weighted Severity Index (SEPT 2002 - AUG 2006)					STATE HIGHWAY Rural Weighted Severity Index (SEPT 2006 - AUG 2010)					
Geometric Combinations		TOTAL	EPDO	Weighted Severity Index	Geometric Combinations		TOTAL	EPDO	Weighted Severity Index	Change in WSI After WSHSP
Horizontal Alignment	Vertical Alignment				Horizontal Alignment	Vertical Alignment				
Straight	Level	54.0%	42.5%	-489.0	Straight	Level	52.8%	45.9%	-319.8	169.2
Straight	Uphill	9.5%	10.2%	7.0	Straight	Uphill	9.2%	7.0%	-15.3	-22.3
Straight	Downhill	10.6%	11.3%	7.6	Straight	Downhill	9.9%	10.3%	3.8	-3.8
Straight	Curve	1.1%	1.0%	-0.1	Straight	Curve	1.6%	1.6%	0.1	0.2
Curve	Level	10.1%	14.0%	55.8	Curve	Level	11.2%	15.6%	68.5	12.7
Curve	Uphill	4.9%	7.0%	14.2	Curve	Uphill	5.4%	7.2%	13.6	-0.6
Curve	Downhill	9.5%	13.6%	55.8	Curve	Downhill	9.0%	11.4%	26.7	-29.1
Curve	Curve	0.3%	0.4%	0.0	Curve	Curve	0.9%	1.1%	0.1	0.1

3.3.1.3 Local Roads

The before-after analysis performed on the Wyoming local rural roadways is displayed in Table 3.7. The results of the crash severity before the WSHSP implementation illustrate the curve-level and curve-downhill sections had very-high severity crashes. The straight-downhill sections also had high severity, but, similar to the curve-level sections, improved significantly after the WSHSP implementation. The curve-downhill sections also improved but were still considered to be producing very-high severity crashes.

Table 3.7 Local Roadway Before-After Analysis

LOCAL Rural Weighted Severity Index (SEPT 2002 - AUG 2006)					LOCAL Rural Weighted Severity Index (SEPT 2006 - AUG 2010)					
Crash Type		TOTAL	EPDO	Weighted Severity Index	Crash Type		TOTAL	EPDO	Weighted Severity Index	Change in WSI After WSHSP
Horizontal Alignment	Vertical Alignment				Horizontal Alignment	Vertical Alignment				
Straight	Level	42.3%	32.6%	-317.9	Straight	Level	43.9%	36.9%	-258.7	59.2
Straight	Uphill	4.2%	4.1%	-0.2	Straight	Uphill	3.9%	3.9%	0.0	0.2
Straight	Downhill	11.0%	13.2%	29.6	Straight	Downhill	8.2%	9.2%	8.9	-20.7
Straight	Curve	1.6%	1.8%	0.4	Straight	Curve	2.6%	3.2%	1.6	1.3
Curve	Level	19.2%	21.9%	60.5	Curve	Level	20.8%	21.2%	8.2	-52.3
Curve	Uphill	4.1%	4.6%	2.1	Curve	Uphill	4.3%	5.8%	8.5	6.4
Curve	Downhill	16.3%	19.7%	67.2	Curve	Downhill	14.1%	16.9%	47.5	-19.7
Curve	Curve	1.3%	2.0%	1.5	Curve	Curve	2.1%	3.0%	2.5	1.0

3.3.1.4 Initial Findings

The phase I analysis results indicate that there was a reduction in the crash severity statewide due to safety improvements associated with the WSHSP. The results also showed evidence that the severity of crashes on various geometric sections improved after the 2006 WSHSP implementation. The results demonstrate compelling evidence that horizontal curves pose a much higher risk to drivers than straight sections on rural Wyoming state highway and local roadways. This most likely explains the high severity crashes occurring on the curve-level and curve-downhill sections statewide, as shown in Table 3.4.

Additional analysis will be conducted on crashes occurring on local and state highway locations with curve-level and curve-downhill geometric combinations in phase II. The interstate sections on the other hand generally did not have high severity crashes; performing additional analysis on the interstate sections was determined unnecessary.

3.3.2 Phase II: Analysis of Roadway Departure Crashes on High Severity Geometric Conditions

A previously mentioned, the WSHSP placed a heavier emphasis on improving safety in four areas, one of which is roadway departure crashes. Since severe run-off-roadway (ROR) crashes are generally associated with roadway curves, phase II will only analyze road departure crashes. In this analysis, a roadway departure crash is defined as one in which a vehicle leaves its lane and runs off the road, is turned in the opposite direction, sideswipes, and is hit head-on.

Wyoming reported that 37% of fatal and serious injury crashes in 2004 were associated with roadway departures. To identify the cause of these high severity ROR crashes, the severity and first harmful event (FHE) of every ROR crash was determined. It should be noted that although they are not being analyzed, driver fatigue, impaired driving, and speeding are contributing factors that have been found to result in roadway departure crashes (WYDOT 2006).

The phase II analysis was performed on the four identified roadway versus geometric combinations identified in phase I: state highway and local roads with curve-downhill and curve-level sections. These crashes were filtered in the CARE 9 program by roadway departure crashes only. The state highway FHE for each crash was compared against three categories: roadway conditions, presence of rumble strips, and the crash severity. For the local roadway FHE, the presence of rumble strips were replaced by an analysis of road surface (paved versus unpaved) because unpaved roads do not have rumble strips. Only the top five FHE in each category were compared against the three above mentioned categories. The raw crash numbers for the phase II analysis are displayed in Appendix B3.

3.3.2.1 State Highway Curve-Downhill Sections

This section summarizes the before-after results for roadway departure crashes on the state highway curve-downhill sections shown in Table 3.8. The before and after WSI values of 426.8 and 309.3, respectively, for rollover crashes indicate that while they are by far the most harmful roadway departure crash type, the severity was greatly reduced. The earth embankment berm crashes increased enough to be considered high, but were not comparable at all to the rollover crash severity.

Table 3.8 State Highway Before-After Analysis on Curve-Downhill Sections

Wyoming Rural State Highway Crashes (Sept 2002-Aug 2006)							
Roadway Deptarture Crashes		Severity on Curve-Downhill Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	10.4%	14.9%	15.8%	41.1%	49.7%	426.8
	Guardrail Face	1.2%	4.4%	6.2%	11.8%	7.0%	-33.8
	Earth Embankment or Berm	0.8%	3.5%	3.3%	7.7%	4.8%	-13.8
	Other Non-Collision MC Loss of Control	3.3%	2.1%	1.5%	6.8%	14.9%	119.2
	Fence including Post	0.4%	1.2%	4.8%	6.4%	2.4%	-9.6
	Other	4.4%	6.6%	15.1%	26.1%	21.3%	-102.9
	TOTAL	20.5%	32.8%	46.7%	100.0%	100.0%	

Wyoming Rural State Highway Crashes (Sept 2006 -Aug 2010)							
Roadway Depature Crashes		Severity on Curve-Downhill Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	6.6%	16.4%	12.5%	35.5%	42.8%	309.3
	Guardrail Face	1.3%	2.6%	8.2%	12.0%	8.3%	-31.0
	Earth Embankment or Berm	1.8%	3.8%	4.1%	9.7%	11.3%	18.1
	Delineator Post	0.8%	2.3%	4.6%	7.7%	5.3%	-12.7
	Trees or Shrubbery	1.0%	1.8%	4.3%	7.2%	6.4%	-4.9
	Other	4.3%	4.6%	18.9%	27.9%	26.0%	-49.3
	TOTAL	15.9%	31.5%	52.7%	100.0%	100.0%	

A separate analysis was performed on roadway conditions and the presence of rumble strips for the crashes occurring after the 2006 WSHSP, as shown in Table 3.9. Since 46% of crashes occurred on dry roadway surfaces, 54% of all crashes occurred on other-than-dry roadway surfaces. This suggests that a majority of the crashes are partially correlated to wet or slick road conditions. Table 3.9 also shows that only 10% of the crashes were reported to occur in locations where rumble strips were present. The "unreported" category shows that in 44% of the crashes, the reporting officer did not record the whether or not there were rumble strips present. However, 46% of the 56% of crashes where rumble strips were reported, ("yes" or "no") indicated that rumble strips were not present in the area of the crash.

Table 3.9 Road Condition and Rumble Strip Analysis on State Highway Curve-Downhill Sections

WYOMING Rural STATE HIGHWAY Roadways Roadway Departure Crashes Curve-Downhill Sections (September 2006 - August 2010)						
		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	17.6%	13.6%	3.1%	1.3%	**35.5%**
	Guardrail Face	3.3%	6.1%	2.3%	0.3%	**12.0%**
	Earth Embankment or Berm	4.6%	4.1%	1.0%	0.0%	**9.7%**
	Delineator Post	4.3%	2.8%	0.5%	0.0%	**7.7%**
	Trees or Shrubbery	2.8%	3.3%	0.8%	0.3%	**7.2%**
	Other	13.6%	11.5%	2.6%	0.3%	**27.9%**
	TOTAL	**46.3%**	**41.4%**	**10.2%**	**2.0%**	**100.0%**

		RUMBLE STRIP			
		Yes	No	Un-Reported	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	4.9%	16.6%	14.1%	**35.5%**
	Guardrail Face	1.3%	5.4%	5.4%	**12.0%**
	Earth Embankment or Berm	0.3%	2.0%	7.4%	**9.7%**
	Delineator Post	0.8%	4.9%	2.0%	**7.7%**
	Trees or Shrubbery	0.3%	3.1%	3.8%	**7.2%**
	Other	2.6%	14.1%	11.3%	**27.9%**
	TOTAL	**10.0%**	**46.0%**	**44.0%**	**100.0%**

3.3.2.2 State Highway Curve-Level Sections

This section summarizes the before-after results for roadway departure crashes on the state highway curve-level sections shown in Table 3.10. The before and after WSI values of 344.5 and 508.2, respectively, for rollover crashes once again indicates that they are by far the most harmful roadway departure crash type. In the "after" category, the total and EPDO percentages were reduced but became more severe due to the increased gap between the two. The delineator post crashes were found to be reduced in severity yet not comparable at all to the rollover crash severity.

Table 3.10 State Highway Before-After Analysis on Curve-Level Sections

Wyoming Rural State Highway Crashes (Sept 2002-Aug 2006)							
Roadway Deptarture Crashes		Severity on Curve-Level Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	10.9%	21.1%	14.4%	46.3%	52.9%	344.5
	Fence including Post	1.3%	2.9%	9.4%	13.6%	6.6%	-46.0
	Earth Embankment or Berm	1.5%	4.0%	2.7%	8.1%	7.5%	-4.7
	Delineator Post	2.5%	1.5%	3.5%	7.5%	11.1%	39.9
	Guardrail Face	1.5%	1.5%	2.7%	5.6%	6.7%	7.1
	Other	3.1%	5.4%	10.2%	18.8%	15.3%	-53.8
	TOTAL	**20.7%**	**36.3%**	**43.0%**	**100.0%**	**100.0%**	

Wyoming Rural State Highway (Sept 2006-Aug 2010)							
Roadway Deptarture Crashes		Severity on Curve-Level Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	9.7%	15.9%	12.2%	37.8%	48.3%	508.2
	Fence including Post	1.7%	2.7%	13.4%	17.8%	8.7%	-78.9
	Delineator Post	2.5%	1.7%	6.0%	10.1%	11.6%	17.6
	Guardrail Face	0.4%	1.7%	3.7%	5.8%	2.5%	-8.2
	Earth Embankment or Berm	0.8%	2.1%	2.7%	5.6%	4.4%	-5.1
	Other	5.0%	6.8%	11.2%	22.9%	24.4%	36.6
	TOTAL	**20.0%**	**30.8%**	**49.2%**	**100.0%**	**100.0%**	

A separate analysis was performed on roadway conditions and the presence of rumble strips for the crashes occurring after the 2006 WSHSP, shown in Table 3.11. About 58% of the crashes occurred on dry roadway surfaces. Similar to the curve-downhill findings, about 43% of crashes recorded did not report the presence of rumble strips. No rumble strips were present in the area of the crash in 73% of the crashes reporting the presence of rumble strips (41.7% of the 57.2% reported in the "yes" or "no" categories).

Table 3.11 Road Condition and Rumble Strip Analysis on State Highway Curve-Level Sections

WYOMING Rural STATE HIGHWAY Roadways Roadway Departure Crashes Curve-Level Sections (September 2006 - August 2010)						
		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	23.8%	10.7%	3.1%	0.2%	**37.8%**
	Fence including Post	8.9%	7.0%	1.4%	0.4%	**17.8%**
	Delineator Post	6.8%	2.3%	0.6%	0.4%	**10.1%**
	Guardrail Face	2.5%	2.7%	0.6%	0.0%	**5.8%**
	Earth Embankment or Berm	3.3%	1.7%	0.6%	0.0%	**5.6%**
	Other	13.0%	7.4%	2.1%	0.4%	**22.9%**
	TOTAL	**58.3%**	**31.8%**	**8.5%**	**1.4%**	**100.0%**

		RUMBLE STRIP			
		Yes	No	Un-Reported	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	6.6%	15.1%	16.1%	**37.8%**
	Fence including Post	3.7%	8.1%	6.0%	**17.8%**
	Delineator Post	1.2%	4.3%	4.5%	**10.1%**
	Guardrail Face	1.0%	1.7%	3.1%	**5.8%**
	Earth Embankment or Berm	0.4%	1.7%	3.5%	**5.6%**
	Other	2.5%	11.0%	9.5%	**22.9%**
	TOTAL	**15.5%**	**41.7%**	**42.8%**	**100.0%**

3.3.2.3 Local Roadway Curve-Downhill Sections

This section summarizes the before-after results for roadway departure crashes on local road curve-downhill sections shown in Table 3.12. The before and after WSI values of 664.6 and -80.7, respectively, for rollover crashes indicates a tremendous reduction in their severity. This occurred because the before-after PDO crashes increased by more than10%. The earth embankment crashes were to increase in severity due to a small increase in critical crashes, although total crashes were reduced by almost 6%.

Table 3.12 Local Road Before-After Analysis on Curve-Downhill Sections

Wyoming Rural Local Roadway Crashes (Sept 2002-Aug 2006)							
Roadway Deptarture Crashes		Severity on Curve-Downhill Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	7.4%	22.8%	18.0%	**48.2%**	59.4%	**664.6**
	Earth Embankment or Berm	1.0%	6.8%	8.0%	**15.8%**	9.9%	**-57.8**
	Fence including Post	1.0%	3.2%	8.0%	**12.2%**	8.2%	**-33.0**
	Trees or Shrubbery	0.0%	1.6%	2.6%	**4.2%**	0.9%	**-3.0**
	Non-Collision MC Loss of Control	1.9%	1.0%	1.3%	**4.2%**	12.8%	**111.3**
	Other	1.0%	3.9%	10.6%	**15.4%**	8.7%	**-58.7**
	TOTAL	**12.2%**	**39.2%**	**48.6%**	**100.0%**	100%	

Wyoming Rural Local Roadway Crashes (Sept 2006-Aug 2010)							
Roadway Deptarture Crashes		Severity on Curve-Downhill Sections					
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	WSI
First Harmful Event (FHE)	Overturn or Rollover	5.7%	17.1%	28.6%	**51.4%**	49.8%	**-80.7**
	Fence including Post	0.5%	2.4%	9.0%	**11.9%**	5.1%	**-34.6**
	Earth Embankment or Berm	1.4%	3.3%	5.2%	**10.0%**	11.8%	**21.7**
	Trees or Shrubbery	0.5%	3.8%	5.2%	**9.5%**	5.6%	**-22.0**
	Ditch	0.5%	1.9%	2.4%	**4.8%**	4.4%	**-1.6**
	Other	3.3%	0.0%	9.0%	**12.4%**	23.3%	**254.7**
	TOTAL	**11.9%**	**28.6%**	**59.5%**	**100.0%**	100%	

A separate analysis was performed on roadway conditions and roadway surface for the crashes occurring after the 2006 WSHSP, shown in Table 3.13. As shown, 55% of the crashes occurred on dry roadway surfaces. Also, 68% of all local curve-downhill crashes occurred on unpaved sections. Only the crashes occurring on paved sections could have rumble strips applicable, but rumble strips were not analyzed for local road crashes. It should be noted that 0.5% of the type of road surfaces was unreported.

Table 3.13 Local Road Condition and Road Surface Analysis on Curve-Downhill Sections

WYOMING Rural LOCAL Roadways - Roadway Departure Crashes
Curve-Downhill Sections (September 2006 - August 2010)

		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	33.8%	12.4%	1.0%	4.3%	**51.4%**
	Fence including Post	4.3%	4.8%	1.0%	1.9%	**11.9%**
	Earth Embankment or Berm	5.7%	3.3%	0.5%	0.5%	**10.0%**
	Trees or Shrubbery	2.9%	4.8%	0.5%	1.4%	**9.5%**
	Ditch	2.9%	0.5%	0.5%	1.0%	**4.8%**
	Other	5.2%	5.2%	1.4%	0.5%	**12.4%**
	TOTAL	**54.8%**	**31.0%**	**4.8%**	**9.5%**	**100.0%**

		Road Surface		
		Paved	Unpaved	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	13.8%	37.6%	**51.4%**
	Fence including Post	4.3%	7.6%	**11.9%**
	Earth Embankment or Berm	4.3%	5.7%	**10.0%**
	Trees or Shrubbery	2.9%	6.2%	**9.0%**
	Ditch	1.4%	3.3%	**4.8%**
	Other	4.8%	7.6%	**12.4%**
	TOTAL	**31.4%**	**68.1%**	**99.5%**

The results are consistent with Table 3.7, which shows a large reduction in crash severity for local curve-downhill. This occurred even though the total crash percentage was about 14% higher than the other three geometric sections analyzed. This suggests that the crash severity for these geometric conditions is impacted heavily by the severity of rollover crashes. Thus, finding a way to reduce the severity of rollover crashes should greatly assist in reducing the overall severity of crashes on geometric conditions.

3.3.2.4 Local Roadway Curve-Level Sections

This section summarizes the before-after results for roadway departure crashes on local road curve-level sections shown in Table 3.14. The before and after WSI values of 457.4 and 847.3, respectively, for rollover crashes proves again that they are by far the most harmful roadway departure crash type. In the "after" category, the total and EPDO percentage were reduced but became more severe due to a 2% increase in critical crashes. In fact, about 55% of the rollover crashes were either serious or critical crashes.

Table 3.14 Local Road Before-After Analysis on Curve-Level Sections

Wyoming Rural Local Roadway Crashes (Sept 2002-Aug 2006)								
Roadway Deptarture Crashes		Severity on Curve-LEVEL Sections						
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	**WSI**
First Harmful Event (FHE)	Overturn or Rollover	4.5%	21.0%	18.0%	43.4%	52.2%	**457.4**
	Fence including Post	0.0%	4.5%	12.3%	16.8%	3.8%	**-49.4**
	Earth Embankment or Berm	1.8%	4.8%	8.7%	15.3%	18.7%	**63.6**
	Trees or Shrubbery	0.3%	1.2%	2.7%	4.2%	3.5%	**-2.5**
	Utility Pole or Light Support	0.3%	1.2%	1.5%	3.0%	3.4%	**1.3**
	Other	1.8%	4.2%	11.4%	17.4%	18.5%	**20.9**
	TOTAL	**8.7%**	**36.8%**	**54.5%**	100.0%	100%	

Wyoming Rural Local Roadway Crashes (Sept 2006-Aug 2010)								
Roadway Deptarture Crashes		Severity on Curve-LEVEL Sections						
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO %	**WSI**
First Harmful Event (FHE)	Overturn or Rollover	6.5%	14.2%	17.0%	37.7%	53.5%	**847.3**
	Fence including Post	1.5%	7.7%	15.7%	25.0%	15.8%	**-145.4**
	Earth Embankment or Berm	0.6%	3.1%	7.7%	11.4%	6.4%	**-32.1**
	Trees or Shrubbery	0.9%	1.9%	3.4%	6.2%	7.6%	**10.9**
	Ditch	0.0%	2.5%	2.2%	4.6%	1.5%	**-4.6**
	Other	1.9%	3.4%	9.9%	15.1%	15.2%	**1.9**
	TOTAL	**11.4%**	**32.7%**	**55.9%**	100.0%	100%	

Table 3.15 shows another analysis performed on roadway conditions and roadway surface for the crashes only occurring after the 2006 WSHSP. As shown, 60% of the crashes occurred on dry roadway surfaces. Also, 52% of all local curve-level crashes occurred on unpaved sections. It should be noted that 0.3% of the type of road surface was unreported. The results suggest that some drivers may be driving too fast for weather or surface conditions. Also, the large percent of crashes hitting fences suggest recovery areas or slopes may not be adequate enough for drivers' speeds.

Table 3.15 Local Road Condition and Road Surface Analysis on Curve-Level Sections

WYOMING Rural LOCAL Roadways - Roadway Departure Crashes
Curve-Level Sections (September 2006 - August 2010)

		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	26.2%	5.2%	1.5%	4.6%	**37.7%**
	Fence including Post	11.7%	9.9%	2.2%	1.2%	**25.0%**
	Earth Embankment or Berm	7.4%	2.8%	0.3%	0.9%	**11.4%**
	Trees or Shrubbery	4.0%	1.5%	0.6%	0.0%	**6.2%**
	Ditch	1.9%	0.9%	0.6%	1.2%	**4.6%**
	Other	8.6%	5.6%	0.6%	0.3%	**15.1%**
	TOTAL	**59.9%**	**25.9%**	**5.9%**	**8.3%**	**100.0%**

		Road Surface		
		Paved	Unpaved	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	15.1%	22.5%	**37.7%**
	Fence including Post	12.0%	12.7%	**24.7%**
	Earth Embankment or Berm	4.0%	7.4%	**11.4%**
	Trees or Shrubbery	2.8%	3.4%	**6.2%**
	Ditch	2.5%	2.2%	**4.6%**
	Other	11.1%	4.0%	**15.1%**
	TOTAL	**47.5%**	**52.2%**	**99.7%**

3.4 Section Summary

This section presented the data collection and analysis methods used to evaluate the overall impact WSHSP, as well as the impact of geometric conditions on roadway departure crashes. Implemented in September 2006, the WSHSP was used as a center point for the four-year “before” and “after” analysis. The statewide safety contributions due to the WSHSP contributed to the reductions in the number of critical and serious crashes statewide considerably. The study was conducted on the Wyoming rural interstates, state highways, and local roadways and included eight combinations of geometric conditions. It was concluded that curve-downhill and curve-level crashes on both the rural state highways and local roadways were the most severe geometric combinations in the phase I analysis. The phase II analysis proved that rollover crashes were the most common and severe roadway departure crash type. This indicates that the chance of rollovers and high severity crashes occurring are greatly increased when departing the roadway on horizontal curves.

4. SHOULDER RUMBLE STRIPS

4.1 Introduction

When vehicles depart the travel lane unexpectedly, the crashes are usually severe. This is due to the vehicle departing the travel lane at higher speeds, leaving less time to safely recover. Shoulder rumble strips improve the chances for a vehicle to safely recover when departing the travel lane by providing motorists with an audible and vibrational warning that their vehicle has partially or completely departed from the roadway. Rumble strips also aid in alerting drivers to the lane limits in reduced visibility situations where there are environmental factors such as rain, fog, or snow. This section summarizes the data collection and analysis for determining the effectiveness of the installed SRS on Wyoming's relatively low volume interstates and state highways. Determining if there is a reduction in the severity of roadway departure crashes is the main focus of the analysis.

4.2 Data Collection

The process for collecting data for this analysis was done in two parts. The first step consisted of compiling the plans for the Wyoming rumble strip projects and establishing analysis time periods. The second step included the extraction of the essential crash data from the CARE 9 crash database. The data were extracted only for the exact milepost (MP) locations where SRS were installed on the selected projects. The essential crash data in this research concentrate primarily on the following categories: shoulder rumble strips, crash severity, and run-off-the-road crashes.

4.2.1 Analysis Parameters

A list of all the safety projects implemented in Wyoming since 2002 was used to acquire a list of rumble strip projects. Four of the seven rumble strip projects installed since 2002 were identified as SRS projects. At the time of this evaluation, the CARE 9 crash database was current through September 2010. Two years was deemed the minimum time period required to obtain the necessary amount of crash data for the research to be statistically viable. This is because Wyoming interstates and state highways have relatively low traffic volumes and corresponding low number of crashes. Consequently, only projects with acceptance dates earlier than October 2008 were deemed eligible for analysis. Only two of the four SRS projects (B039019 and B079019), shown in Table 4.1, were included in the analysis using these conditions.

Table 4.1 Wyoming Rumble Strip Projects

WYOMING RUMBLE STRIPS SAFETY PROJECTS (2002-2010)							
Analyzed	Period	Draft Yr	Project	Reason	Shoulder Length (mi)	Tot Proj Cost	Cost/Mile
Yes	**5 YR**	**2005**	**B039019**	**RUMBLE STRIPS**	**385.4**	**$194,029**	**$503**
No	na	2005	B059017	TRANSVERSE RUMBLE STRIPS	na	$89,000	na
Yes	**2YR**	**2007**	**B079019**	**RUMBLE STRIPS**	**207.4**	**$183,805**	**$886**
No	na	2008	B089017	RUMBLE STRIPS	na	$958,037	na
No	na	2010	N203065	RUMBLE STRIPS/FLASHING BEACON	na	$287,461	na
No	na	2010	N203064	RUMBLE STRIPS/FLASHING BEACON	na	$287,485	na
No	na	2010	B099017	RUMBLE STRIPS	na	$423,310	na
				TOTAL FOR ALL RUMBLE PROJECTS	na	$2,423,127	na
				TOTAL FOR ANALYZED PROJECTS	**592.8**	**$377,834**	**$637**

The two projects had a combined cost of $377,834 for the 592.8 shoulder miles of installed rumble strips. The average costs of these two projects were $503 and $886 per mile. There are a few reasons for the difference in cost per mile between the two SRS projects. First, the projects were performed two years apart. Second, while project B039019 was purely on interstates, project B079019 had 69% of the SRS installed on state highways and 31% on interstates.

The crash data were collected for equal, full year, periods directly before the beginning of construction and directly after the acceptance of the project. This method eliminated the possibility of skewed data from changes in driver behavior during the construction of the projects. Each section of roadway analyzed was tracked by its district, route, direction, and the exact beginning and ending MP locations where rumble strips were installed.

The length of each beginning MP was rounded down to the nearest tenth of a mile and length of each ending MP was rounded up to the nearest tenth of a mile. Any segment of applied SRS that was less than half a mile was not analyzed. Also, the crash data for each section were extracted separately to determine if there were specific sections that had unusually high crash frequencies. This was done to prevent possible skewed data due to the relatively low traffic volumes and the unpredictability of roadway departure crashes.

The first project (B039019) in this research was analyzed using a five-year before-after period. In project B039019, the rumble strips were installed only on interstate segments. Table 4.2 shows the district, route, direction, beginning and ending MP locations, and section lengths.

The second project analyzed in this research was B079019. A two-year before-after analysis period was established for this project based on the construction start date and project acceptance date. Rumble strips in this project were installed on both state highway and interstate segments statewide, and were separated accordingly. The exact analysis dates, along with the details of the analyzed sections, are shown in Table 4.3.

Table 4.2 5-Year Interstate Rumble Strip Analysis Segments

Proj Pre		ACSTP-H		Analysis Period		
Project		B039019				
Begin Date		27-Jul-05		5 Yr Before	01-Jul-00	30-Jun-05
Acceptance Date		23-Sep-05		5 Yr After	1-Oct-05	16-Sep-10
INTERSTATE						
ML	Dist	Route	Direc	Begin MP	End MP	Length (mi)
ML 80 I	3	I-80	E	57.0	65.5	8.5
ML 80 D	3	I-80	W	57.0	65.5	8.5
ML 80 I	3	I-80	E	107.6	120.3	12.7
ML 80 D	3	I-80	W	107.6	120.3	12.7
ML 80 I	3	I-80	E	130.0	138.0	8.0
ML 80 D	3	I-80	W	130.0	138.0	8.0
ML 80 I	1	I-80	E	227.4	233.8	6.4
ML 80 D	1	I-80	W	227.9	233.8	5.9
ML 80 I	1	I-80	E	246.5	253.3	6.8
ML 80 I	1	I-80	E	263.6	275.4	11.8
ML 80 D	1	I-80	W	263.6	275.4	11.8
ML 80 D	1	I-80	W	291.4	300.6	9.2
ML 80 I	1	I-80	E	291.4	302.9	11.5
ML 80 I	1	I-80	E	336.6	349.0	12.4
ML 80 D	1	I-80	W	336.6	349.0	12.4
ML 25 I	1	I-25	N	16.5	17.3	0.8
ML 25 D	1	I-25	S	16.5	17.3	0.8
ML 25 I	1	I-25	N	25.5	31.1	5.6
ML 25 D	1	I-25	S	25.5	31.1	5.6
ML 25 I	2	I-25	N	166.9	174.9	8.0
ML 25 D	2	I-25	S	166.9	174.9	8.0
ML 25 I	4	I-25	N	283.2	284.4	1.2
ML 25 D	4	I-25	S	284.2	285.1	0.9
ML 90 I	4	I-90	E	19.8	22.8	3.0
ML 90 D	4	I-90	W	20.4	22.3	1.9
ML 90 I	4	I-90	E	29.4	40.6	11.2
ML 90 D	4	I-90	W	28.3	40.3	12.0
ML 90 D	4	I-90	W	57.2	58.8	1.6
ML 90 I	4	I-90	E	80.2	81.8	1.6
ML 90 I	4	I-90	E	87.3	88.1	0.8
ML 90 D	4	I-90	W	83.6	85.1	1.5
ML 90 D	4	I-90	W	96.5	97.1	0.6
ML 90 D	4	I-90	W	129.7	135.8	6.1
ML 90 I	4	I-90	E	129.8	135.7	5.9

Table 4.3 2-Year Interstate and State Highway Rumble Strip Analysis Segments

Proj Pre	HISP		Analysis Periods			
Project	B079019					
Begin Date	12-Jun-08		2 Yr Before	01-Jun-06	31-May-08	
Acceptance Date	15-Sep-08		2 Yr After	17-Sep-08	16-Sep-10	
INTERSTATE						
ML	**Dist**	**Route**	**Direc**	**Begin MP**	**End MP**	**Length (mi)**
ML 25 I	4	I-25	N	272.0	279.9	7.90
ML 25 D	4	I-25	S	272.0	279.9	7.90
ML 80 I	3	I-80	E	28.0	28.6	0.60
ML 80 I	3	I-80	E	139.6	141.0	1.40
ML 80 I	1	I-80	E	251.1	255.4	4.30
ML 80 I	1	I-80	E	300.4	302.8	2.40
ML 80 D	1	I-80	W	308.1	308.7	0.60
ML 80 I	1	I-80	E	329.1	336.2	7.10
ML 80 D	1	I-80	W	329.1	336.2	7.10
ML 80 I	1	I-80	E	356.7	357.7	1.00
ML 80 D	1	I-80	W	356.7	357.7	1.00
STATE HIGHWAYS						
ML	**Dist**	**Route**	**Direc**	**Begin MP**	**End MP**	**Length (mi)**
ML 1004 B	4	US 16	B	5.0	17.8	12.80
ML 44 B	4	US 16	B	220.9	233.3	12.40
ML 45 B	4	US 18	B	0.0	2.3	2.30
ML 34 B	5	US 20/26	B	50.6	59.1	8.50
ML 12 B	3	US 30	B	6.3	10.4	4.10
ML 12 B	3	US 30	B	25.3	30.8	5.50
ML 85 B	4	US 85	B	202.0	219.5	17.50
ML 32 B	5	WYO 114	B	29.8	34.2	4.40
ML 26 B	1	WYO 230	B	12.0	12.6	0.60
ML 42 B	2	WYO 387	B	93.6	109.0	15.40

4.2.2 Data Extraction

The area of interest for this research entailed only the crash severity and ROR locations of the crashes. The three crash severity categories for this research are the same as used in Section 3: critical, serious, and PDO. Appendix C1 shows the raw crash numbers that were extracted, by severity, on the sections where SRS were installed.

The ROR crashes are broken into two categories for state highways and three for interstates. Roadway departure, median, and shoulders are the three interstate ROR categories. The “median” category was removed from the state highway analysis since all the sections analyzed were on undivided two-lane highways. Appendix C2 shows that the raw crash numbers for the ROR categories listed above were extracted on the sections where SRS were installed.

Due to the notable difference in roadway volumes between interstates and state highways in Wyoming, the crash data were analyzed separately for the two functional classifications. Table 4.4 shows the number of crashes, by severity type, on the state highway sections.

Table 4.4 Example of Crash Severity Numbers Obtained from CARE 9 Crash Database

ROADWAY DATA				State Highway Crash Severity (#'s)									
Route	Begin MP	End MP	Length (mi)	Critical		Serious		PDO		Total		Critical+Serious	
				Before	After	Before	After	Before	After	Before	After	Before	After
ML 1004 B	5.0	17.8	12.8	0	0	0	1	6	7	6	8	0	1
ML 44 B	220.9	233.3	12.4	6	0	4	3	12	8	22	11	10	3
ML 45 B	0.0	2.3	2.3	0	0	1	0	0	1	1	1	1	0
ML 34 B	50.6	59.1	8.5	4	0	6	1	13	6	23	7	10	1
ML 12 B	6.3	10.4	4.1	0	0	3	1	3	5	6	6	3	1
ML 12 B	25.3	30.8	5.5	1	2	0	0	2	3	3	5	1	2
ML 85 B	202.0	219.5	17.5	1	1	2	2	9	4	12	7	3	3
ML 32 B	29.8	34.2	4.4	0	0	1	1	4	5	5	6	1	1
ML 26 B	12.0	12.6	0.6	0	0	0	0	0	0	0	0	0	0
ML 42 B	93.6	109.0	15.4	2	0	0	1	15	6	17	7	2	1
TOTALS			83.5	14	3	17	10	64	45	95	58	31	13
Crash Reduction due to Rumble Strips				79%		41%		30%		39%		58%	

4.3 Data Analysis

The data were analyzed in two steps. The first step organized the collected data for analysis. The second step statistically analyzed the data in each category by functional classification due to the typical difference in roadway volumes.

The first step in the data analysis converted crashes to crashes per mile for every section. These tables are shown in Appendix C1 and C2 for crash severity and ROR crashes, respectively. This was done by dividing the number of crashes by the segment length for every data set analyzed. This canceled out variation in the data due to different section lengths. The final product of the data preparation for the crash severity on the state highway sections is shown in Table 4.5. The data were prepared in the same way for every analysis.

Table 4.5 Example of Segment Crash/Mile Analysis by Crash Type

ROADWAY DATA				2 Yr - State Highway Crash Severity (crashes/mile)									
Route	Begin MP	End MP	Length (mi)	Critical		Serious		PDO		Total		Critical+Serious	
				Before	After	Before	After	Before	After	Before	After	Before	After
ML 1004 B	5.0	17.8	12.8	0.00	0.00	0.00	0.08	0.47	0.55	0.47	0.63	0.00	0.08
ML 44 B	220.9	233.3	12.4	0.48	0.00	0.32	0.24	0.97	0.65	1.77	0.89	0.81	0.24
ML 45 B	0.0	2.3	2.3	0.00	0.00	0.43	0.00	0.00	0.43	0.43	0.43	0.43	0.00
ML 34 B	50.6	59.1	8.5	0.47	0.00	0.71	0.12	1.53	0.71	2.71	0.82	1.18	0.12
ML 12 B	6.3	10.4	4.1	0.00	0.00	0.73	0.24	0.73	1.22	1.46	1.46	0.73	0.24
ML 12 B	25.3	30.8	5.5	0.18	0.36	0.00	0.00	0.36	0.55	0.55	0.91	0.18	0.36
ML 85 B	202.0	219.5	17.5	0.06	0.06	0.11	0.11	0.51	0.23	0.69	0.40	0.17	0.17
ML 32 B	29.8	34.2	4.4	0.00	0.00	0.23	0.23	0.91	1.14	1.14	1.36	0.23	0.23
ML 26 B	12.0	12.6	0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ML 42 B	93.6	109.0	15.4	0.13	0.00	0.00	0.06	0.97	0.39	1.10	0.45	0.13	0.06

The second step analyzed the data statistically. A one-tailed t-test was the statistical approach used to analyze the crash data. This analysis was selected to test the difference between two population means using matched pairs. The u_1 and u_2 were set up to represent the population means for the crashes per mile of the "before" and "after" categories, respectively. The statistical approach of a one-tailed t-test was used to detect if there was a decrease in crashes per mile after the installation of the rumble strips. The matched pairs were the two-year and five-year analysis periods "before" and "after" the rumble strip installations. Using full years minimized the possibility of variance due to weather related issues. Also, even if there were zero crashes recorded for one of the crash categories in a section, it was still included as part of the t-test. This was done to maintain the validity of the analysis when determining the impact of the rumble strips.

The two statistical values used to interpret the results of the analyses in this research were the test statistic and the p-value. The test statistic has a t distribution based on the degrees of freedom (n - 1). The degrees of freedom vary for each analysis depending on the number of sections (n) where rumble strips were installed. The critical t value for a one tailed test is based on a 95% confidence interval ($\alpha = 0.05$) for all analyses. If the test statistic exceeds the critical value, it means there is sufficient evidence (at $\alpha = 0.05$) to indicate that the mean crashes per mile were reduced due to the installation of rumble strips. The interpretations of the p-value for a one-tailed t-test (Mendenhall & Sincich 2007) are shown in Table 4.6.

Table 4.6 P-value Interpretation

P-value	Interpretation
P< 0.01	very strong evidence against H0
0.01< = P < 0.05	moderate evidence against H0
0.05< = P < 0.10	suggestive evidence against H0
0.10< = P	little or no real evidence against H0

H_0: $(\mu_1 - u_2) = 0$

H_A: $(\mu_1 - u_2) > 0$

Where:

P = p-value
H_o= Null hypothesis
H_A= Alternate hypothesis
u_1 = "before" category population mean
u_2 = "after" category population mean

The null-hypothesis assumes that there is no change in crashes due to the implementation of SRS. The alternate hypothesis assumes there is a reduction in crashes due to the implementation of SRS. Rather than perform these calculations by hand, Microsoft Excel was used to obtain the analysis results.

4.3.1 Analysis of Interstate Sections

There were six separate analyses performed on the data for the interstate sections. The crashes were analyzed by crash types (severity and ROR) for both the two-year and five-year projects. The results from the two-year and five-year before-after analyses were then compared against each other by crash category. This was done to provide better conclusions by determining the differences between the two results. The last two analyses combined the severity and ROR categories together.

The two-year and five-year crash severity analysis results for the interstate sections are shown in Table 4.7. The crash severity analysis included all crashes, not just the ROR crashes.

Table 4.7 Interstate One-Tailed T-Test Before-After Crash Severity Analysis

Statistical Categories	5 Year Interstate Crash Severity (Crashes/Mile)									
	Critical		Serious		PDO		Total		Critical+Serious	
	Before	After	Before	After	Before	After	Before	After	Before	After
Mean	0.780	0.482	1.653	1.476	5.904	6.824	8.336	8.782	2.433	1.958
Variance	0.424	0.183	1.265	0.950	10.130	15.811	18.586	23.745	2.407	1.545
Observations	34	34	34	34	34	34	34	34	34	34
Pearson Correlation	0.362		0.682		0.734		0.753		0.665	
df	33		33		33		33		33	
t Stat	2.723		1.222		-1.977		-0.793		2.351	
P(T<=t) one-tail	0.005		0.115		0.028		0.217		0.012	
t Critical one-tail	1.692		1.692		1.692		1.692		1.692	
	2 Year Interstate Crash Severity (Crashes/Mile)									
Mean	0.422	0.179	1.484	0.504	5.089	3.288	6.995	3.971	1.907	0.683
Variance	0.405	0.074	1.692	0.313	14.016	5.610	23.775	7.228	1.706	0.568
Observations	11	11	11	11	11	11	11	11	11	11
Pearson Correlation	-0.266		0.533		0.653		0.698		0.544	
df	10		10		10		10		10	
t Stat	1.067		2.935		2.106		2.814		3.699	
P(T<=t) one-tail	0.156		0.007		0.031		0.009		0.002	
t Critical one-tail	1.812		1.812		1.812		1.812		1.812	

The results from the two- and five-year before-after interstate analysis in Table 4.7 indicate that critical and serious crashes combined were reduced as a result of installing the SRS. The two-year before-after analysis results indicated a crash rate reduction in every severity category except the critical category. The results also indicated that crash frequencies in the serious, PDO, and total crash categories were not reduced in the five-year analysis. The reason the PDO and total crash category test statistic results were negative in the five-year analysis is because PDO and total crashes increased on those sections after the installation of the SRS.

As previously noted, the primary purpose of implementing SRS is to reduce the severity of ROR crashes. Table 4.8 shows the crash reduction percentages by severity based on the number of ROR crashes. Appendix C3 shows the raw data for Table 4.8.

Table 4.8 Interstate Before-After Crash Reduction Analysis: Crash Severity vs. ROR Categories

Crash Severity v. ROR Category	**Interstate 5 YR Before-After Crash Reduction (%)**				
	CRITICAL	SERIOUS	PDO	**TOTAL**	C + S
Road Departure	47%	25%	-20%	**0%**	31%
Shoulder	56%	-16%	3%	**6%**	11%
Median	38%	7%	-35%	**-13%**	19%
TOTAL	**45%**	**10%**	**-20%**	**-3%**	**22%**

Crash Severity v. ROR Category	**Interstate 2 YR Before-After Crash Reduction (%)**				
	CRITICAL	SERIOUS	PDO	**TOTAL**	C + S
Road Departure	50%	41%	17%	**27%**	42%
Shoulder	0%	55%	44%	**46%**	50%
Median	25%	61%	34%	**43%**	55%
TOTAL	**29%**	**52%**	**31%**	**38%**	**49%**

Table 4.8 shows that critical and serious crashes combined were reduced by 22% in the five-year analysis and 49% in the two-year analysis. The PDO and total crashes increased in the five-year analysis following the installation of SRS as indicated in Table 4.7. Overall, these results suggest that the SRS installations are effectively reducing high severity crashes on Wyoming's relatively low volume interstates.

The two-year and five-year before-after ROR analysis results from the interstate sections are shown in Table 4.9. The results from the five-year before-after interstate analysis indicated that the ROR crash rates were not reduced in any category. This is because the PDO crashes increased enough in each ROR category to indicate that the number of total crashes was not reduced, as shown in Table 4.8. The analysis results indicate that while SRS may not reduce the total number of ROR crashes, they effectively reduce the severity of crashes.

Table 4.9 Interstate One-Tailed T-Test Before-After ROR Analysis

Statistical Categories	5 Year Interstate ROR Crash Location (Crashes/Mile)							
	Roadway Departure		Shoulder		Median		Total	
	Before	After	Before	After	Before	After	Before	After
Mean	1.973	1.912	1.016	0.885	1.586	1.547	4.575	4.344
Variance	2.756	1.804	0.750	0.439	1.803	1.519	10.115	6.997
Observations	34	34	34	34	34	34	34	34
Pearson Correlation	0.665		0.616		0.254		0.649	
df	33		33		33		33	
t Stat	0.281		1.102		0.144		0.541	
P(T<=t) one-tail	0.390		0.139		0.443		0.296	
t Critical one-tail	1.692		1.692		1.692		1.692	
	2 Year Interstate ROR Crash Location (Crashes/Mile)							
Mean	1.573	0.898	0.829	0.576	1.030	0.991	3.433	2.465
Variance	1.059	0.579	0.585	0.592	1.646	0.979	6.571	2.808
Observations	11	11	11	11	11	11	11	11
Pearson Correlation	0.462		0.391		0.002		0.546	
df	10		10		10		10	
t Stat	2.340		0.993		0.081		1.482	
P(T<=t) one-tail	0.021		0.172		0.468		0.085	
t Critical one-tail	1.812		1.812		1.812		1.812	

4.3.2 Analysis of State Highway Sections

The data analyzed for the state highway sections were the severity and ROR crash categories. Unlike the interstate sections, SRS were only implemented on state highway sections in one of the two analyzed projects. This resulted in only one analysis for each crash category. The results of the two-year before-after severity analysis for the state highway SRS sections are shown in Table 4.10.

Table 4.10 State Highway One-Tailed t-Test Before-After Crash Severity Analysis

Statistical Categories	2 Year State Highway Crash Severity (Crashes/Mile)									
	Critical		Serious		PDO		Total		Critical+Serious	
	Before	After	Before	After	Before	After	Before	After	Before	After
Mean	0.132	0.042	0.254	0.109	0.646	0.585	1.031845	0.73611	0.386	0.151
Variance	0.037	0.013	0.083	0.010	0.226	0.140	0.627833	0.202264	0.156	0.014
Observations	10	10	10	10	10	10	10	10	10	10
Pearson Correlation	0.069		0.499		0.501		0.515045		0.201	
df	9		9		9		9		9	
t Stat	1.315		1.804		0.443		1.374		1.914	
P(T<=t) one-tail	0.111		0.052		0.334		0.101		0.044	
t Critical one-tail	1.833		1.833		1.833		1.833		1.833	

The results show that the crash frequencies were reduced due to the SRS when the critical and serious crash categories were combined. However, when analyzed individually, the critical, serious, PDO, and total severity categories in Table 4.10 did not indicate that the SRS reduced crash severity.

Table 4.11 shows the crash reduction percentages by severity based on the number of ROR crashes for the state highway sections. The raw data from Table 4.11 are shown in Appendix C3.

Table 4.11 2-Year State Highway Before-After Crash Reduction Analysis: Crash Severity vs. ROR Categories

Crash Severity v. ROR Category	State Highway 2 YR Before-After Crash Reduction (%)				
	CRITICAL	SERIOUS	PDO	**TOTAL**	C + S
Road Departure	100%	60%	50%	**68%**	82%
Shoulder	0%	50%	75%	**70%**	50%
TOTAL	**100%**	**57%**	**63%**	**69%**	**77%**

Opposed to Table 4.10, the results in Table 4.11 indicate that the crash severity was reduced in all five crash severity categories as well as both ROR categories. The most notable findings from Table 4.11 was that 100% of all critical crashes and 77% of all severe crashes were eliminated due to the installation of SRS.

The two-year before-after analysis results for ROR crashes per mile on the state highway sections are shown in Table 4.12.

Table 4.12 State Highway One-Tailed T-Test Before-After ROR Analysis

Statistical Categories	2 Year State Highway ROR Location (Crashes/Mile)					
	Roadway Departure		Shoulder		Total	
	Before	After	Before	After	Before	After
Mean	0.227	0.067	0.096	0.026	0.322	0.094
Variance	0.113	0.009	0.034	0.002	0.255	0.017
Observations	10	10	10	10	10	10
Pearson Correlation	0.497		0.895		0.712	
df	9		9		9	
t Stat	1.683		1.511		1.714	
P(T<=t) one-tail	0.063		0.083		0.060	
t Critical one-tail	1.833		1.833		1.833	

All three ROR categories indicate that there is a reduction in crash frequency due to the SRS from the p-value results in Table 4.12. Table 4.11, however, showed evidence that SRS reduce ROR crashes and crash severity. The most likely reason for the discrepancies in the analysis results is the low number of crashes on the analyzed state highway sections, as shown in Appendix C3. Overall, the results suggest that the installation of SRS is reducing high severity crashes on Wyoming state highways.

4.1 Section Summary

This section presented the data collection and analysis used to evaluate the effectiveness of SRS on reducing ROR crashes. The CARE 9 database was the tool utilized to obtain the crash data. Only two of seven rumble strip projects installed on Wyoming roadways between 2005 and 2010 met the criterions to be analyzed for this research. A before-after analysis period was established for each project. The crash data were analyzed statistically using a one-tailed t-test on the severity and ROR crash types by crashes per mile. These analyses were performed for interstate and state highway separately due to the typical difference in traffic volumes. The results of the analyses suggest that crash severity was reduced on both the interstate and state highway sections due to SRS installation.

5. CABLE MEDIAN BARRIERS

5.1 Introduction

Cross-median crashes occur when the vehicles go through the median and crash with a vehicle in the opposing traveled lane. These crashes have been proven to have an extremely high crash severity frequency. Cable median barriers help prevent severe crashes by containing or redirecting errant vehicles that enter the median by keeping them from encountering terrain features and roadside objects or entering opposing travel lanes. This chapter includes the data collection and analysis for determining the effectiveness of cable median barriers on Wyoming's relatively low volume interstates. Determining if there is a reduction in the severity of ROR crashes is the main focus of the analysis.

5.2 Data Collection

There were two major steps in the data collection process. The first step included obtaining all the Wyoming cable median barrier project plans and selecting the analysis time periods. The second step included extracting the essential crash data from the CARE 9 crash database for the precise locations where the cable median barrier was installed on the selected projects. The essential crash data in this research concentrate primarily on the following categories: cable median barrier, median and cross-median crashes, and crash severity.

5.2.1 Analysis Parameters

The first step in collecting the data was obtaining information on five cable median barrier projects constructed statewide between 2006 and 2007. WYDOT provided the plans for all the projects. The acceptance date was found for each project to determine which projects could be used in the analysis.

At the time of the study, the CARE 9 crash database was current through September 16, 2010. Since all five projects were constructed within such a close timeframe, a two-year "before" and "after" time period was utilized to analyze every project. This method minimized the possibility of skewed data from weather, changes in average annual daily traffic (AADT), and construction. Thus, the "before" analysis period began two years from the beginning of project construction, and the two-year "after" analysis period, which started September 16, 2008. Four of the five cable median barrier projects were initially accepted for analysis based on this method. Project B061082 was also accepted for analysis even though its acceptance date was October 13, 2008. It was assumed that the project would have been mostly completed by the end of September and would minimally affect crash data for the two-year "after" analysis. Therefore, all five projects were accepted for analysis and their details are shown in Table 5.1. It should be noted that the median widths of the projects were not in the project plans and were not disclosed by WYDOT.

Table 5.1 Wyoming Cable Median Barrier Projects

WY Cable Median Barrier Projects				
Project	Begin Date	Accept Date	TOTAL Miles	Tot Proj Cost
251159	12-Apr-07	26-Oct-07	10.6	$728,125
B061082	21-Aug-07	13-Oct-08	35.6	$2,591,500
I253110	12-Apr-07	26-Oct-07	8.0	$569,359
B063083	22-May-07	26-Jun-08	40.0	$2,837,606
B069084	25-Jun-07	20-Feb-08	8.6	$1,039,979
PROJECT TOTALS			**102.80**	**$7,766,569**

5.2.2 Data Extraction

The second step of the data collection was to extract the crash data from the CARE 9 crash database for the exact locations where cable median barriers were installed. The locations given in the CARE 9 database are only accurate to one-tenth of a mile. Thus the length of each beginning mile post was rounded down to the nearest tenth of a mile and length of each ending mile post was rounded up to the nearest tenth of a mile. All of the individual section lengths for each project were summed and displayed in Table 5.1.

The crash categories used for the analysis was the first harmful event (FHE) and the FHE locations. These crash categories were combined to enhance the analysis. Table 5.2 is an example of the raw data output from the CARE 9 crash database for these combined categories. The only FHE locations necessary for the analysis were those pertaining to median or cross-median crashes, thus the “median” and “on other roadway” were retained. Appendix D1 shows all the raw total crash data for these categories. Similarly, the only FHE categories necessary for the analysis were those pertaining to fixed objects and rollover crashes. The “overturn or rollover” category, along with every category considered to be a fixed object, was retained. The “other fixed objects” category was established to help determine how cable barriers impact crashes by shielding fixed objects in the median, such as culvert ends for example.

The data were extracted for each of the three severity categories utilized in Sections 3 and 4: critical, serious, and PDO. This was done so it would be possible to determine how crash severity was affected due to the installation of cable median barriers. Appendix D2 shows the raw crash data separated into the three severity categories.

Table 5.2 Example of Raw Data Extracted from CARE 9 Crash Database

ALL FHE v. FHE Location Crashes on Project Sections BEFORE Cable Median Barrier Implemenation							
	On Roadway	Off Roadway	Shoulder	Median	On OTHER Roadway	Outside of ROW	**TOTAL**
Overturn or Rollover	259	490	277	543	5	5	**1598**
Fire or Explosion	50	2	15	0	1	0	**69**
Fell or Jumped from a MV	0	0	1	0	0	0	**1**
Other Non-Collision MC Loss of Control	186	84	48	148	0	2	**491**
Pedestrian	4	1	1	0	0	0	**6**
Pedacycle	1	0	0	0	0	0	**1**
Motor Vehicle in Transport on Roadway	1299	11	13	13	5	1	**1400**
Motor Vehicle in Transport on OTHER Roadway	11	0	0	0	9	0	**20**
Parked Motor Vehicle	28	20	43	6	4	0	**103**
Other NON-Fixed Object	115	2	2	8	0	1	**142**
Cow	3	0	0	0	0	0	**3**
Sheep	1	0	0	0	0	0	**1**
Other Domestic eg Dog Llama...	2	0	0	0	0	0	**2**
Elk	30	0	0	0	0	0	**30**
Deer	757	5	3	1	0	0	**988**
Moose	3	0	0	0	0	0	**3**
Antelope	33	1	0	0	0	0	**40**
Buffalo	0	0	0	0	0	0	**0**
Other Wild	11	1	0	0	0	0	**12**
Guardrail End	0	18	18	16	0	0	**52**
Guardrail Face	4	211	152	298	0	1	**686**
Bridge Overhead Structure	5	24	10	2	0	0	**42**
Bridge Rail	2	25	16	2	0	0	**45**
Utility Pole or Light Support	0	8	5	4	0	0	**17**
Traffic Sign Support	0	3	1	0	0	0	**4**
Other Traffic Sign Support	6	46	28	7	0	2	**89**
Barricade	11	16	2	11	0	0	**41**
Trees or Shrubbery	0	12	3	1	0	0	**16**
Cut Slope	0	4	1	3	0	0	**8**
Road Approach	0	0	0	2	0	0	**2**
Rock Boulder Rock Slide	0	5	2	2	0	0	**10**
End of Drainage Pipe or Structure or Culvert	0	7	3	5	0	0	**15**
Building or Other Structure Wall	0	8	1	1	0	0	**10**
Fence including Post	1	114	35	12	0	2	**173**
Delineator Post	2	94	88	54	0	0	**245**
Earth Embankment or Berm	0	69	14	21	0	1	**111**
Snow Embankment	0	3	3	1	0	0	**7**
Other Fixed Object	3	13	2	9	0	0	**29**
Cable Barrier	0	0	0	0	0	0	**0**
TOTAL	**2827**	**1297**	**787**	**1170**	**24**	**15**	**6512**

5.3 Data Analysis

The data were analyzed in two steps. The first step separated out only the pertinent information relating to the analysis from the collected data. The second step analyzed the cable median barrier effectiveness, as well as determining its societal benefits. The analysis is purely a descriptive analysis of the data where no formal statistical analysis was performed.

The WYDOT planning department keeps tabs on the average annual daily traffic (AADT) for a majority of the interstate and state highway sections maintained by WYDOT. Although the AADT for the Wyoming interstate sections varies by month and location, they have remained relatively constant over the past five years. Over the past five years, the AADT on I-80 (13,500) was approximately twice the AADT of I-25 (7,500) and I-90 (7,000).

The first analysis that was performed combined the crashes from I-25 and I-90, since they had similar AADTs, while leaving the I-80 crashes alone. I-80 had 75.6 miles of cable barrier installed, while I-25 and I-90 combined only had 27.2 miles installed. To equalize the difference in volume and miles of installed cable barrier, the data were analyzed using crashes per mile. It was thought the difference in AADT between the two categories would result in about double the crashes per mile on I-80. However, the analysis revealed that the two categories had very similar trends in crashes per mile. As a result, there was no reason to analyze the interstate sections separately; therefore, all interstate sections with cable median barrier installed are analyzed together.

5.3.1 Crash Analysis

The scope of this research is to analyze the effectiveness of the cable median barrier systems in reducing fatal and serious injury roadway departure crashes. Thus, the critical and serious crash severity categories were separated from the PDO crashes for the analysis. Once the data not pertinent to the analysis were removed from Table 5.2, the data were separated into the two severity categories: critical and serious crashes. Table 5.3 shows the two-year before-after crash numbers for critical and serious crashes. The median and cross-median crashes were kept separated. The data were presented this way to give the best representation of the severity and location of every crash.

Table 5.3 Crash Data Relating To Cable Median Barrier Analysis

CRITICAL & SERIOUS		BEFORE		AFTER	
		Critical	Serious	Critical	Serious
Median	Rollover	101	205	58	137
	Cable Median Barrier	0	0	3	27
	ALL Other Fixed Objects	39	61	22	73
	TOTAL MEDIAN	**140**	**266**	**83**	**237**
Cross Median	Rollover	3	2	0	3
	Vehicle on Other Road	11	6	3	2
	TOTAL CROSS-MEDIAN	**14**	**8**	**3**	**5**
TOTAL CRASHES		**154**	**274**	**86**	**242**

A graphical depiction of the number of critical and serious crashes from Table 5.3 is shown in Figure 5.1. The median and cross-median rollover crashes were combined to show the cable median barrier impact. The number of cable median barrier crashes was also shown as a part of the median and fixed object categories.

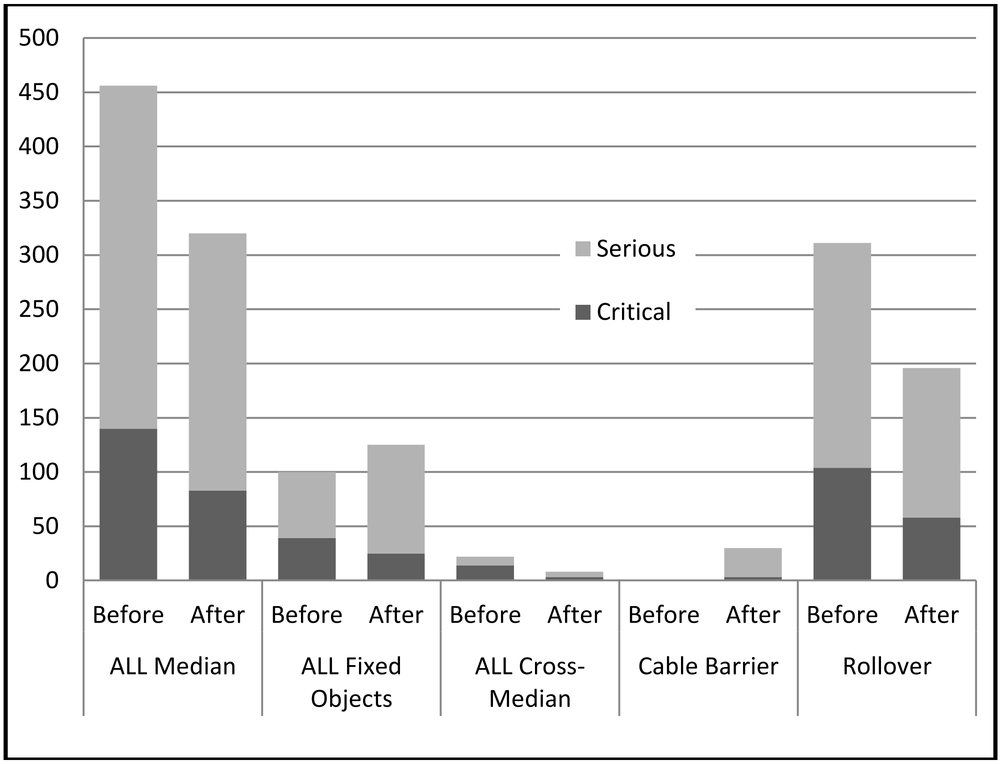

Figure 5.1 Before-After Comparison of Cable Median Barrier Crashes/Mile

The difference in the number of crashes before and after the cable median barrier system implementation, and the corresponding crash reduction percentages are shown in Table 5.4. The crash reduction percentages were calculated for both critical and serious crashes, as well as both crash severities combined. The number of critical cross-median crashes with vehicles on the other road was reduced by 79%. The critical and serious rollover crashes in the median were reduced by 43% and 33%, respectively. The number of critical crashes in the median was reduced by 41%. The overall numbers of critical and serious crashes in the analysis were reduced by 44% and 12%, respectively, and by a combined 23%.

Table 5.4 Crash Data Relating To Cable Median Barrier Analysis

CRITICAL & SERIOUS		Crash Difference (#)			Crash Reduction (%)		
		Critical	Serious	Combined	Critical	Serious	Combined
Median	Rollover	-43	-68	-111	43%	33%	**36%**
	Cable Median Barrier	3	27	30	na	na	**na**
	ALL Other Fixed Objects	-17	12	-5	44%	-20%	**5%**
	TOTAL MEDIAN	**-57**	**-29**	**-86**	**41%**	**11%**	**21%**
Cross Median	Rollover	-3	1	**-2**	100%	-50%	**40%**
	Vehicle on Other Road	-8	-4	**-12**	73%	67%	**71%**
	TOTAL CROSS-MEDIAN	**-11**	**-3**	**-14**	**79%**	**38%**	**64%**
TOTAL		**-68**	**-32**	**-100**	**44%**	**12%**	**23%**

The PDO crashes were analyzed separately from the critical and serious crashes. When implementing cable median barriers, agencies have reported the number of PDO crashes increasing by up to five times. This happens because vehicles that previously could have recovered in the median undamaged now strike the cable barrier, resulting in damage to the vehicle and the cable barrier. Table 5.5 shows the PDO crash numbers before and after cable median barrier installation and the resulting change in crash percentages for each crash type.

T**able 5.5** Difference in PDO Before-After Crash Numbers

PDO		BEFORE	AFTER	Crash Difference (#)	Crash Reduction (%)
Median	Rollover	237	205	-32	14%
	Cable Median Barrier	0	332	332	na
	ALL Other Fixed Objects	311	310	-1	0%
	TOTAL MEDIAN	**548**	**847**	**299**	**-55%**
Cross Median	Rollover	0	1	1	na
	Vehicle on Other Road	8	4	-4	50%
	TOTAL CROSS-MEDIAN	**8**	**5**	-3	**38%**
TOTAL CRASHES		**556**	**852**	**296**	**-53%**

There were 332 PDO crashes that were caused by the cable median barriers. They were the primary contributor in the resulting 55% increase in median crashes and 53% increase in total PDO crashes. This increase is significantly smaller than the agencies that reported increases up to five times the PDO crashes after cable median barrier installation. The most likely explanation is the relatively low traffic volumes on the interstate sections. Despite the overall increase in PDO crashes, the number of rollover, cross-median, and all other fixed-object crashes decreased over the two-year analysis period. This indicates that while cable median barriers inherently increase the number of PDO crashes, they enhance the safety of travelers. A graphical depiction of the number of critical and serious crashes from Table 5.4 is shown in Figure 5.2. The categories are the same as those explained for Figure 5.1.

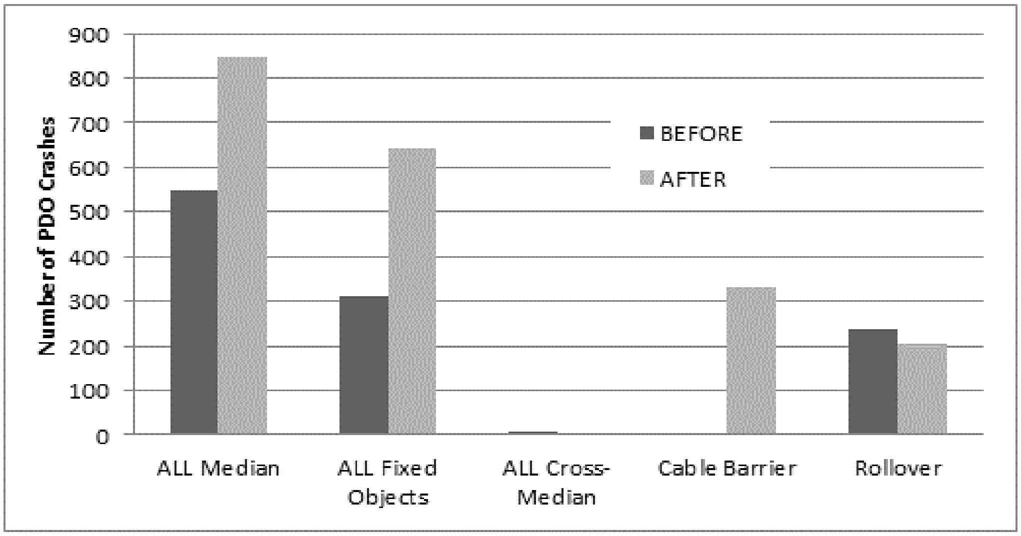

Figure 5.2 PDO Crashes by Category

5.3.2 Societal Benefits

Societal benefits are costs to society that are saved by the installation of safety devices that prevent crashes. Documented mean comprehensive societal costs were assigned by severity in a 2005 FHWA report using costs representing 2001 dollar values. The 2010 HSM adjusted each severity cost to a dollar value for 2007. The HSM comprehensive crash costs were averaged against the number of Wyoming crashes from 2000-2009 in the critical and serious categories. Table 5.6 shows the resulting weighted comprehensive costs for the three crash severity categories.

Table 5.6 Wyoming Crash Cost by Severity Type

CRASH SEVERITY		WY Crashes (2000-09)	HSM Comprehensive Crash Costs (2007)	Weighted Comp. Crash Cost
CRITICAL	K	1428	$ 4,810,700.00	$ 976,667.93
	A	7631	$ 259,200.00	
SERIOUS	B	16847	$ 94,800.00	$ 75,386.24
	C	15222	$ 53,900.00	
PDO		118115	$ 8,900.00	$ 8,900.00

The first step in determining societal benefits was finding the difference in the total “before” and “after” median and cross-median crashes for each crash severity category. The difference in each category was then multiplied by its respective weighted comprehensive crash cost shown in Table 5.6. The total societal savings due to the cable median barrier system installation are shown in Table 5.7.

Table 5.7 Yearly Societal Savings by Cable Median Barrier Implementation

Comparison of ALL Crashes	BEFORE	AFTER	Difference	Ave. Crash Cost	Societal Savings/Yr
CRITCAL	154	86	-68	$ 976,667.93	$ 33,206,709.62
SERIOUS	274	242	-32	$ 75,386.24	$ 1,206,179.84
PDO	556	852	296	$ 8,900.00	$ (1,317,200.00)
			TOTAL Societal Savings /Yr		**$ 33,095,689.46**

The yearly societal savings from critical (fatal and severe injury) crashes was estimated at $33.2 million. Even though there were nearly 300 additional PDO crashes over the two-year analysis, the added yearly societal costs were only $1.3 million. The number of serious crashes was reduced by 32, which resulted in a $1.2 million yearly societal savings. This cost decrease alone made up for the increase in PDO crashes. When adding them all together, the overall societal savings was found to be about $33.1 million per year. That amounts to an estimated annual savings of about $322,000 per mile over the 102.8 miles of cable median barriers.

5.4 Section Summary

This section presented the data collection and analysis methods used to evaluate the effectiveness of installed cable median barriers in reducing ROR crashes on Wyoming's relatively low volume interstates. Data were collected from the CARE 9 database for the various interstate sections statewide where WYDOT installed cable median barriers between 2007 and 2008. The analysis determined that although PDO crashes increased during the study, there was a significant reduction in severe crashes. The resulting societal benefits were enough to suggest expanding the use of cable median barriers in Wyoming.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

To satisfy the report objectives, a general study of literature was carried out for all three main research areas: geometric conditions, shoulder rumble strips, and cable median barriers. The literature search identified crash statistics, obstacles, and effectiveness of various safety improvements based on previous research studies. Next, the data collection methodology for every objective was described. Finally, the data analysis methods for each one of research areas were performed individually.

The impact of geometric conditions on roadway departure crashes was studied. Implemented in September 2006, the WSHSP was used as a center point for the four-year “before” and “after” analysis. The first phase determined the statewide impact of the WSHSP as well as concentrated on locating hazardous geometric conditions. The improvements associated with the WSHSP contributed to the reduction in the number of critical and serious crashes statewide. The research was conducted on the Wyoming rural interstates, state highways, and local roadways and included eight combinations of geometric conditions. It was determined that curve-downhill and curve-level crashes on both the rural state highways and local roadways were found to be the most severe geometric combinations. It was determined unnecessary to perform a more detailed analysis on the interstate system. Roadway departure crashes were observed to be the largest contributor of severe crashes on these sections, the secondary analysis exclusively focused on those areas. Since local roads have a combination of paved and unpaved sections, as well as a major difference in AADT from state highways, the two functional classes were independently analyzed. It was concluded that rollover crashes were the most severe roadway departure crash type in every phase II analysis by accounting for at least 37% of the crashes.

Second, shoulder rumble strips were evaluated to determine the effectiveness in reducing ROR crashes on Wyoming’s relatively low volume rural interstates and state highways. Only two of seven rumble strip projects installed on Wyoming roadways between 2005 and 2010 met the criterions to be analyzed for this research. One project applied SRS on interstate sections only and one project applied them to both interstate and state highways. A before-after analysis period was established for each project. The crash data were analyzed statistically using a one-tailed t-test on the severity and ROR crash types by crashes per mile. These analyses were performed for interstate and state highway sections due to the typical difference in traffic volumes. The severity analyses indicated conclusive evidence that crash rates were reduced on both the interstate and state highway sections due to SRS installation.

Third, the effectiveness of installed cable median barriers on Wyoming’s relatively low volume interstates was studied. Between 2007 and 2008, WYDOT installed 102.8 miles of cable median barriers on various interstate sections statewide. Wyoming interstates have relatively low traffic volumes, with the highest traffic volumes in the state on I-80, which only average an AADT of 13,500 vehicles. According to the RDG, justification for installing cable barriers in Wyoming is needed since roadways don’t meet the 20,000 AADT minimum volume requirements. The justification for WYDOT was the Wyoming Legislature making the installation of cable barriers in narrow medians on I-80 one of their top priorities. The crash data pertaining to cable median barriers, median and cross-median crashes, and crash severity were analyzed. The analysis included every interstate section that had cable median barriers implemented. The analysis was performed using only the crash numbers obtained for a two-year before-after period. Due to the reduction in critical and serious crashes, an overall annual savings of about $322,000 per mile of installed cable median barriers was estimated even though there was an increase of nearly 150 PDO crashes per year.

6.2 Conclusions

Based on the analysis conducted in this study, the following conclusions can be drawn:

6.2.1 Geometric Conditions

1. The statewide safety improvements due to the implementation of the 2006 WSHSP is a contributing factor to the reduction in the number of critical and serious crashes.

2. The results from the phase I analysis suggest there is a high percentage of critical and serious crashes still occurring on curve-level and curve-downhill geometrics on state highway and local road sections.

3. The results from the phase II analysis indicate the severity of these crashes is impacted heavily by the high percent and severity of rollover crashes. Finding a way to reduce the severity of rollover crashes should greatly assist in reducing the overall severity of crashes on geometric conditions.

4. Other phase II analysis results suggest that crashes may be occurring due to motorists driving too fast for weather or/and surface conditions on curve-level and curve-downhill sections.

6.2.2 Shoulder Rumble Strips

1. One of WYDOT's main goals when installing SRS was to reduce the severity of ROR crashes. When combining the ROR crashes with crash severity in a descriptive analysis, the data strongly suggested that the severity of ROR crashes were reduced by SRS installation.

2. The results indicated that critical and serious crashes were reduced on both the interstate and state highway sections due to the installation of SRS.

6.2.3 Cable Median Barriers

1. A very encouraging result was that the number of critical median and cross-median crashes was reduced by 44% during the analysis period. That included a reduction of nearly 79% of critical cross-median crashes and about 43% of critical rollover crashes in the median. The number of serious crashes in the analysis was reduced by about 12%. The number of PDO crashes increased by only 53%.

2. The societal savings associated with the reduction in the number of high severity crashes more than made up for the increase in PDO crashes. The resulting societal benefit of cable median barrier installation was calculated to be $322,000 per mile annually in Wyoming.

3. The reduction in the number of critical and serious crashes combined with the societal benefits strongly suggests that cable median barriers are a cost effective solution to reducing the severity of median and cross-median crashes in the State of Wyoming. This research indicates that cable

median barriers can be a highly effective measure to improve safety on relatively low volume interstate systems.

4. It should be noted that the crash reductions could also have been supplemented by other safety devices implemented by WYDOT after the 2006 WSHSP was published.

6.3 Recommendations

6.3.1 Geometric Conditions

1. Perform a more in-depth analysis on the impact of the WSHSP in reducing the crash severity statewide.

2. Since rollovers are so prominent in roadway departure crashes on state highways, cost effective safety improvements should be considered for these sections. Advanced warning signs for curves, shoulder and/or center rumble strips on paved curved sections, increasing shoulder width, and improving curve alignments should be implemented whenever warranted. Combining these measures on all curve-downhill and curve-level state highways and local road sections should help reduce harmful crashes, as well as are a proactive step toward improving safety across Wyoming.

3. Advanced warning signs for curves would help increase roadway drivers alertness. Shoulder and center rumble strips would alert inattentive or speeding drivers prior to departing the roadway and crossing the roadway centerline, respectively.

4. Increasing shoulder widths where possible would allow more time for drivers to recover if departing the traveled way before leaving the asphalt. Refining the alignment of curves improves the drivability of a road and decreases the potential for crashes.

5. Apart from roadway departures crashes, the other main factors identified by the 2006 WSHSP that contribute to changes in crash severity are alcohol, safety restraints and speeding. The Wyoming legislature passed a speed limit law, lowering the speed limit to 55 mph on unpaved roads statewide effective July 2011. In addition, WYDOT recently implemented a statewide sign program which will provide advance warning signs to high risk rural local roads statewide. While these changes alone may not be as effective as anticipated, the continuation of driver education programs and strict enforcement has the potential to effectively aid in reducing crash severity statewide in Wyoming.

6. The planning through construction phases of projects can take years to complete once a safety plan is in place. Given a few more years and additional implemented safety projects, future analysis should show the real impact of the plan.

6.3.2 Shoulder Rumble Strips

1. Due to the unpredictability of roadway departure crashes, it is hard to pinpoint locations for rumble strip implementation. The results from the analyses of SRS could warrant their expanded use not only on Wyoming interstates and state highways, but on paved roadways statewide.

2. An official study should be performed in order to determine the actual deterioration of shoulders on Wyoming's roads due to weathering. Unless SRS are proven to substantially increase costs by lowering the service life of shoulders, it is recommended to install SRS on as many paved roadway sections as possible statewide.

3. All future state highway shoulders should be designed with SRS while accommodating bicyclists.

4. Other transportation agencies nationwide should also consider the benefits of implementing SRS on their relatively low volume interstates and state highways.

5. A before-after control impact (BACI) analysis should be performed on SRS in Wyoming. This would give more in-depth findings about the true impact of SRS in reducing ROR statewide.

6.3.3 Cable Median Barriers

1. The effectiveness of cable median barriers could warrant their expanded use on Wyoming's relatively low volume interstates.

2. Other agencies should also consider the benefits of implementing cable median barriers on their relatively low volume interstates or divided highways.

3. The effectiveness of cable median barriers could most likely be enhanced by the addition of other cost effective safety devices such as rumble strips on the same roadway sections.

4. WYDOT should look into improving its data collection techniques to make the information more available internally and to other agencies, if requested. This can be done by establishing a uniform and accurate way for maintenance crews to report repair details.

    a. Details such as the number of posts hit in each crash, the time to make each repair, and the cost of each repair.

    b. Reporting each segment repaired individually instead of combining all repairs made on long sections could help WYDOT predict future repair costs.

    c. Comparing the number of crashes reported against the number of repaired sections will help determine the percent of unreported crashes.

    d. Keeping this information centralized and reporting it annually would be beneficial to multiple agencies.

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APPENDIX A: CARE 9 DATA INPUT SCREENS

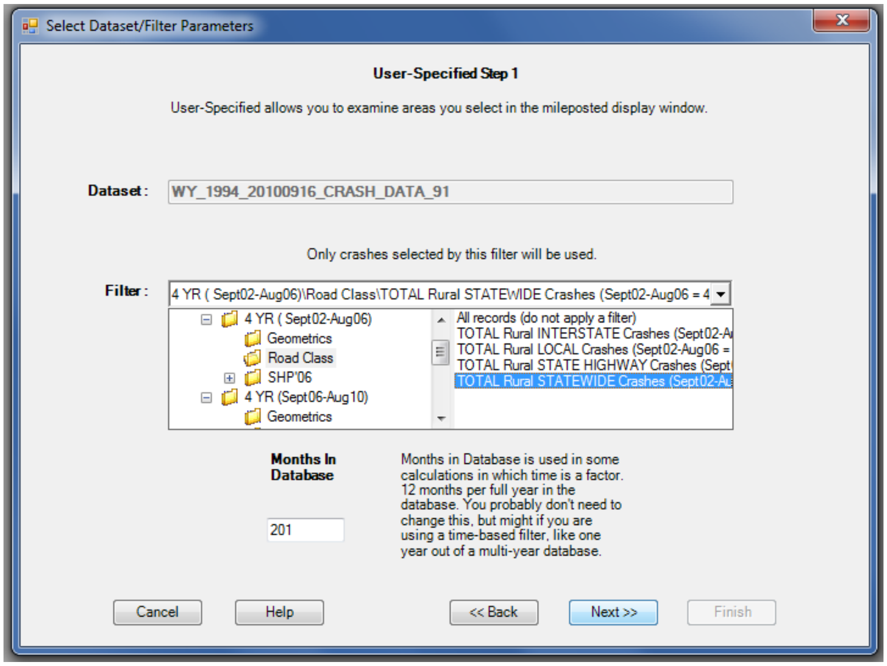


Figure A.1 Selecting a Filter

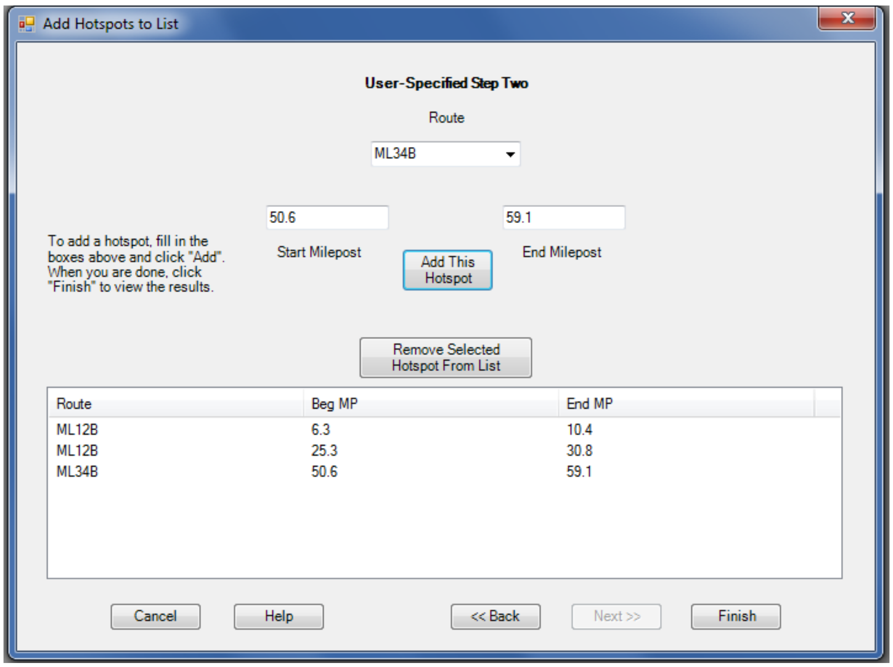


Figure A.2 Adding Specific Milepost Locations for Individual Roads

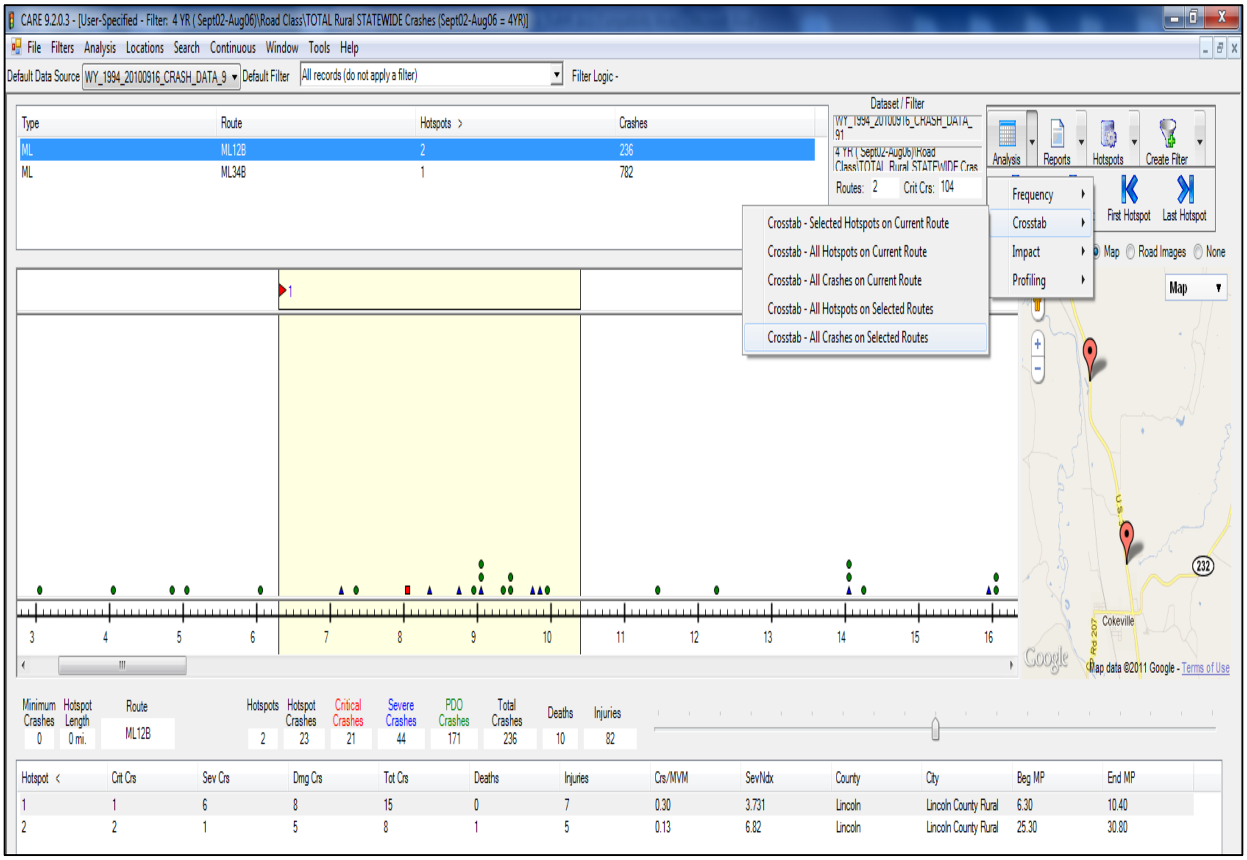


Figure A.3 Detailed Crash Reporting System for Specified Locations

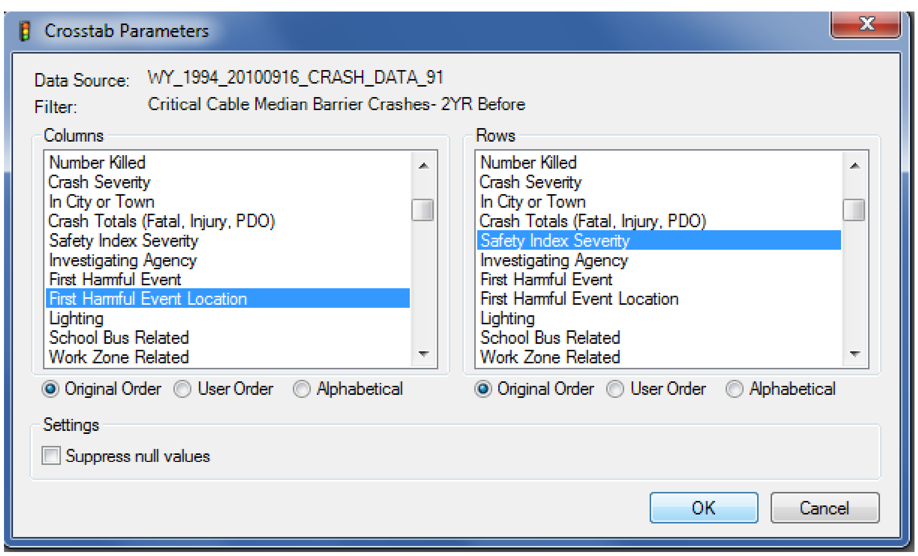
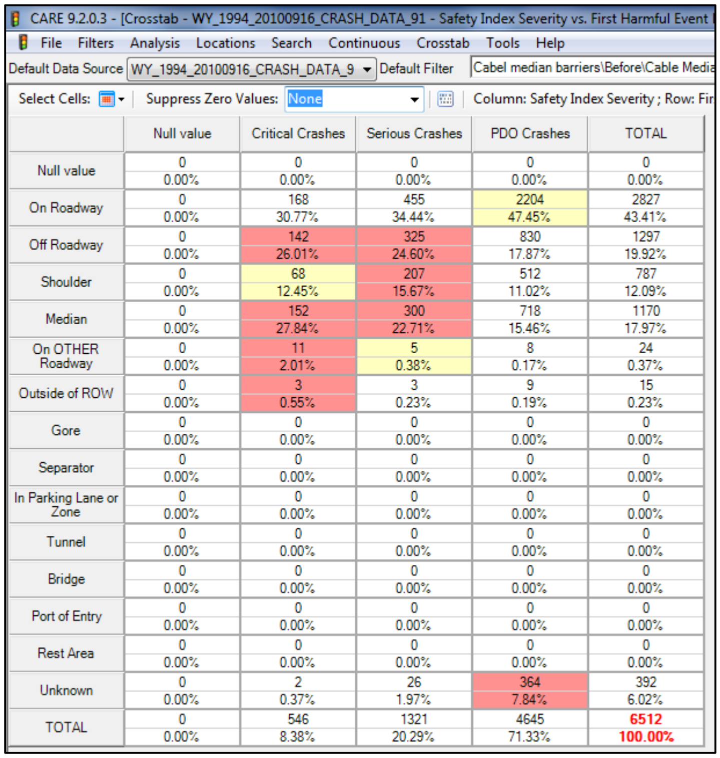


Figure A.4 Selecting Parameters for Analysis



CARE 9.2.0.3 - [Crosstab - WY_1994_20100916_CRASH_DATA_91 - Safety Index Severity vs. First Harmful Event

File Filters Analysis Locations Search Continuous Crosstab Tools Help

Default Data Source WY_1994_20100916_CRASH_DATA_9 Default Filter Cabel median barriers\Before\Cable Media

Select Cells: Suppress Zero Values: None Column: Safety Index Severity ; Row: Fir

	Null value	Critical Crashes	Serious Crashes	PDO Crashes	TOTAL
Null value	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
On Roadway	0 0.00%	168 30.77%	455 34.44%	2204 47.45%	2827 43.41%
Off Roadway	0 0.00%	142 26.01%	325 24.60%	830 17.87%	1297 19.92%
Shoulder	0 0.00%	68 12.45%	207 15.67%	512 11.02%	787 12.09%
Median	0 0.00%	152 27.84%	300 22.71%	718 15.46%	1170 17.97%
On OTHER Roadway	0 0.00%	11 2.01%	5 0.38%	8 0.17%	24 0.37%
Outside of ROW	0 0.00%	3 0.55%	3 0.23%	9 0.19%	15 0.23%
Gore	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Separator	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
In Parking Lane or Zone	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Tunnel	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Bridge	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Port of Entry	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Rest Area	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Unknown	0 0.00%	2 0.37%	26 1.97%	364 7.84%	392 6.02%
TOTAL	0 0.00%	546 8.38%	1321 20.29%	4645 71.33%	6512 100.00%

Figure A.5 Crash Data Output for Selected Filters and Parameters

Table A.1 Example of CARE 9 Crash Database Output in Excel Format

	Null value	Level	Hillcrest	Uphill	Downhill	Sag or Bottom	Unknown	Non-motorist	TOTAL
Null value	4941	0	0	0	0	0	0	0	4941
Null value	100%	0%	0%	0%	0%	0%	0%	0%	18.22%
Straight	0	10416	407	2631	2533	49	21	0	16057
Straight	0%	82.54%	66.07%	69.86%	58.04%	58.33%	7.32%	0%	59.22%
Curve Right	0	601	87	310	476	19	6	0	1499
Curve Right	0%	4.76%	14.12%	8.23%	10.91%	22.62%	2.09%	0%	5.53%
Curve Left	0	614	78	297	488	15	7	0	1499
Curve Left	0%	4.87%	12.66%	7.89%	11.18%	17.86%	2.44%	0%	5.53%
Legacy - Curve	0	965	42	522	848	0	0	0	2377
Legacy - Curve	0%	7.65%	6.82%	13.86%	19.43%	0%	0%	0%	8.77%
Unknown	0	24	2	6	19	1	253	0	305
Unknown	0%	0.19%	0.32%	0.16%	0.44%	1.19%	88.15%	0%	1.12%
Non-motorist caused	0	0	0	0	0	0	0	434	434
Non-motorist caused	0%	0%	0%	0%	0%	0%	0%	100%	1.60%
TOTAL	4941	12620	616	3766	4364	84	287	434	27112
TOTAL	18.22%	46.55%	2.27%	13.89%	16.10%	0.31%	1.06%	1.60%	100%

APPENDIX B1: STATEWIDE RAW CRASH DATA EXTRACTED FOR GEOMETRIC CONDITIONS BY CRASH SEVERITY

Statewide - Raw "Before" CRITICAL Crash Crosstab Results (Sept 02 - Aug 06)									
	Null value	Level	Hillcrest	Uphill	Downhill	Sag or Bottom	Unknown	Non-motorist	TOTAL Vertical
Null value	0	0	0	0	0	0	0	0	0
Straight	0	987	28	298	358	0	0	0	1671
Legacy - Curve	0	320	20	180	330	0	0	0	850
Unknown	0	0	0	0	0	0	6	0	6
Non-motorist caused	0	0	0	0	0	0	0	9	9
TOTAL Horizontal	0	1307	48	478	688	0	6	9	2536

Statewide - Raw "After" CRITICAL Crash Crosstab Results (Sept 06 - Aug 10)									
	Null value	Level	Hillcrest	Uphill	Downhill	Sag or Bottom	Unknown	Non-motorist	TOTAL Vertical
Null value	7	0	0	0	0	0	0	0	7
Straight	0	824	35	170	219	9	0	0	1257
Legacy - Curve	0	276	24	144	227	4	2	0	677
Unknown	0	1	0	0	0	0	14	0	15
Non-motorist caused	0	0	0	0	0	0	0	75	75
TOTAL Horizontal	7	1101	59	314	446	13	16	75	2031

Statewide - Usable " Before" CRITICAL Crash Crosstab Results (Sept 02 - Aug 06)					
	Level	Uphill	Downhill	Vertical Curve	TOTAL Vertical
Straight	987	298	358	28	1671
Horizontal Curve	320	180	330	20	850
TOTAL Horizontal	1307	478	688	48	2521

Statewide - Usable " After" CRITICAL Crash Crosstab Results (Sept 06 - Aug 10)					
	Level	Uphill	Downhill	Vertical Curve	TOTAL Vertical
Straight	824	170	219	44	1257
Horizontal Curve	276	144	227	28	675
TOTAL Horizontal	1100	314	446	72	1932

Statewide - Raw "Before" SERIOUS Crash Crosstab Results (Sept 02 - Aug 06)									
	Null value	Level	Hillcrest	Uphill	Downhill	Sag or Bottom	Unknown	Non-motorist	TOTAL Vertical
Null value	0	0	0	0	0	0	0	0	0
Straight	0	2397	53	690	690	0	0	0	3830
Legacy - Curve	0	656	33	328	657	0	0	0	1674
Unknown	0	0	0	0	0	0	26	0	26
Non-motorist caused	0	0	0	0	0	0	0	7	7
TOTAL Horizontal	0	3053	86	1018	1347	0	26	7	5537

Statewide - Raw "After" SERIOUS Crash Crosstab Results (Sept 06 - Aug 10)									
	Null value	Level	Hillcrest	Uphill	Downhill	Sag or Bottom	Unknown	Non-motorist	TOTAL Vertical
Null value	62	0	0	0	0	0	0	0	62
Straight	0	2285	90	564	594	10	4	0	3547
Legacy - Curve	0	577	64	251	473	5	6	0	1376
Unknown	0	3	1	3	3	1	39	0	50
Non-motorist caused	0	0	0	0	0	0	0	81	81
TOTAL Horizontal	62	2865	155	818	1070	16	49	81	5116

Statewide - Usable " Before" SERIOUS Crash Crosstab Results (Sept 02 - Aug 06)					
	Level	Uphill	Downhill	Vertical Curve	TOTAL Vertical
Straight	2397	690	690	53	3830
Horizontal Curve	656	328	657	33	1674
TOTAL Horizontal	3053	1018	1347	86	5504

Statewide - Usable " After" SERIOUS Crash Crosstab Results (Sept 06 - Aug 10)					
	Level	Uphill	Downhill	Vertical Curve	TOTAL Vertical
Straight	2285	564	594	100	3543
Horizontal Curve	577	251	473	69	1370
TOTAL Horizontal	2862	815	1067	169	4913

Statewide - Raw "Before" PDO Crash Crosstab Results (Sept 02 - Aug 06)									
	Null value	Level	Hillcrest	Uphill	Downhill	Sag or Bottom	Unknown	Non-motorist	TOTAL Vertical
Null value	0	0	0	0	0	0	0	0	0
Straight	0	9364	234	2276	2386	0	0	0	14260
Legacy - Curve	0	1437	47	856	1480	0	0	0	3820
Unknown	0	0	0	0	0	0	228	0	228
Non-motorist caused	0	0	0	0	0	0	0	0	0
TOTAL Horizontal	0	10801	281	3132	3866	0	228	0	18308

Statewide - Raw "After" PDO Crash Crosstab Results (Sept 06 - Aug 10)									
	Null value	Level	Hillcrest	Uphill	Downhill	Sag or Bottom	Unknown	Non-motorist	TOTAL Vertical
Null value	4872	0	0	0	0	0	0	0	4872
Straight	0	7307	282	1897	1720	30	17	0	11253
Legacy - Curve	0	1327	119	734	1112	25	5	0	3322
Unknown	0	20	1	3	16	0	200	0	240
Non-motorist caused	0	0	0	0	0	0	0	278	278
TOTAL Horizontal	4872	8654	402	2634	2848	55	222	278	19965

Statewide - Usable " Before" PDO Crash Crosstab Results (Sept 02 - Aug 06)					
	Level	Uphill	Downhill	Vertical Curve	TOTAL Vertical
Straight	9364	2276	2386	234	14260
Horizontal Curve	1437	856	1480	47	3820
TOTAL Horizontal	10801	3132	3866	281	18080

Statewide - Usable " After" PDO Crash Crosstab Results (Sept 06 - Aug 10)					
	Level	Uphill	Downhill	Vertical Curve	TOTAL Vertical
Straight	7307	1897	1720	312	11236
Horizontal Curve	1327	734	1112	144	3317
TOTAL Horizontal	8634	2631	2832	456	14553

APPENDIX B2: OVERALL DATA EXTRACTED FOR GEOMETRIC CONDITIONS – PHASE I

TOTAL # and % of Reported Crashes (Sept 2002-Aug 2006)								
	# of Crashes by Functional Class & Severity				% of Crashes by Functional Class & Severity			
	Statewide	Interstate	State Highway	Local	Statewide	Interstate	State Highway	Local
Critical	2536	918	1319	299	9.6%	8.9%	10.3%	9.1%
Serious	5537	2077	2511	949	21.0%	20.2%	19.6%	28.8%
PDO	18308	7279	8979	2050	69.4%	70.8%	70.1%	62.2%
TOTAL	26381	10274	12809	3298	100.0%	100.0%	100.0%	100.0%

Usable Reported Crash Data from Geometric Conditions Filter (Sept 2002-Aug 2006)								
	# of Crashes by Functional Class & Severity				% of Crashes by Functional Class & Severity			
	Statewide	Interstate	State Highway	Local	Statewide	Interstate	State Highway	Local
Critical	2521	913	1310	298	9.7%	9.0%	10.3%	9.1%
Serious	5504	2067	2492	945	21.1%	20.3%	19.7%	28.9%
PDO	18080	7194	8861	2025	69.3%	70.7%	70.0%	62.0%
TOTAL	26105	10174	12663	3268	100.0%	100.0%	100.0%	100.0%

	# of Crashes NOT Reporting Geometric Conditions				% Difference Due to Unreported Geometric Condtions			
	Statewide	Interstate	State Highway	Local	Statewide	Interstate	State Highway	Local
Critical	15	5	9	1	0.0%	0.0%	0.0%	0.1%
Serious	33	10	19	4	0.1%	0.1%	0.1%	0.1%
PDO	228	85	118	25	-0.1%	-0.1%	-0.1%	-0.2%
TOTAL	276	100	146	30				

TOTAL # and % of Reported Crashes (Sept 2006-Aug 2010)								
	# of Crashes by Functional Class & Severity				% of Crashes by Functional Class & Severity			
	Statewide	Interstate	State Highway	Local	Statewide	Interstate	State Highway	Local
Critical	2031	656	1081	294	7.5%	6.0%	8.2%	9.4%
Serious	5116	2004	2361	751	18.9%	18.4%	18.0%	24.0%
PDO	19965	8219	9664	2082	73.6%	75.5%	73.7%	66.6%
TOTAL	27112	10879	13106	3127	100.0%	100.0%	100.0%	100.0%

Usable Reported Crash Data from Geometric Conditions Filter (Sept 2006-Aug 2010)								
	# of Crashes by Functional Class & Severity				% of Crashes by Functional Class & Severity			
	Statewide	Interstate	State Highway	Local	Statewide	Interstate	State Highway	Local
Critical	1932	629	1025	278	9.0%	6.7%	10.9%	10.5%
Serious	4913	1943	2259	711	23.0%	20.8%	24.0%	26.7%
PDO	14553	6775	6109	1669	68.0%	72.5%	65.0%	62.8%
TOTAL	21398	9347	9393	2658	100.0%	100.0%	100.0%	100.0%

	# of Crashes NOT Reporting Geometric Conditions				% Difference Due to Unreported Geometric Condtions			
	Statewide	Interstate	State Highway	Local	Statewide	Interstate	State Highway	Local
Critical	99	27	56	16	1.5%	0.7%	2.7%	1.1%
Serious	203	61	102	40	4.1%	2.4%	6.0%	2.7%
PDO	5412	1444	3555	413	-5.6%	-3.1%	-8.7%	-3.8%
TOTAL	5714	1532	3713	469				

APPENDIX B3: DATA EXTRACTED FROM GEOMETRIC CONDITIONS - PHASE II

WYOMING Rural LOCAL Roadways September 2002 - August 2006 Curve-Downhill Sections Roadway Departure Crashes		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	118	20	6	6	**150**
	Earth Embankment or Berm	35	10	3	1	**49**
	Fence including Post	22	15	1	0	**38**
	Trees or Shrubbery	5	7	1	0	**13**
	Other Non-Collision MC Loss of Control	11	2	0	0	**13**
	Other	34	11	2	1	**48**
	TOTAL	**225**	**65**	**13**	**8**	**311**

		Road Surface		
		Paved	Unpaved	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	33	117	**150**
	Earth Embankment or Berm	12	37	**49**
	Fence including Post	21	17	**38**
	Trees or Shrubbery	8	5	**13**
	Other Non-Collision MC Loss of Control	7	6	**13**
	Other	25	23	**48**
	TOTAL	**106**	**205**	**311**

		Severity				
		Critical Crashes	Serious Crashes	PDO Crashes	EPDO	EPDO %
First Harmful Event (FHE)	Overturn or Rollover	23	71	56	3189.5	**59.4%**
	Earth Embankment or Berm	3	21	25	533.5	**9.9%**
	Fence including Post	3	10	25	440	**8.2%**
	Trees or Shrubbery	0	5	8	50.5	**0.9%**
	Other Non-Collision MC Loss of Control	6	3	4	689.5	**12.8%**
	Other	3	12	33	465	**8.7%**
	TOTAL	**38**	**122**	**151**	**5368**	**100.0%**

WYOMING Rural LOCAL Roadways						
September 2006 - August 2010						
Curve-Downhill Sections						
Roadway Departure Crashes						
		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	71	26	2	9	**108**
	Fence including Post	9	10	2	4	**25**
	Earth Embankment or Berm	12	7	1	1	**21**
	Trees or Shrubbery	6	10	1	3	**20**
	Ditch	6	1	1	2	**10**
	Other	11	11	3	1	**26**
	TOTAL	**115**	**65**	**10**	**20**	**210**

		Road Surface		
		Paved	Unpaved	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	29	79	**108**
	Fence including Post	9	16	**25**
	Earth Embankment or Berm	9	12	**21**
	Trees or Shrubbery	6	13	**19**
	Ditch	3	7	**10**
	Other	10	16	**26**
	TOTAL	**66**	**143**	**209**

		Severity				
		Critical Crashes	Serious Crashes	PDO Crashes	EPDO	EPDO %
First Harmful Event (FHE)	Overturn or Rollover	12	36	60	1686	**49.8%**
	Fence including Post	1	5	19	171.5	**5.1%**
	Earth Embankment or Berm	3	7	11	400.5	**11.8%**
	Trees or Shrubbery	1	8	11	189	**5.6%**
	Ditch	1	4	5	149	**4.4%**
	Other	7	0	19	789	**23.3%**
	TOTAL	**25**	**60**	**125**	**3385**	**100.0%**

WYOMING Rural LOCAL Roadways						
September 2002 - August 2006						
Curve-Level Sections						
Roadway Departure Crashes						
		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	111	25	6	3	**145**
	Fence including Post	32	19	3	2	**56**
	Earth Embankment or Berm	33	16	0	2	**51**
	Trees or Shrubbery	7	7	0	0	**14**
	Utility Pole or Light Support	3	5	2	0	**10**
	Other	37	21	0	0	**58**
	TOTAL	**223**	**93**	**11**	**7**	**334**

		Road Surface		
		Paved	Unpaved	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	59	86	**145**
	Fence including Post	28	28	**56**
	Earth Embankment or Berm	17	34	**51**
	Trees or Shrubbery	4	10	**14**
	Utility Pole or Light Support	9	1	**10**
	Other	31	27	**58**
	TOTAL	**148**	**186**	**334**

		Severity				
		Critical Crashes	Serious Crashes	PDO Crashes	EPDO	EPDO %
First Harmful Event (FHE)	Overturn or Rollover	15	70	60	2305	**52.2%**
	Fence including Post	0	15	41	168.5	**3.8%**
	Earth Embankment or Berm	6	16	29	825	**18.7%**
	Trees or Shrubbery	1	4	9	153	**3.5%**
	Utility Pole or Light Support	1	4	5	149	**3.4%**
	Other	6	14	38	817	**18.5%**
	TOTAL	**29**	**123**	**182**	**4417.5**	**100.0%**

WYOMING Rural LOCAL Roadways						
September 2006 - August 2010						
Curve-Level Sections						
Roadway Departure Crashes						
		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	85	17	5	15	**122**
	Fence including Post	38	32	7	4	**81**
	Earth Embankment or Berm	24	9	1	3	**37**
	Trees or Shrubbery	13	5	2	0	**20**
	Ditch	6	3	2	4	**15**
	Other	28	18	2	1	**49**
	TOTAL	**194**	**84**	**19**	**27**	**324**

		Road Surface		
		Paved	Unpaved	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	49	73	**122**
	Fence including Post	39	41	**80**
	Earth Embankment or Berm	13	24	**37**
	Trees or Shrubbery	9	11	**20**
	Ditch	8	7	**15**
	Other	36	13	**49**
	TOTAL	**154**	**169**	**323**

		Severity				
		Critical Crashes	Serious Crashes	PDO Crashes	EPDO	EPDO %
First Harmful Event (FHE)	Overturn or Rollover	21	46	55	2756	**53.5%**
	Fence including Post	5	25	51	813.5	**15.8%**
	Earth Embankment or Berm	2	10	25	330	**6.4%**
	Trees or Shrubbery	3	6	11	392	**7.6%**
	Ditch	0	8	7	75	**1.5%**
	Other	6	11	32	785.5	**15.2%**
	TOTAL	**37**	**106**	**181**	**5152**	**100.0%**

WYOMING Rural STATE HIGHWAY Roadways September 2002 - August 2006 Curve-Downhill Sections Roadway Departure Crashes		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	111	66	19	2	**198**
	Guardrail Face	32	18	7	0	**57**
	Earth Embankment or Berm	17	16	4	0	**37**
	Other Non-Collision MC Loss of Control	25	4	3	1	**33**
	Fence including Post	13	14	3	1	**31**
	Other	59	50	16	1	**126**
	TOTAL	**257**	**168**	**52**	**5**	**482**

		Road Surface		
		Paved	Unpaved	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	197	1	**198**
	Guardrail Face	57	0	**57**
	Earth Embankment or Berm	36	1	**37**
	Other Non-Collision MC Loss of Control	33	0	**33**
	Fence including Post	31	0	**31**
	Other	125	1	**126**
	TOTAL	**479**	**3**	**482**

		Crash Severity			Severity Analysis				
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO	Total %	EPDO %	**WSI**
First Harmful Event (FHE)	Overturn or Rollover	50	72	76	198	6188	41.1%	49.7%	**426.8**
	Guardrail Face	6	21	30	57	868.5	11.8%	7.0%	**-33.8**
	Earth Embankment or Berm	4	17	16	37	600.5	7.7%	4.8%	**-13.8**
	Other Non-Collision MC Loss of Control	16	10	7	33	1852	6.8%	14.9%	**119.2**
	Fence including Post	2	6	23	31	294	6.4%	2.4%	**-9.6**
	Other	21	32	73	126	2655	26.1%	21.3%	**-102.9**
	TOTAL	**99**	**158**	**225**	482	12458	100.0%	100.0%	

WYOMING Rural STATE HIGHWAY Roadways						
September 2006 - August 2010						
Curve-Downhill Sections						
Roadway Departure Crashes						
		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	69	53	12	5	**139**
	Guardrail Face	13	24	9	1	**47**
	Earth Embankment or Berm	18	16	4	0	**38**
	Delineator Post	17	11	2	0	**30**
	Trees or Shrubbery	11	13	3	1	**28**
	Other	53	45	10	1	**109**
	TOTAL	**181**	**162**	**40**	**8**	**391**

		RUMBLE STRIP			
		Yes	No	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	19	65	55	**139**
	Guardrail Face	5	21	21	**47**
	Earth Embankment or Berm	1	8	29	**38**
	Delineator Post	3	19	8	**30**
	Trees or Shrubbery	1	12	15	**28**
	Other	10	55	44	**109**
	TOTAL	**39**	**180**	**172**	**391**

		Crash Severity			Severity Analysis				
		CRITICAL	SERIOUS	PDO	TOTAL	EPDO	Total %	EPDO %	**WSI**
First Harmful Event (FHE)	Overturn or Rollover	26	64	49	139	3453	35.5%	42.8%	**309.3**
	Guardrail Face	5	10	32	47	667	12.0%	8.3%	**-31.0**
	Earth Embankment or Berm	7	15	16	38	913.5	9.7%	11.3%	**18.1**
	Delineator Post	3	9	18	30	424.5	7.7%	5.3%	**-12.7**
	Trees or Shrubbery	4	7	17	28	516.5	7.2%	6.4%	**-4.9**
	Other	17	18	74	109	2097	27.9%	26.0%	**-49.3**
	TOTAL	**62**	**123**	**206**	391	8071.5	100.0%	100.0%	

WYOMING Rural STATE HIGHWAY Roadways						
September 2002 - August 2006						
Curve-Level Sections						
Roadway Departure Crashes						
		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	142	65	15	0	**222**
	Fence including Post	33	25	7	0	**65**
	Earth Embankment or Berm	24	13	2	0	**39**
	Delineator Post	28	6	2	0	**36**
	Guardrail Face	14	10	2	1	**27**
	Other	52	28	9	1	**90**
	TOTAL	**293**	**147**	**37**	**2**	**479**

		Road Surface		
		Paved	Unpaved	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	221	1	**222**
	Fence including Post	64	0	**64**
	Earth Embankment or Berm	39	0	**39**
	Delineator Post	36	0	**36**
	Guardrail Face	27	0	**27**
	Other	83	7	**90**
	TOTAL	**470**	**8**	**478**

		Severity				
		Critical Crashes	Serious Crashes	PDO Crashes	EPDO	EPDO %
First Harmful Event (FHE)	Overturn or Rollover	52	101	69	6647.5	**52.9%**
	Fence including Post	6	14	45	824	**6.6%**
	Earth Embankment or Berm	7	19	13	944.5	**7.5%**
	Delineator Post	12	7	17	1396.5	**11.1%**
	Guardrail Face	7	7	13	842.5	**6.7%**
	Other	15	26	49	1920	**15.3%**
	TOTAL	**99**	**174**	**206**	**12575**	**100.0%**

WYOMING Rural STATE HIGHWAY Roadways September 2006 - August 2010 Curve-Level Sections Roadway Departure Crashes						
		Roadway Condtions				
		Dry	Ice or Frost or Snow	Wet or Slush	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	115	52	15	1	**183**
	Fence including Post	43	34	7	2	**86**
	Delineator Post	33	11	3	2	**49**
	Guardrail Face	12	13	3	0	**28**
	Earth Embankment or Berm	16	8	3	0	**27**
	Other	63	36	10	2	**111**
	TOTAL	**282**	**154**	**41**	**7**	**484**

		RUMBLE STRIP PRESENT			
		Yes	No	Other	**TOTAL**
First Harmful Event (FHE)	Overturn or Rollover	32	73	78	**183**
	Fence including Post	18	39	29	**86**
	Delineator Post	6	21	22	**49**
	Guardrail Face	5	8	15	**28**
	Earth Embankment or Berm	2	8	17	**27**
	Other	12	53	46	**111**
	TOTAL	**75**	**202**	**207**	**484**

		Severity				
		Critical Crashes	Serious Crashes	PDO Crashes	EPDO	EPDO %
First Harmful Event (FHE)	Overturn or Rollover	47	77	59	5883.5	**48.3%**
	Fence including Post	8	13	65	1055.5	**8.7%**
	Delineator Post	12	8	29	1417	**11.6%**
	Guardrail Face	2	8	18	306	**2.5%**
	Earth Embankment or Berm	4	10	13	538	**4.4%**
	Other	24	33	54	2974.5	**24.4%**
	TOTAL	**97**	**149**	**238**	**12174.5**	**100.0%**

APPENDIX C1: SEVERITY OF RUMBLE STRIP CRASHES AND CRASHES/MILE

ROADWAY DATA				State Highway Crash Severity (#'s)									
Route	Begin MP	End MP	Length (mi)	Critical		Serious		PDO		Total		Critical+Serious	
				Before	After	Before	After	Before	After	Before	After	Before	After
ML 1004 B	5.0	17.8	12.8	0	0	0	1	6	7	6	8	0	1
ML 44 B	220.9	233.3	12.4	6	0	4	3	12	8	22	11	10	3
ML 45 B	0.0	2.3	2.3	0	0	1	0	0	1	1	1	1	0
ML 34 B	50.6	59.1	8.5	4	0	6	1	13	6	23	7	10	1
ML 12 B	6.3	10.4	4.1	0	0	3	1	3	5	6	6	3	1
ML 12 B	25.3	30.8	5.5	1	2	0	0	2	3	3	5	1	2
ML 85 B	202.0	219.5	17.5	1	1	2	2	9	4	12	7	3	3
ML 32 B	29.8	34.2	4.4	0	0	1	1	4	5	5	6	1	1
ML 26 B	12.0	12.6	0.6	0	0	0	0	0	0	0	0	0	0
ML 42 B	93.6	109.0	15.4	2	0	0	1	15	6	17	7	2	1
TOTALS			83.5	14	3	17	10	64	45	95	58	31	13

ROADWAY DATA				2 Yr - State Highway Crash Severity (crashes/mile)									
Route	Begin MP	End MP	Length (mi)	Critical		Serious		PDO		Total		Critical+Serious	
				Before	After	Before	After	Before	After	Before	After	Before	After
ML 1004 B	5.0	17.8	12.8	0.00	0.00	0.00	0.08	0.47	0.55	0.47	0.63	0.00	0.08
ML 44 B	220.9	233.3	12.4	0.48	0.00	0.32	0.24	0.97	0.65	1.77	0.89	0.81	0.24
ML 45 B	0.0	2.3	2.3	0.00	0.00	0.43	0.00	0.00	0.43	0.43	0.43	0.43	0.00
ML 34 B	50.6	59.1	8.5	0.47	0.00	0.71	0.12	1.53	0.71	2.71	0.82	1.18	0.12
ML 12 B	6.3	10.4	4.1	0.00	0.00	0.73	0.24	0.73	1.22	1.46	1.46	0.73	0.24
ML 12 B	25.3	30.8	5.5	0.18	0.36	0.00	0.00	0.36	0.55	0.55	0.91	0.18	0.36
ML 85 B	202.0	219.5	17.5	0.06	0.06	0.11	0.11	0.51	0.23	0.69	0.40	0.17	0.17
ML 32 B	29.8	34.2	4.4	0.00	0.00	0.23	0.23	0.91	1.14	1.14	1.36	0.23	0.23
ML 26 B	12.0	12.6	0.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ML 42 B	93.6	109.0	15.4	0.13	0.00	0.00	0.06	0.97	0.39	1.10	0.45	0.13	0.06

2 Year Interstate Crash Severity (#'s)													
Route	Begin MP	End MP	Length (mi)	Critical		Serious		PDO		Total		Critical+Serious	
				Before	After	Before	After	Before	After	Before	After	Before	After
ML 25 I	272.0	279.9	7.9	1	1	3	1	7	4	11	6	4	2
ML 25 D	272.0	279.9	7.9	0	2	0	0	7	4	7	6	0	2
ML 80 I	28.0	28.6	0.6	0	0	1	0	1	3	2	3	1	0
ML 80 I	139.0	141.0	2.0	2	0	3	2	10	7	15	9	5	2
ML 80 I	251.1	255.4	4.3	0	2	17	2	43	23	60	27	17	4
ML 80 I	300.4	302.8	2.4	0	0	2	1	7	6	9	7	2	1
ML 80 D	308.1	308.7	0.6	1	0	0	0	3	2	4	2	1	0
ML 80 I	329.1	336.2	7.1	3	6	14	11	27	32	44	49	17	17
ML 80 D	329.1	336.2	7.1	0	2	24	9	90	52	114	63	24	11
ML 80 I	356.7	357.7	1.0	1	0	1	1	5	0	7	1	2	1
ML 80 D	356.7	357.7	1.0	0	0	1	0	6	5	7	5	1	0
TOTALS			41.3	8	13	66	27	206	138	280	178	74	40

2 Yr - Interstate Crash Severity (crashes/mile)													
Route	Begin MP	End MP	Length (mi)	Critical		Serious		PDO		Total		Critical+Serious	
				Before	After	Before	After	Before	After	Before	After	Before	After
ML 25 I	272.0	279.9	7.9	0.13	0.13	0.38	0.13	0.89	0.51	1.39	0.76	0.51	0.25
ML 25 D	272.0	279.9	7.9	0.00	0.25	0.00	0.00	0.89	0.51	0.89	0.76	0.00	0.25
ML 80 I	28.0	28.6	0.6	0.00	0.00	1.67	0.00	1.67	5.00	3.33	5.00	1.67	0.00
ML 80 I	139.0	141.0	2.0	1.43	0.00	2.14	0.71	7.14	2.14	10.71	2.86	3.57	0.71
ML 80 I	251.1	255.4	4.3	0.00	0.47	3.95	0.47	10.00	5.35	13.95	6.28	3.95	0.93
ML 80 I	300.4	302.8	2.4	0.00	0.00	0.83	0.42	2.92	2.50	3.75	2.92	0.83	0.42
ML 80 D	308.1	308.7	0.6	1.67	0.00	0.00	0.00	5.00	3.33	6.67	3.33	1.67	0.00
ML 80 I	329.1	336.2	7.1	0.42	0.85	1.97	1.55	3.80	4.51	6.20	6.90	2.39	2.39
ML 80 D	329.1	336.2	7.1	0.00	0.28	3.38	1.27	12.68	7.32	16.06	8.87	3.38	1.55
ML 80 I	356.7	357.7	1.0	1.00	0.00	1.00	1.00	5.00	0.00	7.00	1.00	2.00	1.00
ML 80 D	356.7	357.7	1.0	0.00	0.00	1.00	0.00	6.00	5.00	7.00	5.00	1.00	0.00

5 Year Interstate Crash Severity (#'s)														
Route	Begin MP	End MP	Length (mi)	Critical		Serious		PDO		Total		Critical+Serious	
				Before	After	Before	After	Before	After	Before	After	Before	After
ML 25 D	16.5	17.3	0.8	0	0	2	1	7	4	9	5	2	1
ML 25 D	25.5	31.1	5.6	2	0	11	6	13	14	26	20	13	6
ML 25 D	166.9	174.9	8.0	7	2	9	10	34	28	50	40	16	12
ML 25 D	284.2	285.1	0.9	0	0	0	0	2	2	2	2	0	0
ML 25 I	16.5	17.3	0.8	2	1	4	3	8	8	14	12	6	4
ML 25 I	25.5	31.1	5.6	5	0	8	5	23	23	36	28	13	5
ML 25 I	166.9	174.9	8.0	7	2	12	7	27	28	46	37	19	9
ML 25 I	283.2	284.4	1.2	0	0	0	0	1	0	1	0	0	0
ML 80 D	57.0	65.5	8.5	4	2	15	16	34	44	53	62	19	18
ML 80 D	107.6	120.3	12.7	12	5	23	25	60	97	95	127	35	30
ML 80 D	130.0	138.0	8.0	13	4	15	15	50	66	78	85	28	19
ML 80 D	227.9	233.8	5.9	5	4	16	11	33	53	54	68	21	15
ML 80 D	263.6	275.4	11.8	24	7	26	23	154	155	204	185	50	30
ML 80 D	291.4	300.6	9.2	5	5	18	22	38	57	61	84	23	27
ML 80 D	336.6	349.0	12.4	13	8	39	24	107	93	159	125	52	32
ML 80 I	57.0	65.5	8.5	3	5	9	6	30	45	42	56	12	11
ML 80 I	107.6	120.3	12.7	8	7	11	18	53	53	72	78	19	25
ML 80 I	130.0	138.0	8.0	6	6	12	25	54	132	72	163	18	31
ML 80 I	227.4	233.8	6.4	9	9	5	5	23	33	37	47	14	14
ML 80 I	246.5	253.3	6.8	7	4	12	26	70	87	89	117	19	30
ML 80 I	263.6	275.4	11.8	11	7	23	25	82	109	116	141	34	32
ML 80 I	291.4	302.9	11.5	16	6	26	20	44	57	86	83	42	26
ML 80 I	336.6	349.0	12.4	27	8	35	24	139	100	201	132	62	32
ML 90 D	20.4	22.3	1.9	0	0	7	2	16	22	23	24	7	2
ML 90 D	28.3	40.3	12.0	5	4	24	26	128	105	157	135	29	30
ML 90 D	57.2	58.8	1.6	1	0	1	0	3	0	5	0	2	0
ML 90 D	83.6	85.1	1.5	2	0	0	0	2	4	4	4	2	0
ML 90 D	96.5	97.1	0.6	0	0	0	0	3	8	3	8	0	0
ML 90 D	129.7	135.8	6.1	7	3	16	13	53	49	76	65	23	16
ML 90 I	19.8	22.8	3.0	1	4	7	6	24	34	32	44	8	10
ML 90 I	29.4	40.6	11.2	7	11	11	13	93	97	111	121	18	24
ML 90 I	80.2	81.8	1.6	0	0	1	1	2	2	3	3	1	1
ML 90 I	87.3	88.1	0.8	0	1	0	1	6	5	6	7	0	2
ML 90 I	129.8	135.7	5.9	2	6	8	7	42	37	52	50	10	13
		Total	223.7	211	121	406	386	1458	1651	2075	2158	617	507

5 Year Interstate Crash Severity (Crashes/Mile)													
Route	Begin MP	End MP	Length (mi)	Critical		Serious		PDO		Total		Critical+Serious	
				Before	After	Before	After	Before	After	Before	After	Before	After
ML 25 D	16.5	17.3	0.8	0.00	0.00	2.50	1.25	8.75	5.00	11.25	6.25	2.50	1.25
ML 25 D	25.5	31.1	5.6	0.36	0.00	1.96	1.07	2.32	2.50	4.64	3.57	2.32	1.07
ML 25 D	166.9	174.9	8.0	0.88	0.25	1.13	1.25	4.25	3.50	6.25	5.00	2.00	1.50
ML 25 D	284.2	285.1	0.9	0.00	0.00	0.00	0.00	2.22	2.22	2.22	2.22	0.00	0.00
ML 25 I	16.5	17.3	0.8	2.50	1.25	5.00	3.75	10.00	10.00	17.50	15.00	7.50	5.00
ML 25 I	25.5	31.1	5.6	0.89	0.00	1.43	0.89	4.11	4.11	6.43	5.00	2.32	0.89
ML 25 I	166.9	174.9	8.0	0.88	0.25	1.50	0.88	3.38	3.50	5.75	4.63	2.38	1.13
ML 25 I	283.2	284.4	1.2	0.00	0.00	0.00	0.00	0.83	0.00	0.83	0.00	0.00	0.00
ML 80 D	57.0	65.5	8.5	0.47	0.24	1.76	1.88	4.00	5.18	6.24	7.29	2.24	2.12
ML 80 D	107.6	120.3	12.7	0.94	0.39	1.81	1.97	4.72	7.64	7.48	10.00	2.76	2.36
ML 80 D	130.0	138.0	8.0	1.63	0.50	1.88	1.88	6.25	8.25	9.75	10.63	3.50	2.38
ML 80 D	227.9	233.8	5.9	0.85	0.68	2.71	1.86	5.59	8.98	9.15	11.53	3.56	2.54
ML 80 D	263.6	275.4	11.8	2.03	0.59	2.20	1.95	13.05	13.14	17.29	15.68	4.24	2.54
ML 80 D	291.4	300.6	9.2	0.54	0.54	1.96	2.39	4.13	6.20	6.63	9.13	2.50	2.93
ML 80 D	336.6	349.0	12.4	1.05	0.65	3.15	1.94	8.63	7.50	12.82	10.08	4.19	2.58
ML 80 I	57.0	65.5	8.5	0.35	0.59	1.06	0.71	3.53	5.29	4.94	6.59	1.41	1.29
ML 80 I	107.6	120.3	12.7	0.63	0.55	0.87	1.42	4.17	4.17	5.67	6.14	1.50	1.97
ML 80 I	130.0	138.0	8.0	0.75	0.75	1.50	3.13	6.75	16.50	9.00	20.38	2.25	3.88
ML 80 I	227.4	233.8	6.4	1.41	1.41	0.78	0.78	3.59	5.16	5.78	7.34	2.19	2.19
ML 80 I	246.5	253.3	6.8	1.03	0.59	1.76	3.82	10.29	12.79	13.09	17.21	2.79	4.41
ML 80 I	263.6	275.4	11.8	0.93	0.59	1.95	2.12	6.95	9.24	9.83	11.95	2.88	2.71
ML 80 I	291.4	302.9	11.5	1.39	0.52	2.26	1.74	3.83	4.96	7.48	7.22	3.65	2.26
ML 80 I	336.6	349.0	12.4	2.18	0.65	2.82	1.94	11.21	8.06	16.21	10.65	5.00	2.58
ML 90 D	20.4	22.3	1.9	0.00	0.00	3.68	1.05	8.42	11.58	12.11	12.63	3.68	1.05
ML 90 D	28.3	40.3	12.0	0.42	0.33	2.00	2.17	10.67	8.75	13.08	11.25	2.42	2.50
ML 90 D	57.2	58.8	1.6	0.63	0.00	0.63	0.00	1.88	0.00	3.13	0.00	1.25	0.00
ML 90 D	83.6	85.1	1.5	1.33	0.00	0.00	0.00	1.33	2.67	2.67	2.67	1.33	0.00
ML 90 D	96.5	97.1	0.6	0.00	0.00	0.00	0.00	5.00	13.33	5.00	13.33	0.00	0.00
ML 90 D	129.7	135.8	6.1	1.15	0.49	2.62	2.13	8.69	8.03	12.46	10.66	3.77	2.62
ML 90 I	19.8	22.8	3.0	0.33	1.33	2.33	2.00	8.00	11.33	10.67	14.67	2.67	3.33
ML 90 I	29.4	40.6	11.2	0.63	0.98	0.98	1.16	8.30	8.66	9.91	10.80	1.61	2.14
ML 90 I	80.2	81.8	1.6	0.00	0.00	0.63	0.63	1.25	1.25	1.88	1.88	0.63	0.63
ML 90 I	87.3	88.1	0.8	0.00	1.25	0.00	1.25	7.50	6.25	7.50	8.75	0.00	2.50
ML 90 I	129.8	135.7	5.9	0.34	1.02	1.36	1.19	7.12	6.27	8.81	8.47	1.69	2.20
		Average		**0.78**	**0.48**	**1.65**	**1.48**	**5.90**	**6.82**	**8.34**	**8.78**	**2.43**	**1.96**

APPENDIX C2: ROR RUMBLE STRIP CRASHES AND CRASHES/MILE

2 Year Interstate ROR Crash Location (Crashes)									
Route	Begin MP	End MP	Length (mi)	Roadway Departure		Shoulder		Total	
				Before	After	Before	After	Before	After
ML 1004 B	5.0	17.8	12.80	0	0	1	0	1	0
ML 44 B	220.9	233.3	12.40	5	1	2	1	7	2
ML 45 B	0.0	2.3	2.30	1	0	0	0	1	0
ML 34 B	50.6	59.1	8.50	9	2	5	1	14	3
ML 12 B	6.3	10.4	4.10	0	0	0	0	0	0
ML 12 B	25.3	30.8	5.50	1	0	0	0	1	0
ML 85 B	202.0	219.5	17.50	1	0	0	0	1	0
ML 32 B	29.8	34.2	4.40	0	1	0	0	0	1
ML 26 B	12.0	12.6	0.60	0	0	0	0	0	0
ML 42 B	93.6	109.0	15.40	2	2	2	1	4	3
TOTALS			83.5	19	6	10	3	29	9

2 Year Interstate ROR Crash Location (Crashes/Mile)									
Route	Begin MP	End MP	Length (mi)	Roadway Departure		Shoulder		Total	
				Before	After	Before	After	Before	After
ML 1004 B	5.0	17.8	12.80	0.000	0.000	0.078	0.000	0.078	0.000
ML 44 B	220.9	233.3	12.40	0.403	0.081	0.161	0.081	0.565	0.161
ML 45 B	0.0	2.3	2.30	0.435	0.000	0.000	0.000	0.435	0.000
ML 34 B	50.6	59.1	8.50	1.059	0.235	0.588	0.118	1.647	0.353
ML 12 B	6.3	10.4	4.10	0.000	0.000	0.000	0.000	0.000	0.000
ML 12 B	25.3	30.8	5.50	0.182	0.000	0.000	0.000	0.182	0.000
ML 85 B	202.0	219.5	17.50	0.057	0.000	0.000	0.000	0.057	0.000
ML 32 B	29.8	34.2	4.40	0.000	0.227	0.000	0.000	0.000	0.227
ML 26 B	12.0	12.6	0.60	0.000	0.000	0.000	0.000	0.000	0.000
ML 42 B	93.6	109.0	15.40	0.130	0.130	0.130	0.065	0.260	0.195

2 Year Interstate ROR Crash Location (Crashes)											
Route	Begin MP	End MP	Length (mi)	Roadway Departure		Shoulder		Median		Total	
				Before	After	Before	After	Before	After	Before	After
ML 25 I	272.0	279.9	7.90	0	0	3	0	3	1	**6**	**1**
ML 25 D	272.0	279.9	7.90	0	0	1	0	0	1	**1**	**1**
ML 80 I	28.0	28.6	0.60	1	1	0	0	0	2	**1**	**3**
ML 80 I	139.0	141.0	2.00	3	4	1	0	3	1	**7**	**5**
ML 80 I	251.1	255.4	4.30	11	8	5	3	10	6	**26**	**17**
ML 80 I	300.4	302.8	2.40	5	3	2	0	1	0	**8**	**3**
ML 80 D	308.1	308.7	0.60	2	0	1	1	0	1	**3**	**2**
ML 80 I	329.1	336.2	7.10	10	7	5	4	8	9	**23**	**20**
ML 80 D	329.1	336.2	7.10	15	12	18	10	28	9	**61**	**31**
ML 80 I	356.7	357.7	1.00	1	1	1	0	1	0	**3**	**1**
ML 80 D	356.7	357.7	1.00	1	0	0	2	0	1	**1**	**3**
TOTALS			41.3	49	36	37	20	54	31	140	87

2 Year Interstate ROR Crash Location (Crashes/Mile)											
Route	Begin MP	End MP	Length (mi)	Roadway Departure		Shoulder		Median		Total	
				Before	After	Before	After	Before	After	Before	After
ML 25 I	272.0	279.9	7.90	0.000	0.000	0.380	0.000	0.380	0.127	0.759	0.127
ML 25 D	272.0	279.9	7.90	0.000	0.000	0.127	0.000	0.000	0.127	0.127	0.127
ML 80 I	28.0	28.6	0.60	1.667	1.667	0.000	0.000	0.000	3.333	1.667	5.000
ML 80 I	139.0	141.0	2.00	2.143	1.429	0.714	0.000	2.143	0.714	5.000	2.143
ML 80 I	251.1	255.4	4.30	2.558	1.860	1.163	0.698	2.326	1.395	6.047	3.953
ML 80 I	300.4	302.8	2.40	2.083	1.250	0.833	0.000	0.417	0.000	3.333	1.250
ML 80 D	308.1	308.7	0.60	3.333	0.000	1.667	1.667	0.000	1.667	5.000	3.333
ML 80 I	329.1	336.2	7.10	1.408	0.986	0.704	0.563	1.127	1.268	3.239	2.817
ML 80 D	329.1	336.2	7.10	2.113	1.690	2.535	1.408	3.944	1.268	8.592	4.366
ML 80 I	356.7	357.7	1.00	1.000	1.000	1.000	0.000	1.000	0.000	3.000	1.000
ML 80 D	356.7	357.7	1.00	1.000	0.000	0.000	2.000	0.000	1.000	1.000	3.000

5 Year Interstate ROR Crash Location (Crashes)											
Route	Begin MP	End MP	Length (mi)	Roadway Departure		Shoulder		Median		Total	
				Before	After	Before	After	Before	After	Before	After
ML 25 D	16.5	17.3	0.8	4	3	1	0	3	2	**8**	**5**
ML 25 D	25.5	31.1	5.6	11	5	4	2	5	7	**20**	**14**
ML 25 D	166.9	174.9	8.0	9	11	9	6	9	8	**27**	**25**
ML 25 D	284.2	285.1	0.9	0	0	0	0	0	0	**0**	**0**
ML 25 I	16.5	17.3	0.8	7	4	0	1	5	0	**12**	**5**
ML 25 I	25.5	31.1	5.6	12	8	4	8	9	7	**25**	**23**
ML 25 I	166.9	174.9	8.0	12	6	7	2	7	11	**26**	**19**
ML 25 I	283.2	284.4	1.2	0	0	0	0	0	0	**0**	**0**
ML 80 D	57.0	65.5	8.5	14	12	6	8	10	16	**30**	**36**
ML 80 D	107.6	120.3	12.7	26	22	11	17	24	30	**61**	**69**
ML 80 D	130.0	138.0	8.0	21	14	9	10	13	20	**43**	**44**
ML 80 D	227.9	233.8	5.9	8	13	13	6	15	17	**36**	**36**
ML 80 D	263.6	275.4	11.8	33	45	32	17	34	28	**99**	**90**
ML 80 D	291.4	300.6	9.2	18	17	9	13	13	23	**40**	**53**
ML 80 D	336.6	349.0	12.4	45	31	17	15	41	26	**103**	**72**
ML 80 I	57.0	65.5	8.5	14	7	1	8	11	17	**26**	**32**
ML 80 I	107.6	120.3	12.7	20	14	6	15	7	25	**33**	**54**
ML 80 I	130.0	138.0	8.0	18	33	8	12	10	46	**36**	**91**
ML 80 I	227.4	233.8	6.4	7	10	4	4	4	11	**15**	**25**
ML 80 I	246.5	253.3	6.8	22	34	13	10	22	22	**57**	**66**
ML 80 I	263.6	275.4	11.8	21	34	15	13	11	13	**47**	**60**
ML 80 I	291.4	302.9	11.5	25	18	5	14	17	17	**47**	**49**
ML 80 I	336.6	349.0	12.4	46	25	15	14	36	31	**97**	**70**
ML 90 D	20.4	22.3	1.9	4	3	7	4	2	3	**13**	**10**
ML 90 D	28.3	40.3	12.0	21	29	23	18	25	18	**69**	**65**
ML 90 D	57.2	58.8	1.6	0	0	0	0	1	0	**1**	**0**
ML 90 D	83.6	85.1	1.5	1	0	0	1	0	0	**1**	**1**
ML 90 D	96.5	97.1	0.6	0	2	0	0	0	0	**0**	**2**
ML 90 D	129.7	135.8	6.1	20	15	7	1	19	11	**46**	**27**
ML 90 I	19.8	22.8	3.0	4	7	7	7	1	4	**12**	**18**
ML 90 I	29.4	40.6	11.2	13	27	19	17	14	26	**46**	**70**
ML 90 I	80.2	81.8	1.6	2	0	0	0	0	0	**2**	**0**
ML 90 I	87.3	88.1	0.8	0	1	1	0	2	0	**3**	**1**
ML 90 I	129.8	135.7	5.9	9	10	5	0	8	2	**22**	**12**
		Total	223.7	467	460	258	243	378	441	**1103**	**1144**

5 Year Interstate ROR Crash Location (Crashes/Mile)											
Route	Begin MP	End MP	Length (mi)	Roadway Departure		Shoulder		Median		Total	
				Before	After	Before	After	Before	After	Before	After
ML 25 D	16.5	17.3	0.8	5.00	3.75	1.25	0.00	3.75	2.50	**10.00**	**6.25**
ML 25 D	25.5	31.1	5.6	1.96	0.89	0.71	0.36	0.89	1.25	**3.57**	**2.50**
ML 25 D	166.9	174.9	8.0	1.13	1.38	1.13	0.75	1.13	1.00	**3.38**	**3.13**
ML 25 D	284.2	285.1	0.9	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**0.00**
ML 25 I	16.5	17.3	0.8	8.75	5.00	0.00	1.25	6.25	0.00	**15.00**	**6.25**
ML 25 I	25.5	31.1	5.6	2.14	1.43	0.71	1.43	1.61	1.25	**4.46**	**4.11**
ML 25 I	166.9	174.9	8.0	1.50	0.75	0.88	0.25	0.88	1.38	**3.25**	**2.38**
ML 25 I	283.2	284.4	1.2	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**0.00**
ML 80 D	57.0	65.5	8.5	1.65	1.41	0.71	0.94	1.18	1.88	**3.53**	**4.24**
ML 80 D	107.6	120.3	12.7	2.05	1.73	0.87	1.34	1.89	2.36	**4.80**	**5.43**
ML 80 D	130.0	138.0	8.0	2.63	1.75	1.13	1.25	1.63	2.50	**5.38**	**5.50**
ML 80 D	227.9	233.8	5.9	1.36	2.20	2.20	1.02	2.54	2.88	**6.10**	**6.10**
ML 80 D	263.6	275.4	11.8	2.80	3.81	2.71	1.44	2.88	2.37	**8.39**	**7.63**
ML 80 D	291.4	300.6	9.2	1.96	1.85	0.98	1.41	1.41	2.50	**4.35**	**5.76**
ML 80 D	336.6	349.0	12.4	3.63	2.50	1.37	1.21	3.31	2.10	**8.31**	**5.81**
ML 80 I	57.0	65.5	8.5	1.65	0.82	0.12	0.94	1.29	2.00	**3.06**	**3.76**
ML 80 I	107.6	120.3	12.7	1.57	1.10	0.47	1.18	0.55	1.97	**2.60**	**4.25**
ML 80 I	130.0	138.0	8.0	2.25	4.13	1.00	1.50	1.25	5.75	**4.50**	**11.38**
ML 80 I	227.4	233.8	6.4	1.09	1.56	0.62	0.62	0.62	1.72	**2.34**	**3.91**
ML 80 I	246.5	253.3	6.8	3.24	5.00	1.91	1.47	3.24	3.24	**8.38**	**9.71**
ML 80 I	263.6	275.4	11.8	1.78	2.88	1.27	1.10	0.93	1.10	**3.98**	**5.08**
ML 80 I	291.4	302.9	11.5	2.17	1.57	0.43	1.22	1.48	1.48	**4.09**	**4.26**
ML 80 I	336.6	349.0	12.4	3.71	2.02	1.21	1.13	2.90	2.50	**7.82**	**5.65**
ML 90 D	20.4	22.3	1.9	2.11	1.58	3.68	2.11	1.05	1.58	**6.84**	**5.26**
ML 90 D	28.3	40.3	12.0	1.75	2.42	1.92	1.50	2.08	1.50	**5.75**	**5.42**
ML 90 D	57.2	58.8	1.6	0.00	0.00	0.00	0.00	0.63	0.00	**0.63**	**0.00**
ML 90 D	83.6	85.1	1.5	0.67	0.00	0.00	0.67	0.00	0.00	**0.67**	**0.67**
ML 90 D	96.5	97.1	0.6	0.00	3.33	0.00	0.00	0.00	0.00	**0.00**	**3.33**
ML 90 D	129.7	135.8	6.1	3.28	2.46	1.15	0.16	3.11	1.80	**7.54**	**4.43**
ML 90 I	19.8	22.8	3.0	1.33	2.33	2.33	2.33	0.33	1.33	**4.00**	**6.00**
ML 90 I	29.4	40.6	11.2	1.16	2.41	1.70	1.52	1.25	2.32	**4.11**	**6.25**
ML 90 I	80.2	81.8	1.6	1.25	0.00	0.00	0.00	0.00	0.00	**1.25**	**0.00**
ML 90 I	87.3	88.1	0.8	0.00	1.25	1.25	0.00	2.50	0.00	**3.75**	**1.25**
ML 90 I	129.8	135.7	5.9	1.53	1.69	0.85	0.00	1.36	0.34	**3.73**	**2.03**
		Average		1.97	1.91	1.02	0.89	1.59	1.55	**4.58**	**4.34**

APPENDIX C3: DESCRIPTIVE ANALYSIS OF SHOULDER RUMBLE STRIPS

FHE Location v. Crash Severity	State Highway 2 YR Before-After Crashes (#)									
	CRITICAL		SERIOUS		PDO		TOTAL		Critical & Serious	
	Before	After	Before	After	Before	After	**Before**	**After**	**Before**	**After**
Off Roadway	6	0	5	2	8	4	**19**	**6**	**11**	**2**
Shoulder	0	0	2	1	8	2	**10**	**3**	**2**	**1**
TOTAL	**6**	**0**	**7**	**3**	**16**	**6**	**29**	**9**	**13**	**3**

FHE Location v. Crash Severity	State Highway 2 YR Before-After Crash Reduction (%)				
	CRITICAL	SERIOUS	PDO	TOTAL	C + S
Road Departure	100%	60%	50%	68%	82%
Shoulder	0%	50%	75%	70%	50%
TOTAL	100%	57%	63%	69%	77%

FHE Location v. Crash Severity	Interstate 2 YR Before-After Crashes (#)									
	CRITICAL		SERIOUS		PDO		TOTAL		Critical & Serious	
	Before	After	Before	After	Before	After	**Before**	**After**	**Before**	**After**
Off Roadway	2	1	17	10	30	25	**49**	**36**	**19**	**11**
Shoulder	1	1	11	5	25	14	**37**	**20**	**12**	**6**
Median	4	3	18	7	32	21	**54**	**31**	**22**	**10**
TOTAL	**7**	**5**	**46**	**22**	**87**	**60**	**140**	**87**	**53**	**27**

FHE Location v. Crash Severity	Interstate 2 YR Before-After Crash Reduction (%)				
	CRITICAL	SERIOUS	PDO	TOTAL	C + S
Road Departure	50%	41%	17%	27%	42%
Shoulder	0%	55%	44%	46%	50%
Median	25%	61%	34%	43%	55%
TOTAL	29%	52%	31%	38%	49%

FHE Location v. Crash Severity	Interstate 5 YR Before-After Crashes (#)									
	CRITICAL		SERIOUS		PDO		TOTAL		C & S	
	Before	After	Before	After	Before	After	**Before**	**After**	**Before**	**After**
Off Roadway	51	27	125	94	277	333	**453**	**454**	**176**	**121**
Shoulder	34	15	57	66	167	162	**258**	**243**	**91**	**81**
Median	64	40	96	89	231	312	**391**	**441**	**160**	**129**
TOTAL	**149**	**82**	**278**	**249**	**675**	**807**	**1102**	**1138**	**427**	**331**

FHE Location v. Crash Severity	Interstate 5 YR Before-After Crash Reduction (%)				
	CRITICAL	SERIOUS	PDO	**TOTAL**	C + S
Road Departure	47%	25%	-20%	**0%**	31%
Shoulder	56%	-16%	3%	**6%**	11%
Median	38%	7%	-35%	**-13%**	19%
TOTAL	**45%**	**10%**	**-20%**	**-3%**	**22%**

APPENDIX D1: EXTRACTED CABLE MEDIAN BARRIER CRASH DATA - TOTAL

TOTAL FHE v FHE Loc Crashes - BEFORE	Off Roadway	Median	On OTHER Roadway	TOTAL
Overturn or Rollover	490	543	5	1038
Fire or Explosion	2	0	1	3
Other Non-Collision MC Loss of Control	84	148	0	232
Pedestrian	1	0	0	1
Motor Vehicle in Transport on Roadway	11	13	25	49
Parked Motor Vehicle	20	6	4	30
Other NON-Fixed Object	2	8	0	10
Deer	5	1	0	6
Antelope	1	0	0	1
Other Wild	1	0	0	1
Guardrail End	18	16	0	34
Guardrail Face	215	298	0	513
Bridge Overhead Structure	24	2	0	26
Bridge Rail	25	2	0	27
Utility Pole or Light Support	8	4	0	12
Traffic Sign Support	3	0	0	3
Other Traffic Sign Support	46	7	0	53
Barricade	16	11	0	27
Trees or Shrubbery	12	1	0	13
Cut Slope	4	3	0	7
Road Approach	0	2	0	2
Rock Boulder Rock Slide	5	2	0	7
End of Drainage Pipe or Structure or Culvert	7	5	0	12
Building or Other Structure Wall	8	1	0	9
Fence including Post	114	12	0	126
Delineator Post	96	54	0	150
Earth Embankment or Berm	69	21	0	90
Snow Embankment	3	1	0	4
Other Fixed Object	13	9	0	22
Cable Barrier	0	0	0	0
TOTAL	**1303**	**1170**	**35**	**2508**

TOTAL FHE v FHE Loc - AFTER	Off Roadway	Median	On OTHER Roadway	TOTAL
Overturn or Rollover	367	400	4	771
Fire or Explosion	0	2	0	2
Jacknife	64	97	1	162
Cargo or Equipment Loss of Shift	4	1	0	5
Thrown or Falling Object	1	0	0	1
Injuries by being thrown again part of vehicle	1	0	0	1
Other Non-Collision MC Loss of Control	3	8	0	11
Motor Vehicle in Transport on Roadway	6	11	9	26
Parked Motor Vehicle	3	7	0	10
Work Zone Channeling Device	2	0	0	2
Object Set in Motion by Another Vehicle	0	1	0	1
Deer	4	0	0	4
Antelope	1	0	0	1
Other Wild	2	1	0	3
Guardrail End	19	20	0	39
Guardrail Face	309	225	0	534
Impact Attenuator or Crash Cushion	1	2	0	3
Bridge Pier or Support	0	1	0	1
Bridge Rail	13	3	0	16
Concrete Traffic Barrier or Jersey Barrier	54	96	0	150
Other Traffic Barrier includes temporary	4	6	0	10
Utility Pole or Light Support	9	1	0	10
Traffic Sign Support	5	2	0	7
Sign Support Single Post	27	2	0	29
Sign Support Multiple Post	14	2	0	16
Barricade	0	2	0	2
Trees or Shrubbery	5	2	0	7
Cut Slope	8	1	0	9
Road Approach	1	1	0	2
Rock Boulder Rock Slide	3	0	0	3
End of Drainage Pipe or Structure or Culvert	8	2	0	10
Building or Other Structure Wall	2	0	0	2
Fence including Post	105	8	0	113
Raised Median or Curb	1	4	0	5
Delineator Post	110	48	0	158
Earth Embankment or Berm	30	3	0	33
Ditch	25	4	0	29
Snow Embankment	4	3	0	7
Tunnel	1	0	0	1
Other Fixed Object	2	3	0	5
Cable Barrier	0	362	0	362
TOTAL	**1218**	**1331**	**14**	**2563**

APPENDIX D2: EXTRACTED CABLE MEDIAN BARRIER CRASH DATA – BY SEVERITY

Critical FHE vs. FHE Loc - BEFORE	Off Roadway	Median	On OTHER Roadway	TOTAL
Overturn or Rollover	90	101	3	194
Other Non-Collision MC Loss of Control	4	6	0	10
Motor Vehicle in Transport on Roadway	0	1	11	12
Parked Motor Vehicle	4	1	0	5
Guardrail Face	17	22	0	39
Bridge Overhead Structure	1	0	0	1
Utility Pole or Light Support	1	0	0	1
Other Traffic Sign Support	2	0	0	2
Barricade	2	3	0	5
Trees or Shrubbery	2	0	0	2
Road Approach	0	1	0	1
End of Drainage Pipe or Structure or Culvert	1	2	0	3
Fence including Post	4	1	0	5
Delineator Post	9	9	0	18
Earth Embankment or Berm	5	3	0	8
Other Fixed Object	1	2	0	3
TOTAL	**143**	**152**	**14**	**309**

Critical FHE vs. FHE Loc - AFTER	Off Roadway	Median	On OTHER Roadway	TOTAL
Overturn or Rollover	46	58	0	104
Other Non-Collision MC Loss of Control	2	2	0	4
Motor Vehicle in Transport on Roadway	0	2	3	5
Guardrail End	1	1	0	2
Guardrail Face	6	7	0	13
Bridge Rail	1	0	0	1
Concrete Traffic Barrier or Jersey Barrier	2	5	0	7
Traffic Sign Support	0	1	0	1
Sign Support Single Post	1	0	0	1
Trees or Shrubbery	0	1	0	1
Road Approach	0	1	0	1
Fence including Post	4	1	0	5
Delineator Post	6	6	0	12
Earth Embankment or Berm	4	0	0	4
Other Fixed Object	1	0	0	1
Cable Barrier	1	2	0	3
TOTAL	**75**	**87**	**3**	**165**

Serious FHE vs. FHE Loc - BEFORE	Off Roadway	Median	On OTHER Roadway	TOTAL
Overturn or Rollover	182	205	2	389
Other Non-Collision MC Loss of Control	8	21	0	29
Motor Vehicle in Transport on Roadway	5	5	6	16
Parked Motor Vehicle	2	1	0	3
Other NON-Fixed Object	0	2	0	2
Deer	1	0	0	1
Guardrail End	3	4	0	7
Guardrail Face	39	43	0	82
Bridge Overhead Structure	4	1	0	5
Bridge Rail	7	0	0	7
Utility Pole or Light Support	2	0	0	2
Traffic Sign Support	1	0	0	1
Other Traffic Sign Support	11	2	0	13
Barricade	10	2	0	12
Trees or Shrubbery	2	0	0	2
Cut Slope	0	1	0	1
Rock Boulder Rock Slide	2	1	0	3
Building or Other Structure Wall	3	1	0	4
Fence including Post	12	0	0	12
Delineator Post	15	6	0	21
Earth Embankment or Berm	16	3	0	19
Other Fixed Object	5	2	0	7
TOTAL	**330**	**300**	**8**	**638**

Serious FHE vs. FHE Loc - AFTER	Off Roadway	Median	On OTHER Roadway	TOTAL
Overturn or Rollover	168	137	3	308
Jacknife	1	4	0	5
Injuries by being thrown again part of vehicle	1	0	0	1
Other Non-Collision MC Loss of Control	1	2	0	3
Motor Vehicle in Transport on Roadway	3	3	2	8
Parked Motor Vehicle	1	2	0	3
Guardrail End	2	3	0	5
Guardrail Face	53	39	0	92
Impact Attenuator or Crash Cushion	0	1	0	1
Bridge Pier or Support	0	1	0	1
Bridge Rail	2	1	0	3
Concrete Traffic Barrier or Jersey Barrier	6	19	0	25
Utility Pole or Light Support	5	1	0	6
Sign Support Single Post	0	1	0	1
Barricade	0	1	0	1
Rock Boulder Rock Slide	1	0	0	1
End of Drainage Pipe or Structure or Culvert	2	0	0	2
Building or Other Structure Wall	1	0	0	1
Fence including Post	10	2	0	12
Raised Median or Curb	0	1	0	1
Delineator Post	14	6	0	20
Earth Embankment or Berm	2	1	0	3
Ditch	3	0	0	3
Snow Embankment	2	0	0	2
Tunnel	1	0	0	1
Other Fixed Object	0	2	0	2
Cable Barrier	6	21	0	27
TOTAL	**285**	**248**	**5**	**538**