DiExSys, LLC
8608 W Mountain View Lane Littleton, CO 80125

June 30, 2015

Kraig McLeod, P.E.
Traffic Safety Engineer
Montana DOT

Dear Kraig:

Re: **MONTANA ROADWAY DEPARTURE SAFETY IMPLEMENTATION PLAN**

DiExSys, LLC is very pleased to submit this report intended to assist Montana Department of Transportation (MDT) with providing the highest level of safety possible on the Montana highways with construction funds available. This report describes the development of Montana Roadway Departure Safety Implementation Plan (RDSIP) using data driven approach. This approach was enabled by the development of Montana-specific Safety Knowledge Base developed earlier in the project.

We would like to express our gratitude to the MDT staff and management for the valuable assistance provided during the course of the work. DiExSys LLC sincerely appreciates the opportunity to conduct this important study and be of service to the Montana Department of Transportation.

Respectfully submitted,

DiExSys, LLC

Jake Kononov, P.E., Ph.D.

Bryan K. Allery, P.E.

ROADWAY DEPARTURE SAFETY IMPLEMENTATION PLAN
(RDSIP)

June 2015

Reproduction of any Portion of this Document is Prohibited without Expressed Written Authority from the Montana Department of Transportation

This report is prepared solely for the purpose of identifying, evaluating and planning safety improvements on public roads in Montana. It is subject to the provisions of 23 U.S.C.A. 409, and therefore is not subject to discovery and is excluded from evidence. Applicable provisions of 23 U.S.C.A. 409 are cited below:

> *Notwithstanding any other provision of law, reports, surveys, schedules, lists, or data compiled or collected for the purpose of identifying, evaluating, or planning the safety enhancement of potential accident sites, hazardous roadway conditions, or railway-highway crossings, pursuant to sections 130, 144, and 152 of this title or for the purpose of developing any highway safety construction improvement project which may be implemented utilizing Federal-aid highway funds Shall not be subject to discovery or admitted into evidence in a Federal or State court proceeding or considered for other purposes in any action for damages arising from any occurrence at a location mentioned or addressed in such reports, surveys, schedules, lists or data.*

Any intentional or inadvertent release of this report, or any data derived from its use shall not constitute a waiver of privilege pursuant to 23 U.S.C.A. 409.

RDSIP - Table of Contents

EXECUTIVE SUMMARY

This report describes the development of the Montana Roadway Departure Safety Implementation Plan (RDSIP) using a data driven approach. This approach was enabled by the development of the Montana-Specific Safety Knowledge Base. The Montana-Specific Safety Knowledge Base is intended to serve as an analytical engine to assist Montana Department of Transportation (MDT) staff with maximizing safety improvements on Montana roads. It is comprised of predictive tools in the form of Safety Performance Functions (SPF) and diagnostic tools in the form of diagnostic menus and pattern recognition algorithms.

The primary use of SPF is to assess the magnitude of the safety problem while diagnostic menus and pattern recognition analysis are used to identify its nature. Both are used in the development of the Roadway Departure Safety Implementation Plan as well as providing safety decision support analysis on all projects at the Montana DOT.

RDSIP developed a planning level estimate of $73 million per year necessary to meet MDT's goal of reducing Montana roadway departure crashes by 5% annually. It will require funding a sustained program of safety improvements aimed at locations with potential for crash reduction using traditional and systemic approaches with benefit/cost (B/C) ratio of at least 2:1, to meet the goal. This estimate is based on conservative assumptions, recognizing that some degree of uncertainty may exist about the magnitude of actual crash reductions, cost of construction and traffic exposure. The expenditure of $73 Million annually is well beyond the current annual allocation of Highway Safety Improvement Plan (HSIP) funds, however, each construction project presents an opportunity for cost-effective safety improvements that are consistent with the intent of the project scope. Only when all branches of MDT are working in concert toward the important and ambitious goal of reducing 5% of the roadway departure crashes annually will this goal become a reality. Scheduled maintenance, Intelligent transportation System (ITS), pavement preservation, rehabilitation, reconstruction, major widening and realignment projects all have significant potential for crash reduction within constraints of available budgets when this potential and need are identified at the project scoping phase. Using Montana-Specific Safety Knowledge Base will enable MDT to identify these opportunities.

To aid MDT with identification of locations with potential for crash reduction RDSIP includes GIS maps with Level of Service of Safety (LOSS)-categories and with roadway departure-related crash patterns. These maps were developed on the basis of the statewide SPF and Pattern Recognition Analysis using newly developed Montana-specific predictive and diagnostic tools. To demonstrate how locations for crash reduction can be selected RDSIP includes a list of 30 sites exhibiting elevated number of the roadway departure injury crashes or roadway departure-related crash patterns. Each potential site was examined further through diagnostic examination, followed by countermeasure development and the B/C analysis. An abbreviated example of a typical Safety Assessment Report is provided.

Additionally RDSIP developed requisite 5 year threshold of the number of injury crashes per mile (10 miles for rumble strips) *to produce* B/C Ratios of 2:1 or greater for the following selected countermeasures:

- Improvements of signing and delineation
- Center-line Rumble Strips
- Shoulder Rumble Strips
- Guardrail Installation
- Intensification of Snow and Ice Removal above Standard Levels of Maintenance

Using these thresholds enables MDT to identify future Roadway Departure Safety Improvement (RDSI) projects by considering how cost and safety benefits can be anticipated at the time of initial screening.

RDSIP provides a GIS map of locations where alcohol-related crashes are over-represented. These maps were developed on the basis of statewide pattern recognition analysis and can be used to target enforcement and possibly education efforts. In some cases behavioral intervention on selected corridors can be combined with engineering countermeasures to produce Enforcement-Education-Engineering (3E) projects.

To assist with the evaluation of effectiveness of constructed safety improvements using Montana-specific Safety Knowledge Base the RDSIP provides technical guidance and examples.

STATEMENT OF PHILOSOPHY

The efficient and responsible investment of resources in addressing safety problems is a difficult task. Since crashes occur on all highways in use, it is inappropriate to say of any highway that it is safe. However, it is correct to say that highways can be built to be safer or less safe. Road safety is a matter of degree. When making decisions effecting road safety it is critical to understand that expenditure of limited available funds on improvements in places where it prevents few injuries and saves few lives can mean that injuries will occur and lives will be lost by not spending them in places where more accidents could have been prevented[1]. It is Montana Department of Transportation's (MDT's) objective to maximize crash reduction within the limitations of available budgets by making road safety improvements at locations where it does the most good or prevents the most crashes.

GOALS and OBJECTIVES

Relating Reduction in the Roadway Departure Crashes with Planned Expenditures or *What would it Cost to Reduce Montana Roadway Departure Crashes by 5% Annually?*

The Montana Comprehensive Highway Safety Plan (CHSP) suggests a goal of 5% annual reduction in roadway departure crashes. An effective Roadway Departure Safety Implementation Plan (RDSIP) should contain a linkage between expenditures and expected safety improvement outcomes, recognizing that some degree of uncertainty may exist about the magnitude of actual crash reductions, cost of construction and traffic exposure. A quantitative framework to establish this linkage is based on the following conservative assumptions:

- Only Roadway Departure Safety Improvement (RDSI) projects with an expected average Benefit/Cost (B/C) Ratio of 2:1 or better will be constructed, so an assumed B/C of 2 used in this analysis is very conservative.
- The assumed average service life cycle of the constructed safety improvements is 10 years
- Discount Rate = 5%, and Annual Growth in Traffic = 2%
- The cost of a Property Damage Only (PDO) crash is $8,900[2]
- The cost of an Injury Crash is $78,900[2]
- The cost of a Fatal Crash is $1,410,000[2]

If we construct highway safety improvement project that prevents 1 injury crash per year over its service life of 10 years we will then realize a societal benefit of $670,000 (present worth of 10 prevented injury crashes, using discount rate of 5% with AADT annual growth of 2%) over a 10 year period.

---

[1] Hauer, E., Safety Review of Highway 407: Confronting Two Myths. In Transportation Research Record 1693, TRB, National Research Council, Washington, D.C., 1999 pp 9-12.

[2] Estimating the Costs of Unintentional Injuries, Fatal and Nonfatal Injuries, ***National Safety Council (NSC)*** 2012.

It is important to note that crash reduction benefit begins once the improvement has been constructed. If we select projects in such a way that following construction we can observe benefit/cost ratio of 2:1; then the cost of this improvement should be $335,000 spent in the year one (**Table 1**). ***In other words, onetime cost of $335,000 in construction will prevent 1 injury crash per year for 10 years.***

MONTANA

Montana Department of Transportation
DiExSys™ Roadway Safety Systems
Economic Analysis Report

10/29/2014

Job #: 20141029112256

Location: 1A **Begin:** 0.00 **End:** 0.00 **From:** 01/01/2012 **To:** 12/31/2012

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	0		Weighted PDO:	0.00	0% :ARF for PDO	Cost of PDO:	$ 8,900
INJ:	1	0 :Injured	Weighted INJ:	1.10	100% :ARF for INJ	Cost of INJ:	$ 78,900
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :ARF for FAT	Cost of FAT:	$ 1,410,000
			B/C Weighted Year Factor:	1.00	100% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
	Cost: $ 335,000					Service Life:	10
	From: 01/01/2012					Capital Recovery Factor:	0.129
	To: 12/31/2012		Days: 366			Annual Maintenance Cost:	$ 0

Benefit Cost Ratio: 2.00 (B/C Based on Crash Numbers : PDO/INJ/FAT)

Type of Improvement: RDSIP PLANNING LEVEL ANALYSIS AIMED AT REDUCTION OF INJURY CRASHES

Special Notes:

Table 1 Estimate of the Cost of Preventing 1 Injury Crash per year for 10 Years

Similar reasoning, albeit accounting for different societal benefits and different costs of construction, can be applied to estimating the cost of preventing 1 fatal crash per year (Table 2) and the cost of preventing 1 PDO crash per year (Table 3). Table 2 shows that onetime construction expenditure of $5,975,000 will prevent 1 fatal crash per year for 10 years and Table 3 shows that the cost of preventing 1 PDO crash per year for 10 years is $37,800. Considering that there are approximately 3,890 PDO, 2017 Injury and 130 Fatal roadway departure crashes per year in Montana it is possible to estimate the cost of meeting the 5% goal of annual crash reduction of the roadway departure crashes.

MONTANA

Montana Department of Transportation
DiExSys™ Roadway Safety Systems
Economic Analysis Report

11/10/2014

Job #: 20141110194610

Location: 1A **Begin:** 0.00 **End:** 0.00 **From:** 01/01/2012 **To:** 12/31/2012

Benefit Cost Ratio Calculations

	Accidents		Projected Accidents and Reduction Factors			Other Information	
PDO:	0		Weighted PDO:	0.00	0% :ARF for PDO	Cost of PDO:	$ 8,900
INJ:	0	0 :Injured	Weighted INJ:	0.00	0% :ARF for INJ	Cost of INJ:	$ 78,900
FAT:	1	0 :Killed	Weighted FAT:	1.10	100% :ARF for FAT	Cost of FAT:	$ 1,410,000
			B/C Weighted Year Factor:	1.00	100% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
	Cost: $ 5,975,000					Service Life:	10
	From: 01/01/2012					Capital Recovery Factor:	0.129
	To: 12/31/2012		Days: 366			Annual Maintenance Cost:	$ 0

Benefit Cost Ratio: 2.00 (B/C Based on Crash Numbers : PDO/INJ/FAT)

Type of Improvement: RDSIP PLANNING LEVEL ANALYSIS AIMED AT REDUCTION OF FATAL CRASHES
Special Notes:

Table 2 Estimate of the Cost of Preventing 1 Fatal Crash per year for 10 years

MONTANA

Montana Department of Transportation
DiExSys™ Roadway Safety Systems
Economic Analysis Report

10/29/2014

Job #: 20141029112256

Location: 1A **Begin:** 0.00 **End:** 0.00 **From:** 01/01/2012 **To:** 12/31/2012

Benefit Cost Ratio Calculations

	Accidents		Projected Accidents and Reduction Factors			Other Information	
PDO:	1		Weighted PDO:	1.10	100% :ARF for PDO	Cost of PDO:	$ 8,900
INJ:	0	0 :Injured	Weighted INJ:	0.00	0% :ARF for INJ	Cost of INJ:	$ 78,900
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :ARF for FAT	Cost of FAT:	$ 1,410,000
			B/C Weighted Year Factor:	1.00	100% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
	Cost: $ 37,800					Service Life:	10
	From: 01/01/2012					Capital Recovery Factor:	0.129
	To: 12/31/2012		Days: 366			Annual Maintenance Cost:	$ 0

Benefit Cost Ratio: 2.00 (B/C Based on Crash Numbers : PDO/INJ/FAT)

Type of Improvement: RDSIP PLANNING LEVEL ANALYSIS AIMED AT REDUCTION OF PDO CRASHES
Special Notes:

Table 3 Estimate of the Cost of Preventing 1 PDO Crash per year for 10 years

Assuming that there is sufficient number of sites available to achieve the B/C of 2/1 and considering frequency and severity of the roadway departure crashes in Montana; **Table 4** Shows how the cost of preventing 5% of these crashes annually can be computed.

Type of Crash	Average Number of Crashes Per Year	5%	Cost to Prevent 1 Crash Per Year	Cost to Prevent 5% Annually
Property Damage	3,890	194.50	$37,500	$7,294,000
Injury	2,017	100.85	$335,000	$33,785,000
Fatal	130	6.50	$5,975,000	$38,838,000
Total				**$72,626,000**

Table 4 Cost of Preventing 5% of Roadway Departure Crashes per year

Therefore a sustained RDSI program of about $73 Million per year in safety improvements aimed at locations with potential for crash reduction using traditional and systemic approaches with benefit/cost of at least 2 would be expected to reduce roadway departure crashes of all severities by at least 5% each year.

Clearly, the expenditure of $73 Million annually is well beyond current annual HSIP, however, each construction project presents an opportunity for cost-effective safety improvements that are consistent with the intent of the project scope. When all branches of MDT are working in concert toward the important and ambitious goal of reducing 5% of the roadway departure crashes annually this goal will become a reality. For instance; scheduled maintenance, pavement preservation, rehabilitation, reconstruction, major widening and realignment projects all have significant potential for crash reduction within constraints of available budgets when this potential and need are identified at the project scoping phase. The data driven approach to solving safety problems presented later in this report is based on the new Montana-Specific predictive and diagnostic tools. These analytical tools are intended to be used in providing safety decision support analysis not only on safety motivated projects identified thru the HSIP, but on all projects at MDT.

MONTANA-SPECIFIC SAFETY KNOWLEDGE BASE

The Montana-Specific Safety Knowledge Base was developed as part of the Montana RDSIP. Its detailed description is provided in a separate document[3]. The Montana-Specific Safety Knowledge Base is intended to serve as an analytical engine to assist MDT staff with maximizing safety improvements on Montana highways. It is comprised of predictive tools in the form of Safety Performance Functions (SPF) and diagnostic tools in the form of diagnostic menus and pattern recognition algorithms.

[3] Montana-Specific Safety Knowledge Base. DiExSys, 2013.

The primary use of SPF is to assess the magnitude of the safety problem while diagnostic menus and pattern recognition analysis are used to identify its nature. Both are used in the development of the Roadway Departure Safety Implementation Plan and in providing safety decision support analysis on all projects at the Montana DOT.

Montana Dataset Preparation

All of the dataset preparation was performed using the MDT crash database. Crash history for each facility was prepared over the period of 5 years (1/1/2008 to 12/31/2012). The Annualized Average Daily Traffic (AADT) for each roadway segment for each of the 5 years was entered into the same dataset; intersection related crashes were removed prior to fitting of the model. Isolating a distance of approximately 250 ft. on both sides of rural intersections is a conservative measure, but it will ensure that intersection related conflicts will not pollute the data-set comprised of non-intersection related crashes and road segments. **Figure 1** illustrates how segments datasets were prepared. For freeways, all of the interchange related crashes including crashes, which occurred on ramps, and crossroads were removed from the crash database prior to fitting the model. The reason for removing ramp and cross road crashes was to isolate main line only crashes required for the development of Freeway Safety Performance Functions. **Figure 2** illustrates how freeway segments datasets were prepared.

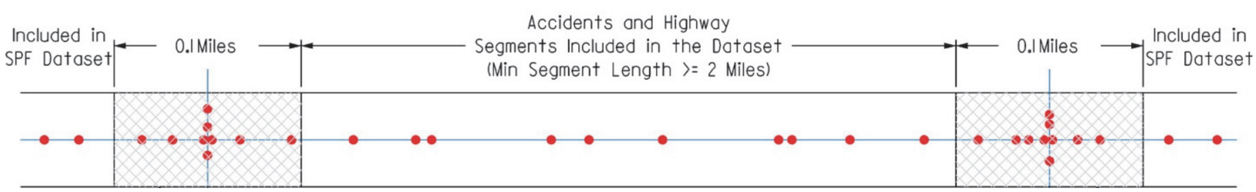

Figure 1 – Dataset Preparation for Rural Highways

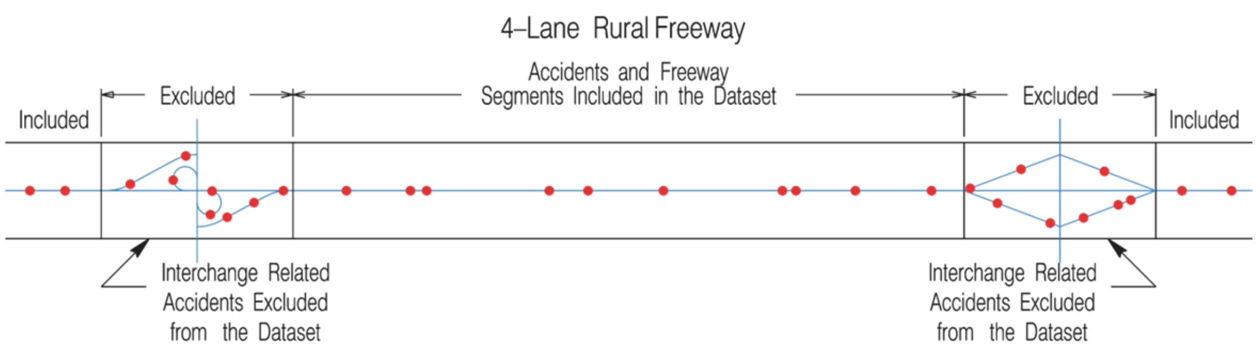

Figure 2 – Dataset Model for 4-Lane Interstates

Montana-Specific Predictive and Diagnostic Tools

SPFs, Level of Service of Safety (LOSS) Boundaries and Diagnostic Menus were developed for the following facilities:

- Rural Flat and Rolling 2-Lane Highways
- Rural Flat and Rolling 4-Lane Highways
- Rural Flat and Rolling 4-Lane Freeways
- Rural Mountainous 2-Lane Highways
- Rural Mountainous 4-Lane Freeways
- Urban 4-Lane Freeways

Considering that the focus of this effort is on the Run Off the Road (ROR) crashes, Safety Performance Functions (SPF-ROR) for ROR only crashes were also developed for:

- 2-Lane Rural Flat and Rolling Highways (ROR)
- 4-Lane Rural Flat and Rolling Divided Freeways (ROR)
- 2-Lane Mountainous Highways (ROR)

The datasets were prepared as described above, however the crash types in the ROR datasets were limited only to the following: overturning, fixed object, head-on and sideswipe-opposite crashes. All other crash types were filtered out prior to regression.

Development of the SPF lends itself well to the conceptual formulation of *Level of Service of Safety* (LOSS). The level of service concept provides quantitative assessment and qualitative description of the magnitude of the safety problem in reference to its expected performance. If the level of safety predicted by the SPF will represent a normal or expected number of crashes at a specific level of AADT, then the degree of deviation from the norm was stratified to represent specific levels of safety.

- LOSS I - Indicates low potential for crash reduction
- LOSS II - Indicates low to moderate potential for crash reduction
- LOSS III - Indicates moderate to high potential for crash reduction
- LOSS IV - Indicates high potential for crash reduction

Application of the LOSS concept to Montana highways enables MDT to do the following:

- Qualitatively and quantitatively describe the degree of safety or un-safety of Montana Highways
- Effectively communicate the magnitude of the safety problem to other professionals and elected officials
- Bring the perception of roadway safety in line with the reality of safety performance of different road types in Montana.
- Provide a frame of reference for decision making on non-safety motivated projects (resurfacing, reconstruction or widening, for instance)
- Provide a frame of reference from a safety perspective for planning major corridor improvements

Application of the pattern recognition analysis statewide enables MDT to identify crash patterns that may be susceptible to cost-effective correction. It is important to realize that crash patterns may be present with and without elevated crash frequency reflected by the LOSS-III and IV categories. Diagnostic analysis and subsequent construction of safety improvements at sites that can be identified by the LOSS and pattern recognition analyses are expected to result in significant and cost-effective crash reduction. To aid MDT with identification of locations with potential for crash reduction RDSIP includes maps with LOSS-categories and crash patterns. Selected Maps are provided on (**Figures 3-12**). To illustrate the utility of using these maps enlarged details of several maps are also included. These maps were developed on the basis of the statewide SPF and Pattern Recognition Analysis using newly developed Montana-specific predictive and diagnostic tools.

Level of Service and Crash Pattern Maps

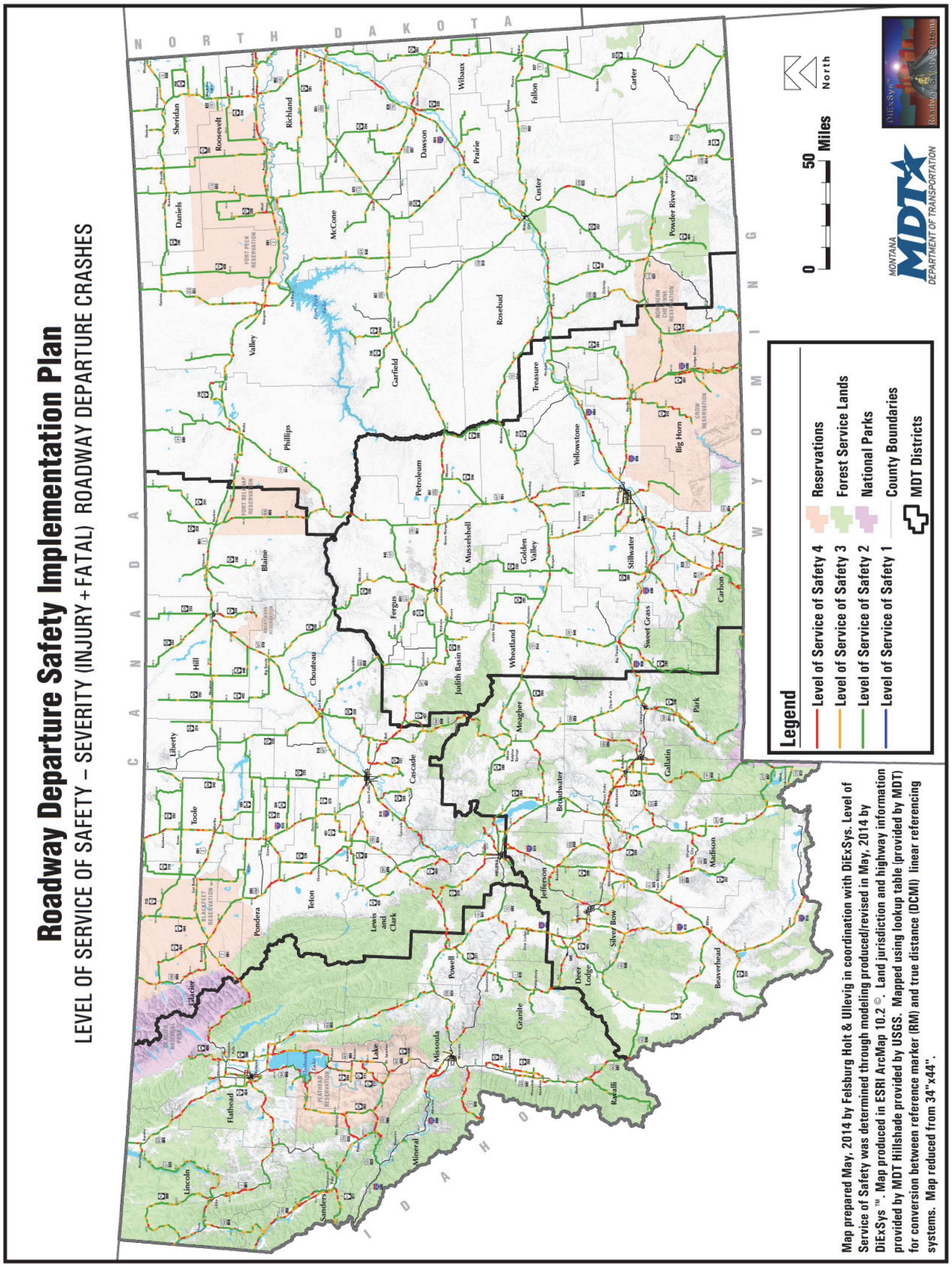

Figure 3 SPF-based Roadway Departure LOSS Map (Injury+Fatal Crashes)

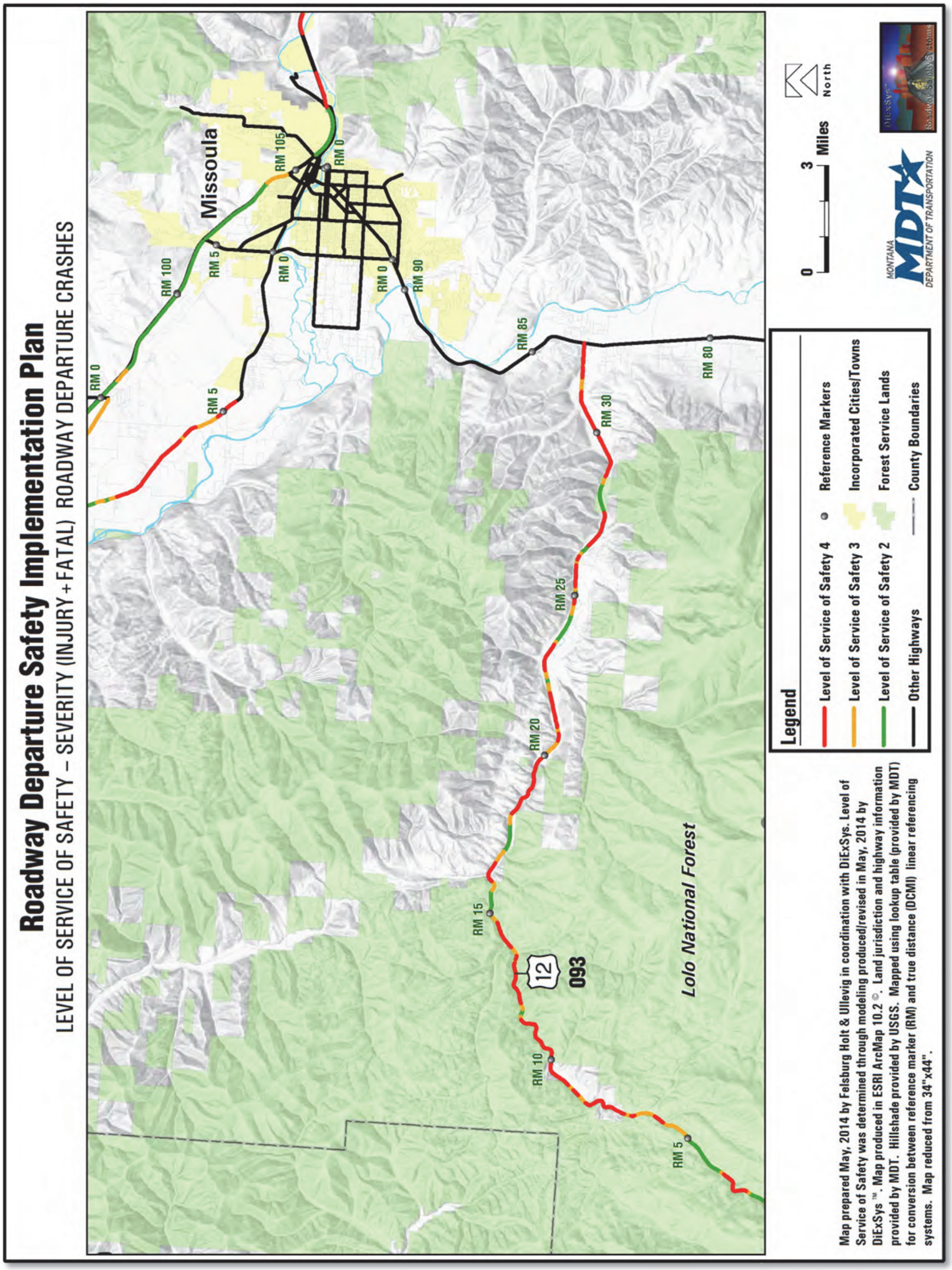

Figure 4 Zoom-in of SPF-based Roadway Departure LOSS Map (Injury+Fatal Crashes)

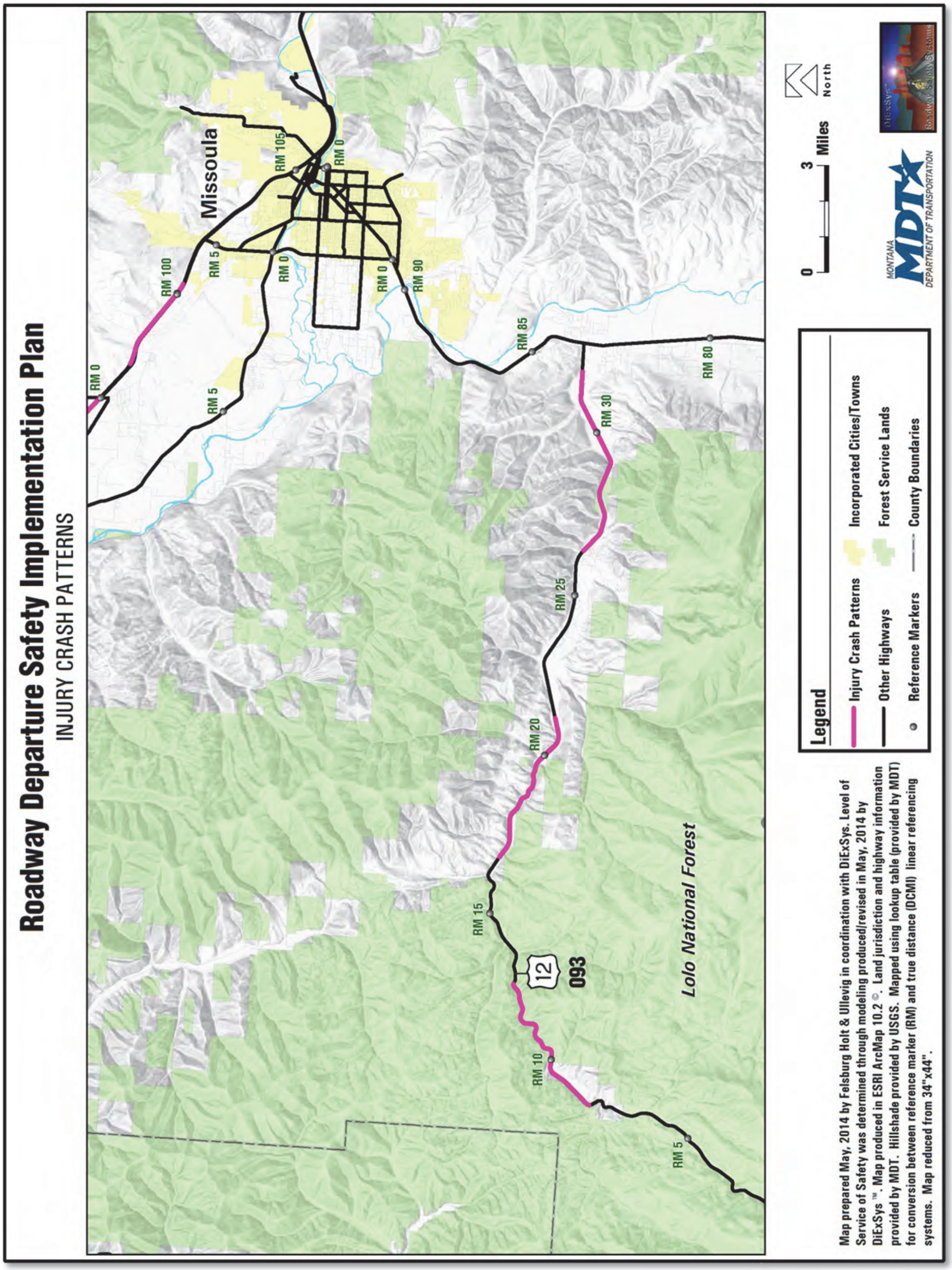

Figure 5 Zoom-in Map Injury Crash Patterns

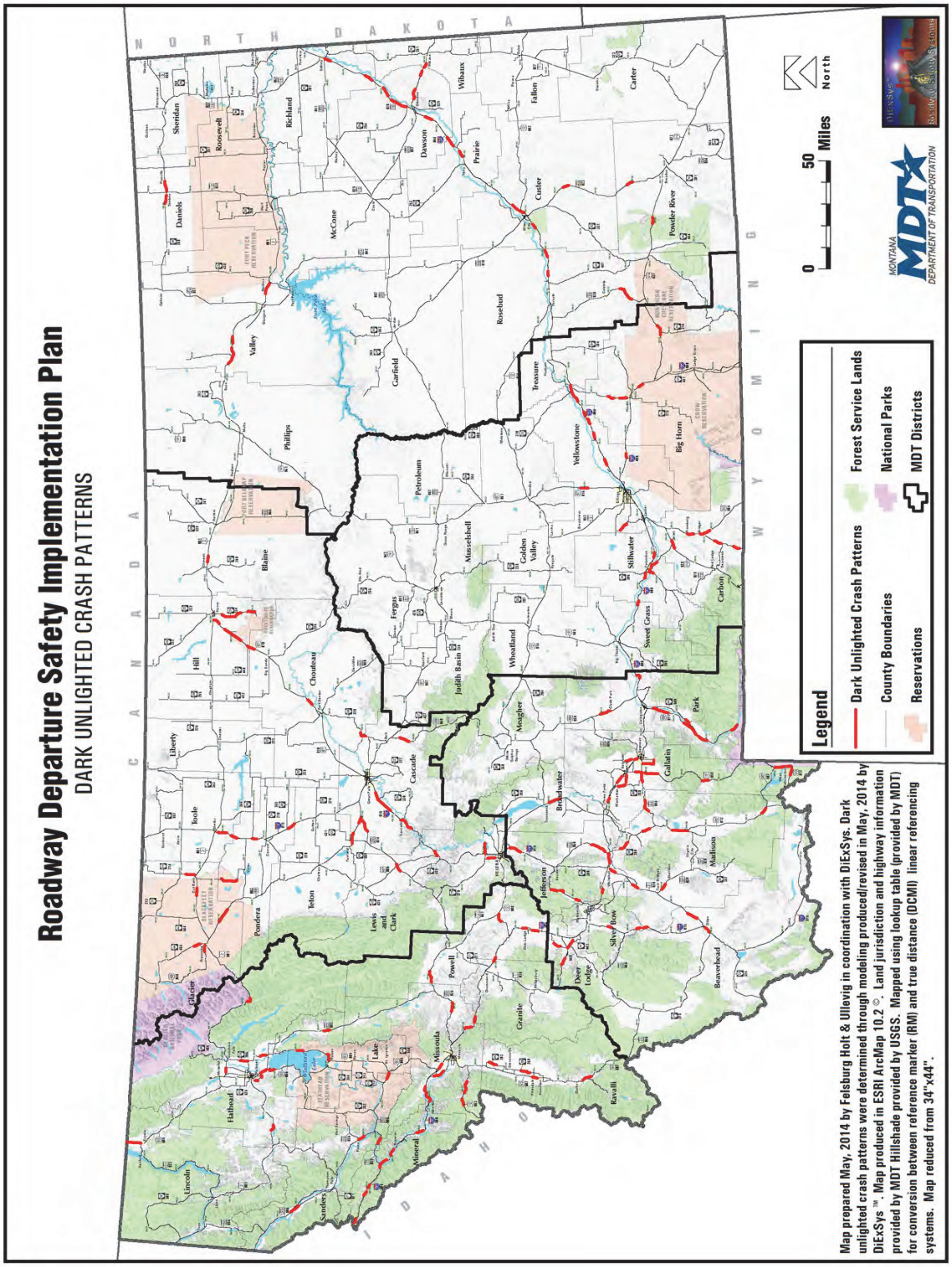

Figure 6 Dark Unlighted Crash Patterns Statewide Map

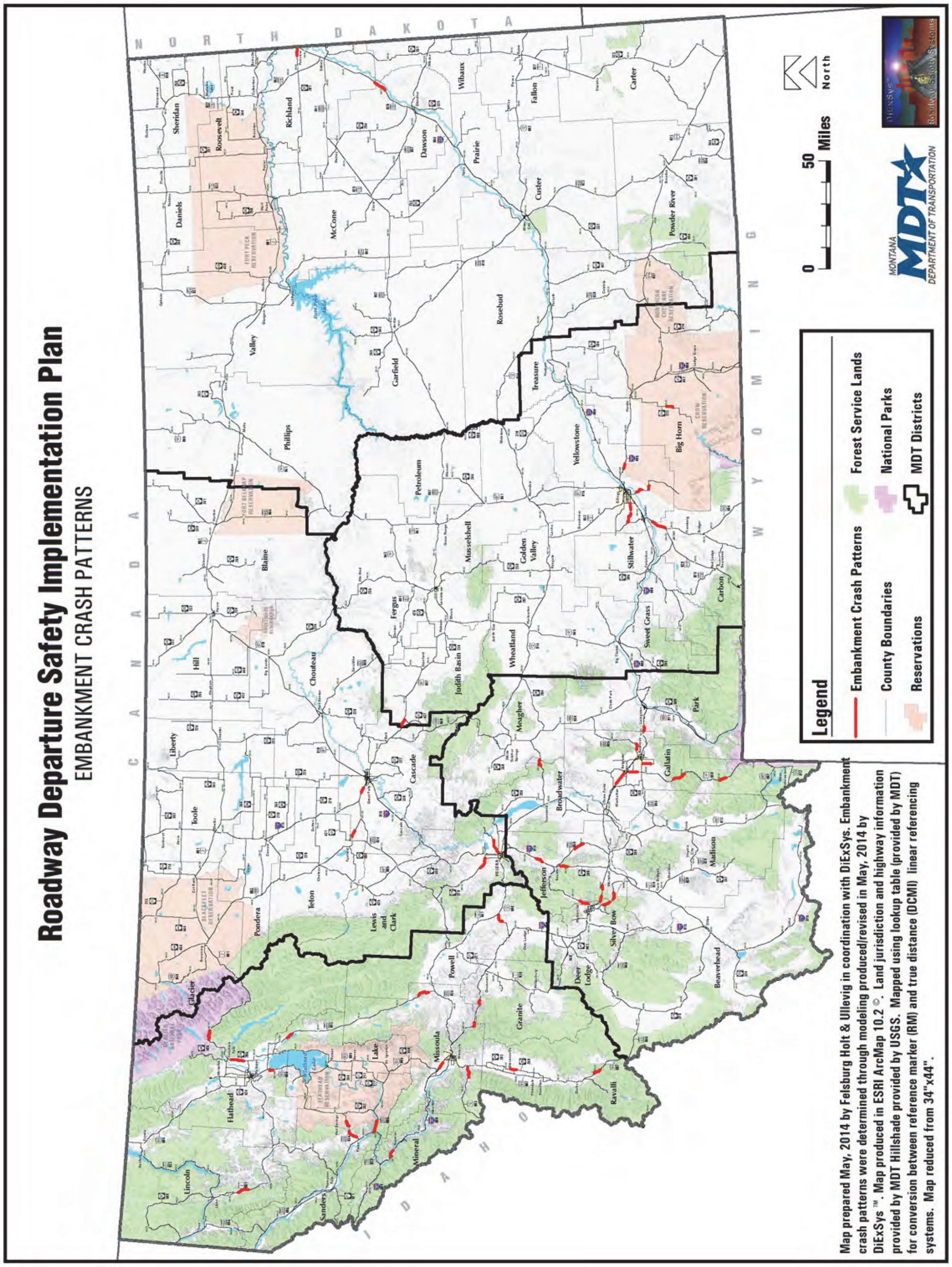

Figure 7 Embankment Crash Patterns Statewide Map

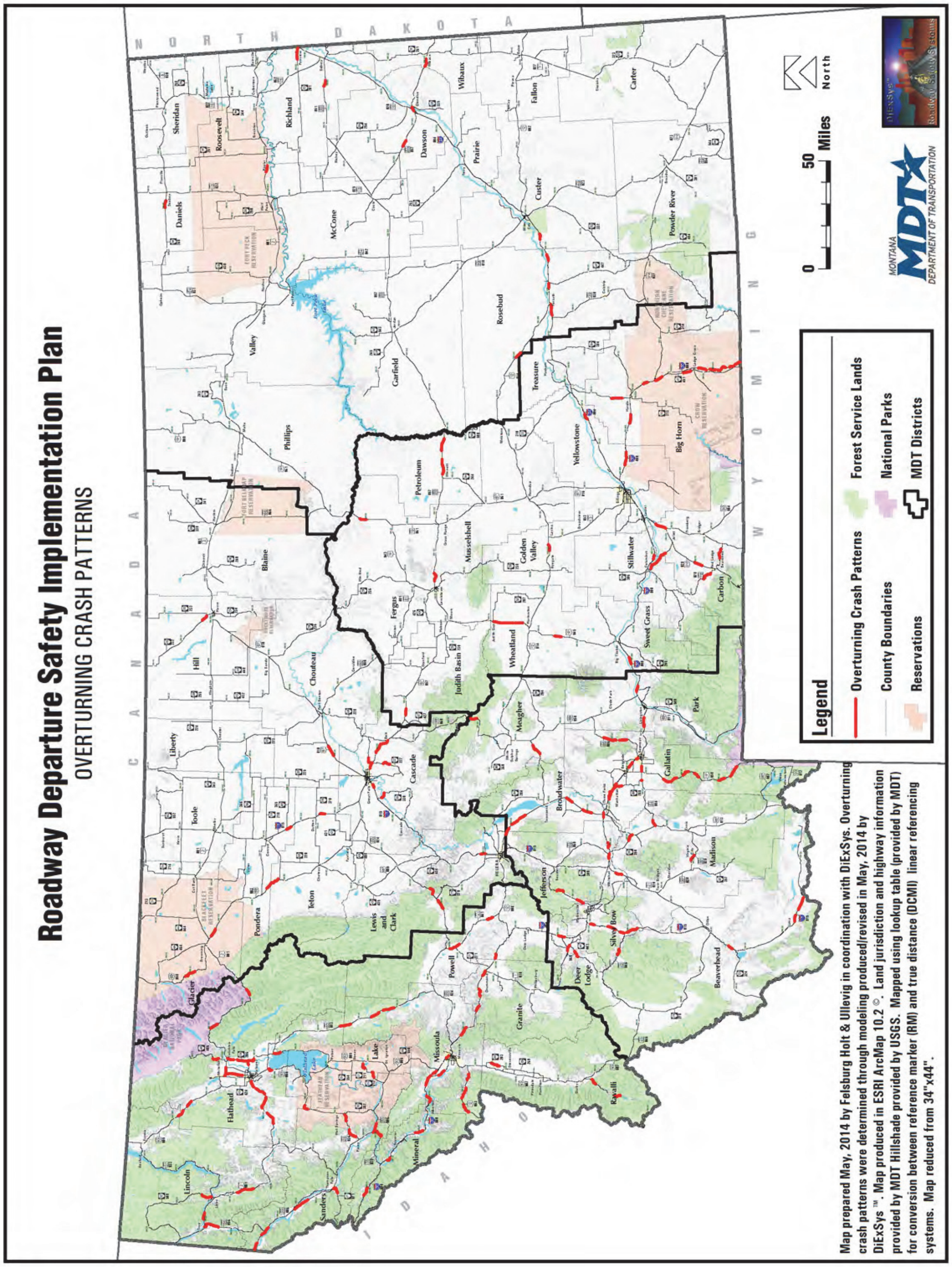

Figure 8 Overturning Crash Patterns Statewide Map

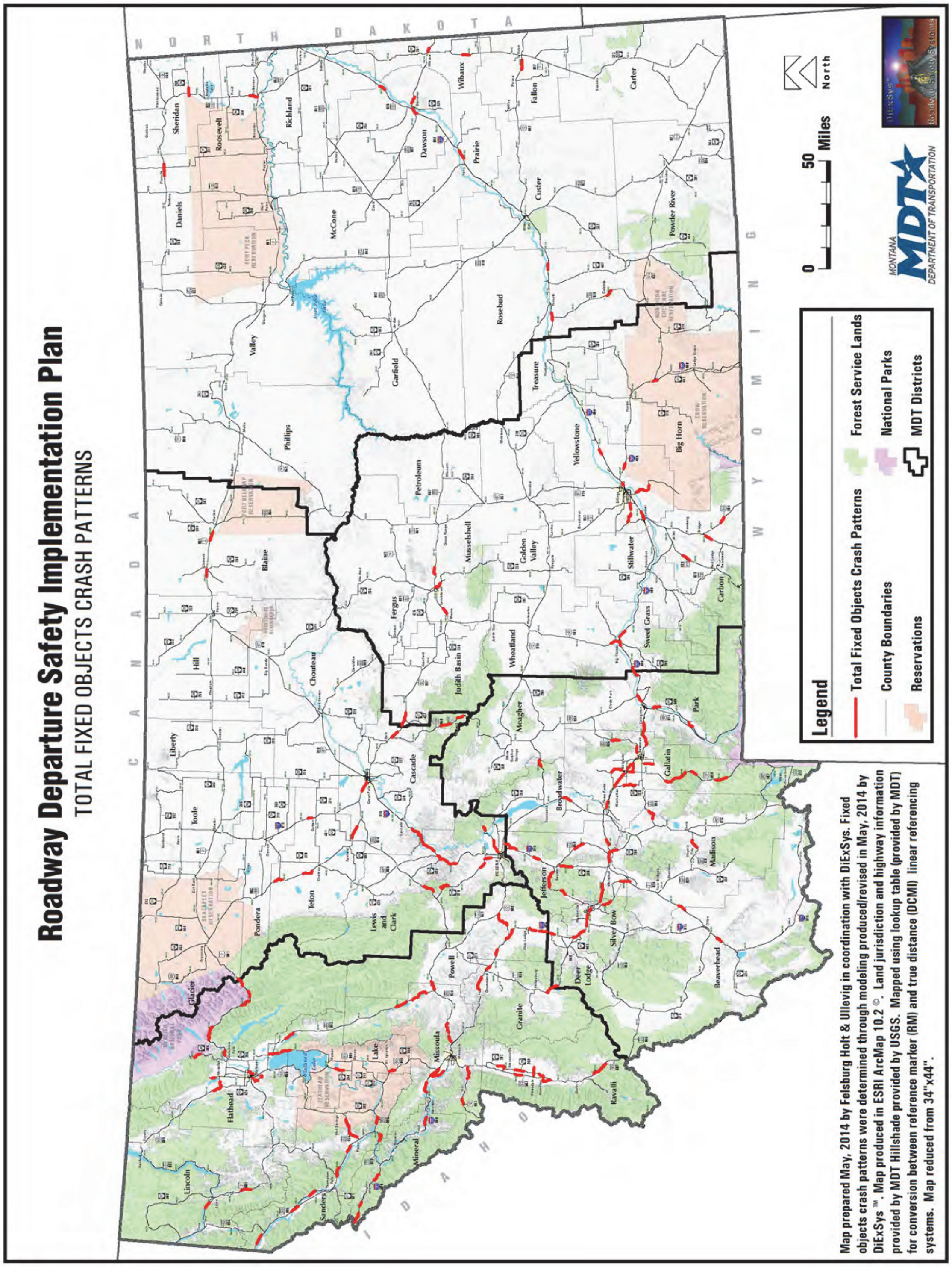

Figure 9 Fixed Objects Crash Patterns Statewide Map

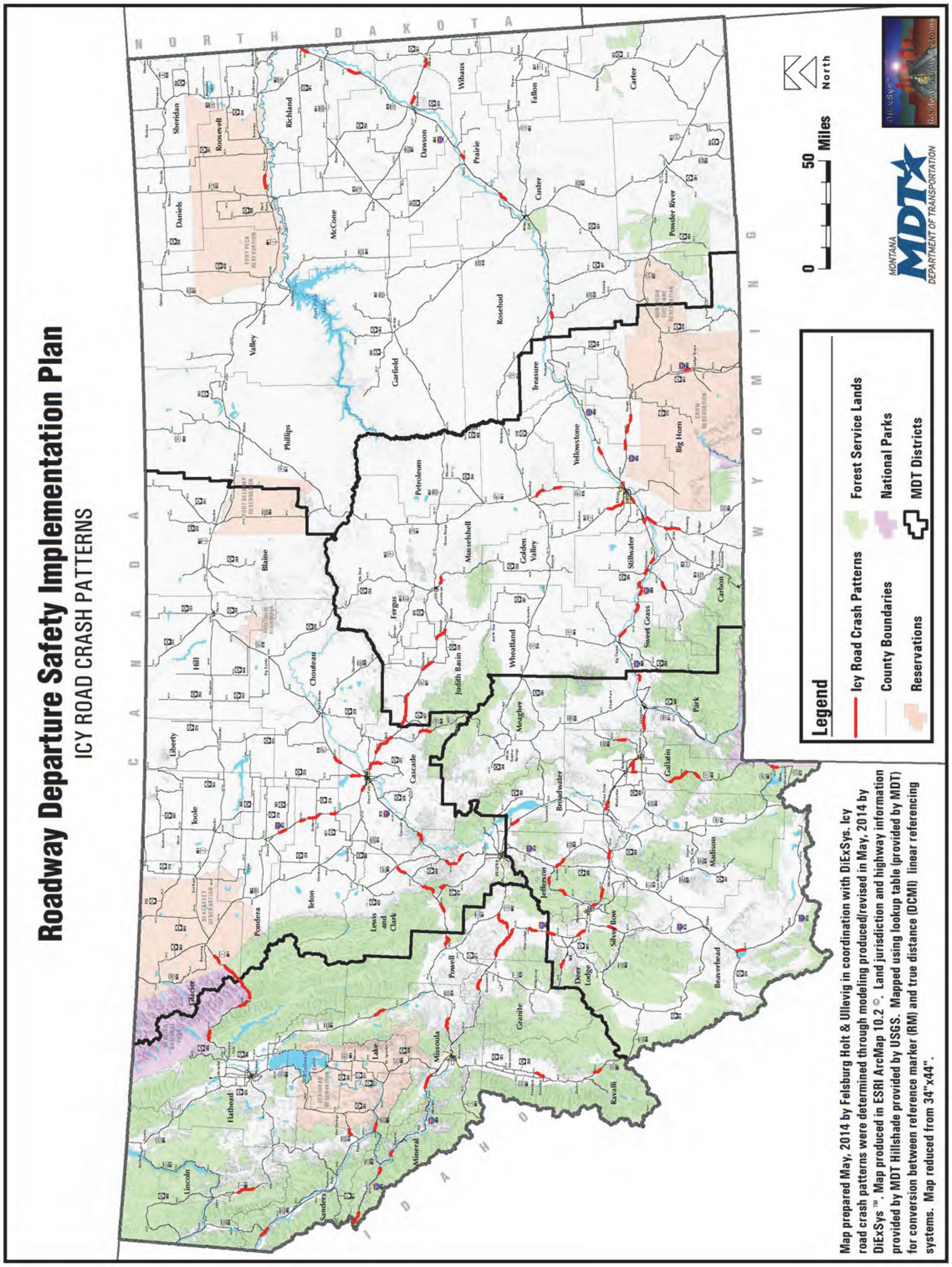

Figure 10 Icy Road Crash Patterns Statewide Map

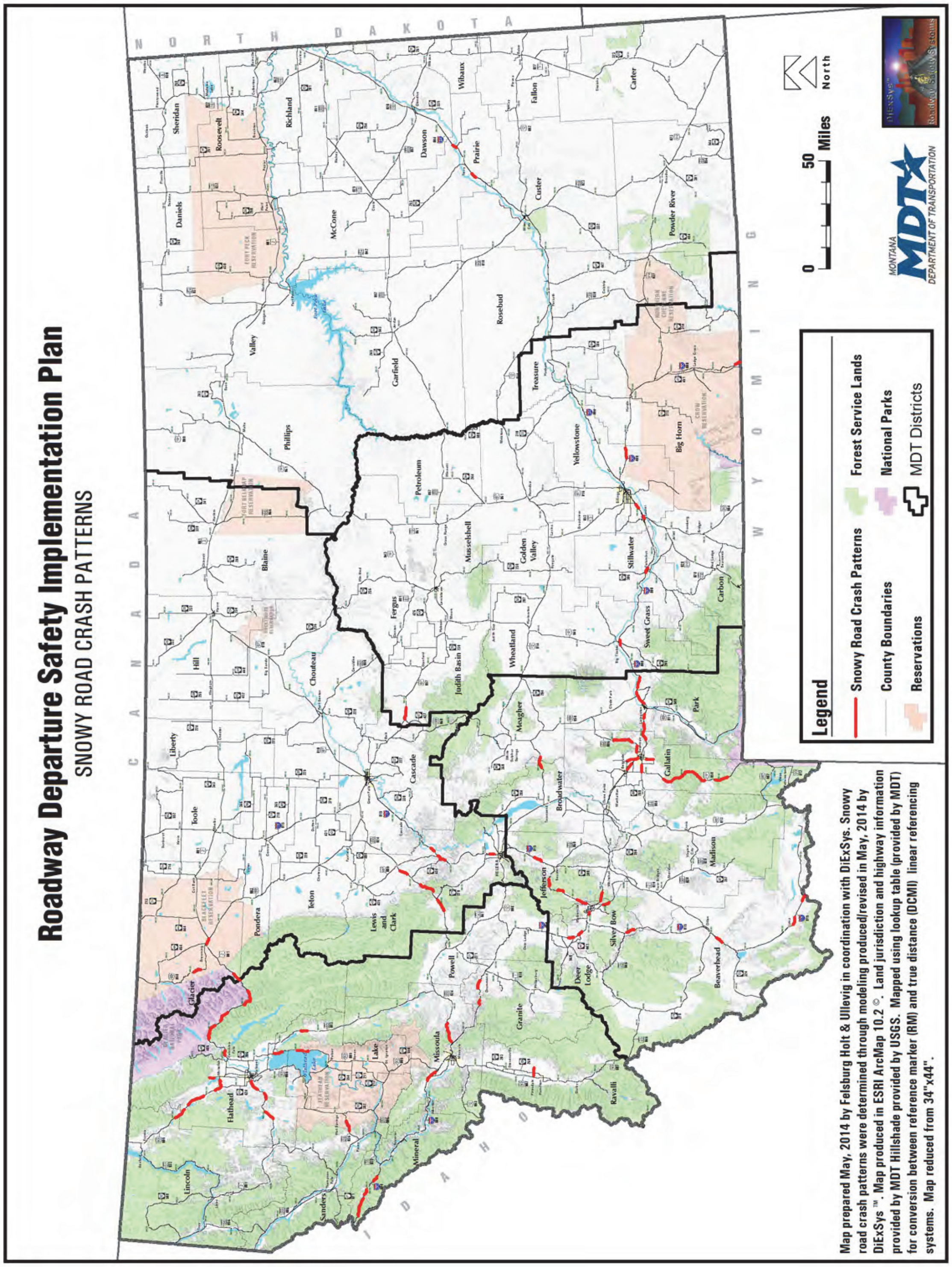

Figure 11 Snowy Road Crash Patterns Statewide Map

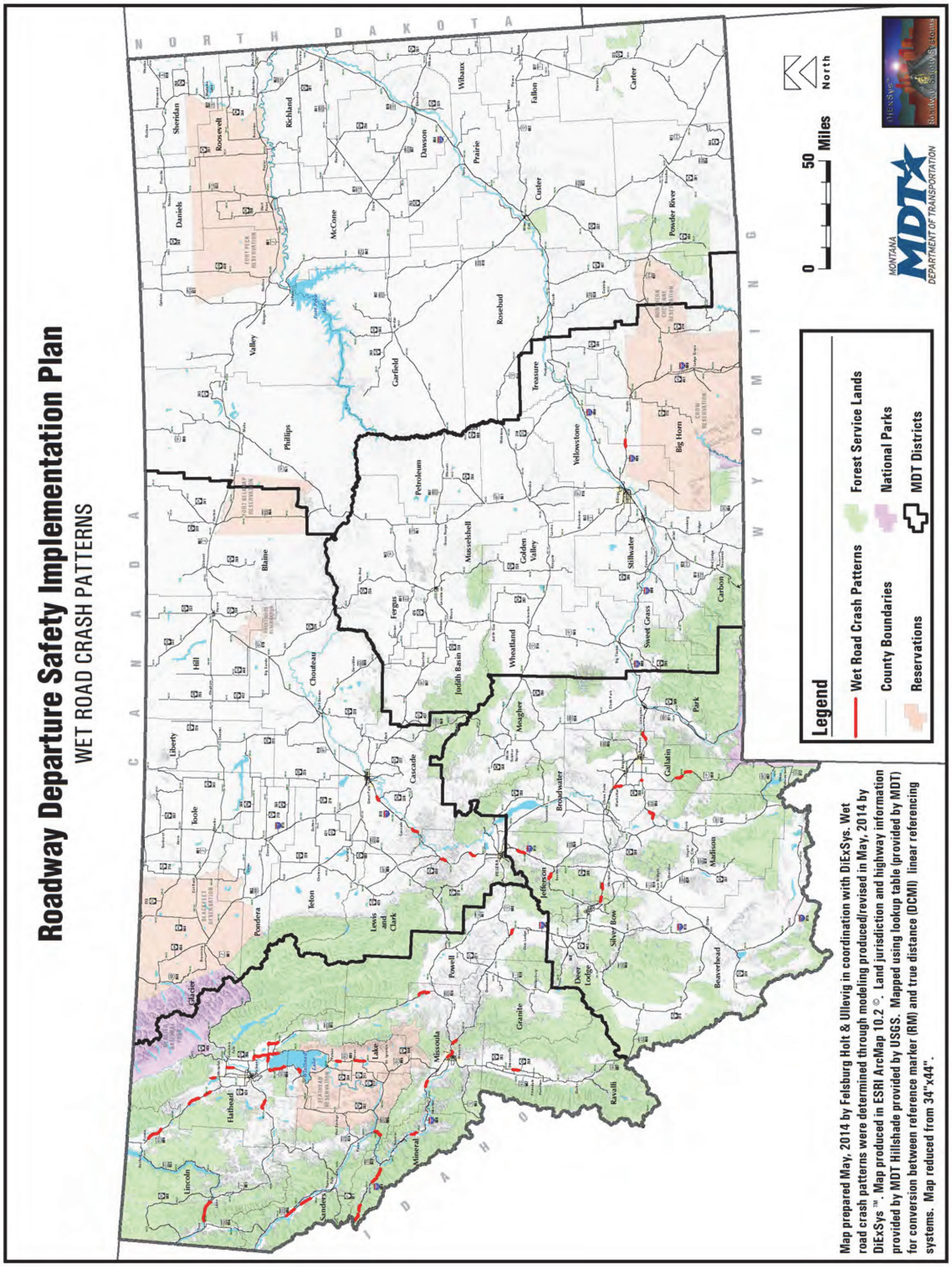

Figure 12 Wet Road Crash Patterns Statewide Map

HOW TO SELECT PROJECTS FOR RDSIP

The primary goal for the Roadway Departure Safety Implementation Plan (RDSIP) project selection criteria is to select projects in such a way that following construction they will maximize crash reduction within constraints of the available budgets. Conceptually the selected sites should exhibit elevated frequency and severity of crashes or crash patterns susceptible to cost-effective correction. Additionally, these sites should contain sufficiently high number of injury crashes to produce projects that will result in high benefit/cost ratios. It is important to realize that in some instances even the sites with the average number of crashes may be susceptible to cost-effective counter-measures. Crash patterns may be present with and without overall elevated crash frequency. If this fact is not considered we may miss an important opportunity to improve safety. An ideal mix of projects may contain locations with abnormally high or at least elevated number of roadway departure injury crashes as well locations with some correctable crash pattern.

Sites with Promise - Traditional Approach and Countermeasures with Promise – Systemic Approach

The terms Sites with Promise (SWIP) and Countermeasures with Promise (CWIP) were introduced by Dr. Ezra Hauer in his published research[4] and working papers. Sites with Promise (SWIP) are identified by screening the entire roadway network for sites with elevated frequency and severity of crashes. To accomplish this goal the Montana-specific Safety Performance Functions (SPF) and the EB procedure will be used to correct for the regression to the mean bias. These sites are then examined for causes using diagnostic tools. Following diagnostic examination the countermeasures to address observed problems will be identified. In addition to selecting sites in the Level of Service of Safety (LOSS) IV category a minimum number of injury crashes to ensure cost-effectiveness of future construction from the safety stand point is identified. **Figure 13** provides conceptual illustrations of how LOSS based SWIPs are selected by considering how cost and safety benefits can be anticipated at the time of initial screening.

In contrast to screening for SWIPs the Countermeasure with Promise (CWIP) approach begins by choosing an effective countermeasure first and then looking for sites where it can be applied cost-effectively. Both approaches, SWIP and CWIP can used to identify projects for RDSIP. SWIP approach is generally referred to as a traditional approach and CWIP as a systemic approach.

[4] Hauer, E., Kononov, J., Allery, B., and Griffith, M. Screening the Road Network for Sites with Promise. In Transportation Research Record 1784, TRB, National Research Council, Washington, D.C., 2002 pp 27-42.

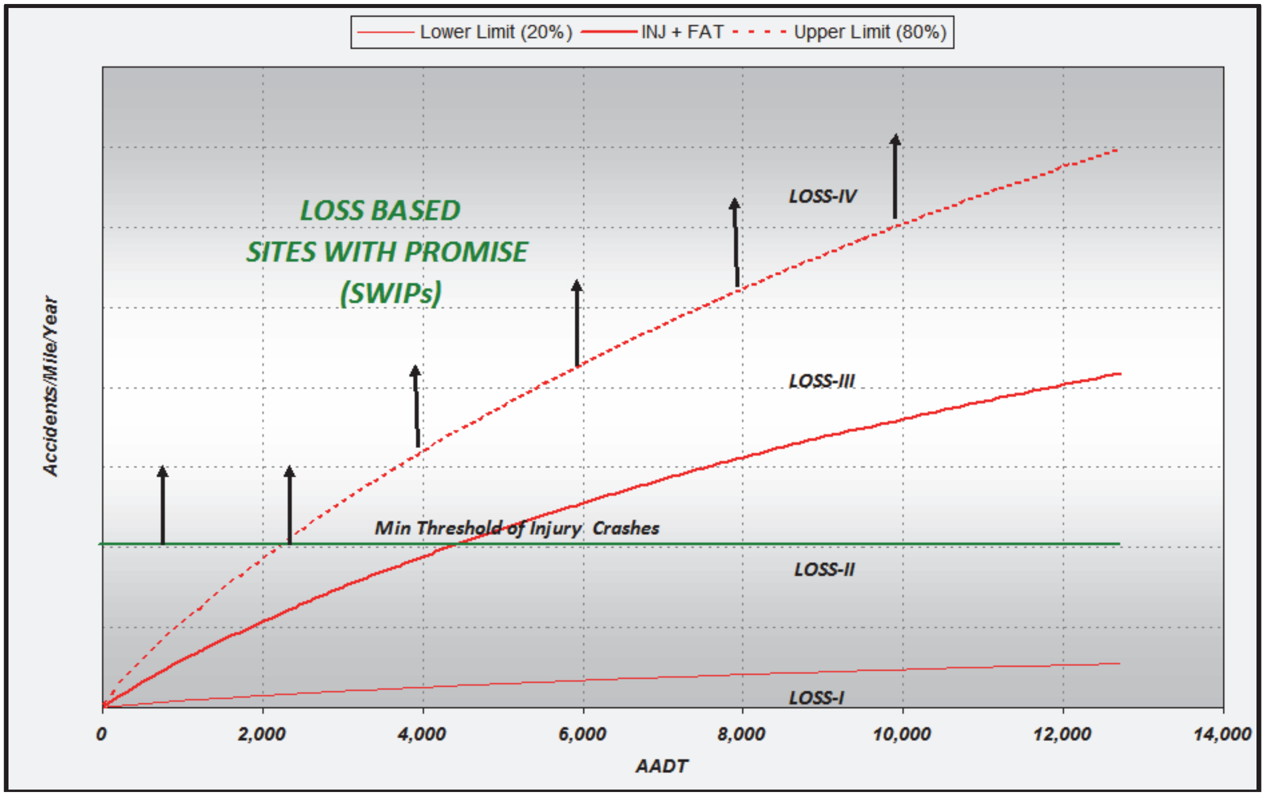

Figure 13 Conceptual Illustration of How to Select LOSS Based SWIPs

Economic Considerations and Sensitivity Analysis

The guiding principal behind an effective highway safety program is that the money should go to where it achieves the greatest safety effect. The cost-effectiveness is measured by the Benefit-Cost (B/C) ratio which represents the ratio of the benefits derived from the crash reduction expressed in dollars to the cost of construction and maintenance over the life cycle of the project. The following assumptions were used to identify requisite 5 year threshold of the integer number of injury crashes per mile (10 miles for rumble strips) *to produce* B/C Ratios of 2:1 or greater for the selected countermeasures under consideration.

- Improvements of signing and delineation – Crash Reduction Factor (CRF) 10%, (applied to all roadway departure crashes) Cost of Construction $5,000 per mile, Service Life 8 years.

- Center-line Rumble Strips – CRF 20% (applied only to head-on, sideswipe opposite and run off left crashes), Cost of Construction $1,000 per mile ($10,000 for 10 Miles), Service Life 10 years.

- Shoulder Rumble Strips – CRF 20% (applied only to overturning and fixed object crashes on roadways that meet requirements of MDT rumble strips policy). Cost of Construction $2,000 per mile, Service Life 10 years.

- Install Guard Rail - CRF 44% Injuries, Cost of Construction $200,000 per mile (applied only to overturning and fixed object crashes). Cost of Maintenance $1,000 per mile/year, Service Life 20 years.

- Intensification of Snow and Ice Removal above Standard Levels of Maintenance on Rural Interstates – Crash Modification Factor 20%, (applied only to crashes occurred on icy and snowy roads).Cost of Implementation $10,000 per mile annually

Table 5 presents results of the B/C Sensitivity Analysis to identify the requisite number of observed injury crashes to obtain B/C ratios of 2:1 or greater from the improved signing and delineation.

MONTANA

Montana Department of Transportation
DiExSys™ Roadway Safety Systems
Economic Analysis Report

10/31/2014
Job #: 20141031114627

Location: 1A **Begin:** 0.00 **End:** 1.00 **From:** 01/01/2008 **To:** 12/31/2012

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	0		Weighted PDO:	0.00	0% :ARF for PDO	Cost of PDO:	$ 8,900
INJ:	1	0 :Injured	Weighted INJ:	0.21	10% :ARF for INJ	Cost of INJ:	$ 78,900
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :ARF for FAT	Cost of FAT:	$ 1,410,000
			B/C Weighted Year Factor:	5.00	10% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
						Service Life:	8
						Capital Recovery Factor:	0.154
						Annual Maintenance Cost:	$ 0

Cost: $ 5,000
From: 01/01/2008
To: 12/31/2012 Days: 1827

Benefit Cost Ratio: 2.19 (B/C Based on Crash Numbers : PDO/INJ/FAT)

Type of Improvement: SIGNING AND DELINEATION
Special Notes: ROADWAY DEPARTURE CRASHES

Table 5 B/C Sensitivity Analysis for the Improvements in Signing and Delineation

Table 6 presents results of the B/C Sensitivity Analysis to identify the requisite number of observed injury crashes to obtain B/C ratios of 2:1 or greater from the construction of the Center Line Rumble Strips. (Increment of 10 miles).

MONTANA

Montana Department of Transportation
DiExSys™ Roadway Safety Systems
Economic Analysis Report

10/31/2014

Job #: 20141031115007

Location: 1A **Begin:** 0.00 **End:** 10.00 **From:** 01/01/2008 **To:** 12/31/2012

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	0		Weighted PDO:	0.00	0% :ARF for PDO	Cost of PDO:	$ 8,900
INJ:	1	0 :Injured	Weighted INJ:	0.22	20% :ARF for INJ	Cost of INJ:	$ 78,900
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :ARF for FAT	Cost of FAT:	$ 1,410,000
			B/C Weighted Year Factor:	5.00	20% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
						Service Life:	10
						Capital Recovery Factor:	0.129
						Annual Maintenance Cost:	$ 0

Cost: $ 10,000
From: 01/01/2008
To: 12/31/2012 Days: 1827

Benefit Cost Ratio: 2.67 (B/C Based on Crash Numbers : PDO/INJ/FAT)

Type of Improvement: CENTER LINE RUMBLESTRIP (COST PER 10 MILES)
Special Notes: HEAD-ON, SIDESWIPE OPPOSITE AND RUN OFF LEFT

Table 6 B/C Sensitivity Analysis-Center Line Rumble Strips

Table 7 presents results of the B/C Sensitivity Analysis to identify the requisite number of observed injury crashes to obtain B/C ratios of 2:1 or greater from the construction of shoulder rumble strips.

MONTANA

Montana Department of Transportation
DiExSys™ Roadway Safety Systems
Economic Analysis Report

10/31/2014
Job #: 20141031115007

Location: 1A **Begin:** 0.00 **End:** 10.00 **From:** 01/01/2008 **To:** 12/31/2012

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	0		Weighted PDO:	0.00	0% :ARF for PDO	Cost of PDO:	$ 8,900
INJ:	2	0 :Injured	Weighted INJ:	0.44	20% :ARF for INJ	Cost of INJ:	$ 78,900
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :ARF for FAT	Cost of FAT:	$ 1,410,000
			B/C Weighted Year Factor:	5.00	20% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
						Service Life:	10
						Capital Recovery Factor:	0.129
						Annual Maintenance Cost:	$ 0

Cost: $ 20,000
From: 01/01/2008
To: 12/31/2012 Days: 1827

Benefit Cost Ratio: 2.67 (B/C Based on Crash Numbers : PDO/INJ/FAT)

Type of Improvement: SHOULDER RUMBLESTRIPS (COST PER 10 MILES)
Special Notes: OVERTURNING AND FIXED OBJECT CRASHES

Table 7 B/C Sensitivity Analysis-Shoulder Line Rumble Strips

Table 8 presents results of the B/C Sensitivity Analysis to identify the requisite number of observed injury crashes to obtain B/C ratios of 2:1 or greater from the construction of guardrail.

MONTANA

Montana Department of Transportation
DiExSys™ Roadway Safety Systems
Economic Analysis Report

10/31/2014

Job #: 20141031115804

Location: 1A **Begin:** 0.00 **End:** 1.00 **From:** 01/01/2008 **To:** 12/31/2012

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	0		Weighted PDO:	0.00	0% :ARF for PDO	Cost of PDO:	$ 8,900
INJ:	4	0 :Injured	Weighted INJ:	0.98	44% :ARF for INJ	Cost of INJ:	$ 78,900
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :ARF for FAT	Cost of FAT:	$ 1,410,000
			B/C Weighted Year Factor:	5.00	44% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
						Service Life:	20
		Cost: $ 200,000				Capital Recovery Factor:	0.080
		From: 01/01/2008				Annual Maintenance Cost:	$ 1,000
		To: 12/31/2012	Days: 1827				

Benefit Cost Ratio: 2.00 (B/C Based on Crash Numbers : PDO/INJ/FAT)

Type of Improvement: NEW GUARDRAIL
Special Notes: RUN OFF THE ROAD CRASHES

Table 8 B/C Sensitivity Analysis – Guardrail

Table 9 presents results of the B/C Sensitivity Analysis to identify the requisite number of observed injury crashes to obtain B/C ratios of 2:1 or greater from the intensified maintenance.

MONTANA

Montana Department of Transportation
DiExSys™ Roadway Safety Systems
Economic Analysis Report

10/31/2014
Job #: 20141031115804

Location: 1A	Begin: 0.00	End: 1.00	From: 01/01/2008	To: 12/31/2012

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	0		Weighted PDO:	0.00	0% :ARF for PDO	Cost of PDO:	$ 8,900
INJ:	7	0 :Injured	Weighted INJ:	1.40	20% :ARF for INJ	Cost of INJ:	$ 78,900
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :ARF for FAT	Cost of FAT:	$ 1,410,000
			B/C Weighted Year Factor:	5.00	20% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
						Service Life:	1
	Cost: $ 0					Capital Recovery Factor:	1.050
	From: 01/01/2008					Annual Maintenance Cost:	$ 10,000
	To: 12/31/2012		Days: 1827				

Benefit Cost Ratio: 2.21 (B/C Based on Crash Numbers : PDO/INJ/FAT)

Type of Improvement: INTENSIFIED MAINTENANCE $10,000 PER MILE/YEAR - EMPHASIS ON FREEWAYS
Special Notes: ICY, SNOWY AND WET CRASHES

Table 9 B/C Sensitivity Analysis-Intensified Maintenance

The results of the B/C sensitivity analysis in concert with the use of Montana SPFs and Pattern Recognition Analysis will inform MDT's selection of the candidate sites for the inclusion in the Montana RDSIP. The list of 30 SPF based candidate sites **(Table 10)** is provided to demonstrate how with the initial site selection can be made. SPF graph for each site is provided on **Figures 14 through 43**. Each potential site will be examined further through diagnostic examination, followed by countermeasure development and the B/C analysis. An abbreviated example of the typical Safety Assessment Report is provided later in the report (Pages 41-49) including how the analysis is performed and the countermeasures are selected.

List of 30 Candidate Sites Identified through SWIP based Analysis	
Rural 2-Lane Highways in Flat and Rolling Terrain	
Corridor 1 MP 140.00-142.60	West of Kalispell
Corridor 1 MP 167.00-169.00	Near West Glacier
Corridor 5 MP 23.00-28.00	South of Darby
Corridor 5 MP 94.40-103.00	North of Lolo
Corridor 6 MP 3.00-6.00	Heron/Idaho Border
Corridor 6 MP 85.00-88.00	Plains
Corridor 36 MP 3.00-5.00	North of Plains
Corridor 52 MP 24.00-27.00	East Shore Highway
Corridor 52 MP 29.00-32.00	South of Bigfork
Corridor 86 MP 2.70-5.00	Bridger Bowl Road
Corridor 93 MP 8.50-12.00	Lolo Pass
Corridor 93 MP 25.00-30.00	West of Lolo
Corridor 279 MP 2.00-5.00	Lincoln Road East of Green Meadow
Corridor 269 MP 12.00-18.00	South of Stevensville
Corridor 279 MP 5.5-7.50	Lincoln Road (near Birdseye)
Corridor 308 MP 1.90-3.00	Bear Creek
Corridor 354 MP 1.00-3.00	South of Polson
Corridor 532 MP 7.50-10.00	King Avenue (Laurel/Molt)
Rural 2-Lane Highways in Mountainous Terrain	
Corridor 29 MP 74.00-78.00	Pipestone Pass
Corridor 35 MP 15.80-17.10	North of St. Regis
Corridor 56 MP 26.50-30.50	Troy/Thompson Falls
Corridor 60 MP 30.00-35.00	Kings Hill
Corridor 280 MP 12.00-15.00	York Road
Rural 4-Lane Divided Freeways in Flat and Rolling Terrain	
I-15, MP 280.00-285.00	Great Falls to Vaughn
I-90 MP 209.00-212.00	Fairmont
I-90, MP 307.00-310.00	North 7th Bozeman
I-90, MP 314.00-320.00	Bozeman Hill
Rural 4-Lane Divided Freeways in Mountainous Terrain	
I-15, MP 143.80-144.80	Basin
I-90, MP 5.40-7.50	Lookout Pass
I-90, MP 230.00-240.00	Homestake Pass

Table 10 List of Potential Sites

<u>**Rural 2-Lane Highways in Flat and Rolling Terrain**</u>

Corridor 1 - MP 140.00-142.60

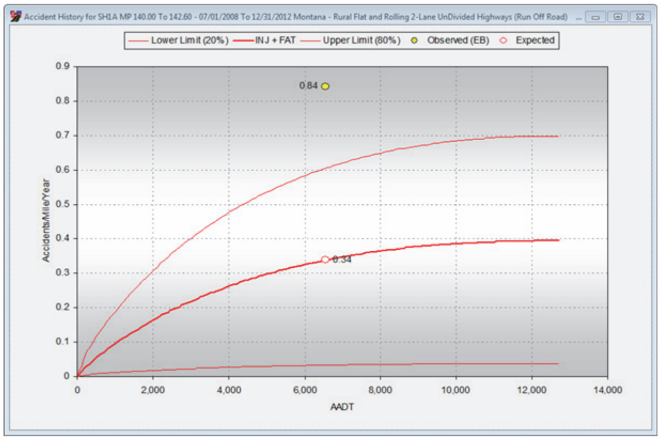

Figure 14 EB Corrected Inj+Fat ROR SPF

Corridor 1 - MP 167.00-169.00

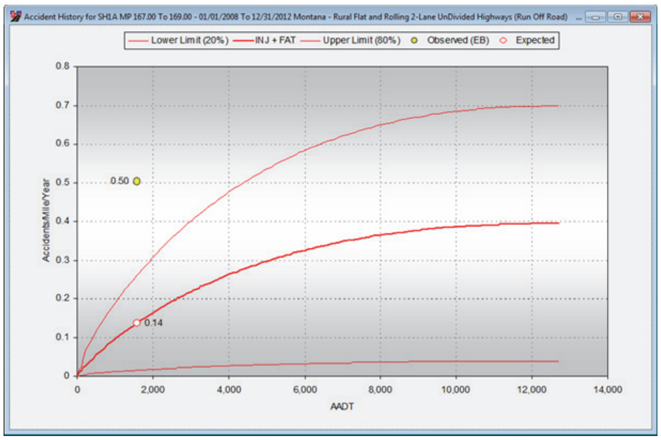

Figure 15 EB Corrected Inj+Fat ROR SPF

Corridor 5 - MP 23.00-28.00

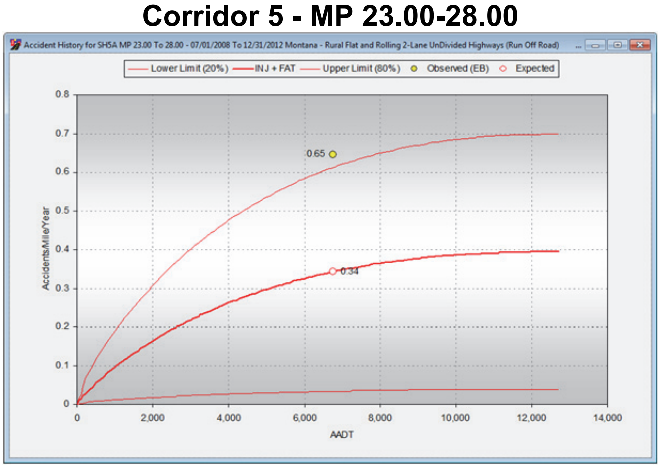

Figure 16 EB Corrected Inj+Fat ROR SPF

Corridor 5 - MP 94.40-103.00

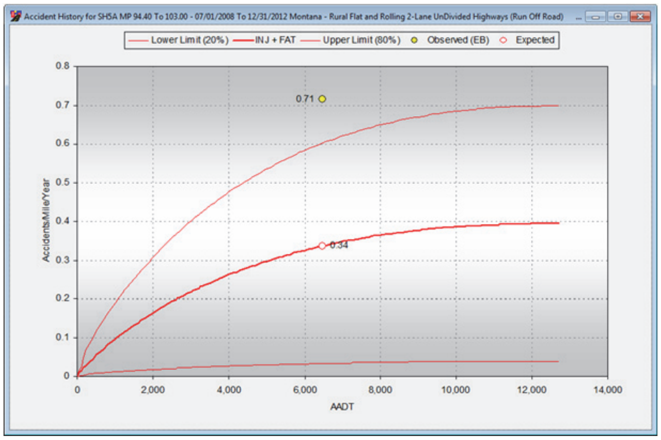

Figure 17 EB Corrected Inj+Fat ROR SPF

Corridor 6 - MP 3.00-6.00

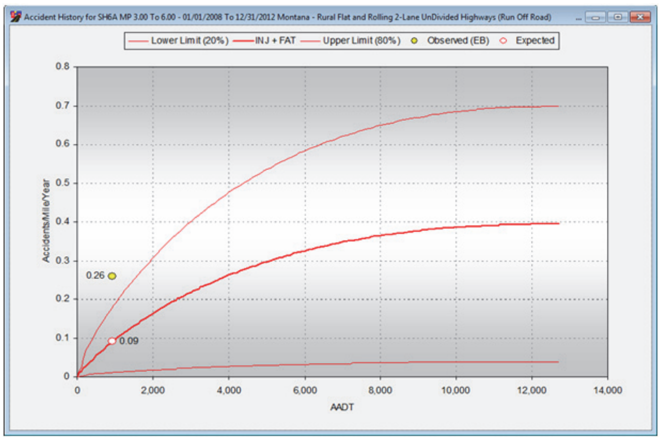

Figure 18 EB Corrected Inj+Fat ROR SPF

Corridor 6 - MP 85.00-88.00

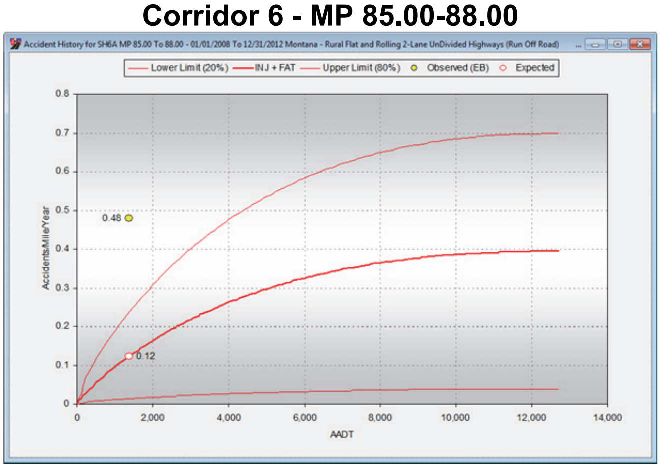

Figure 19 EB Corrected Inj+Fat ROR SPF

Corridor 36 - MP 3.00-5.00

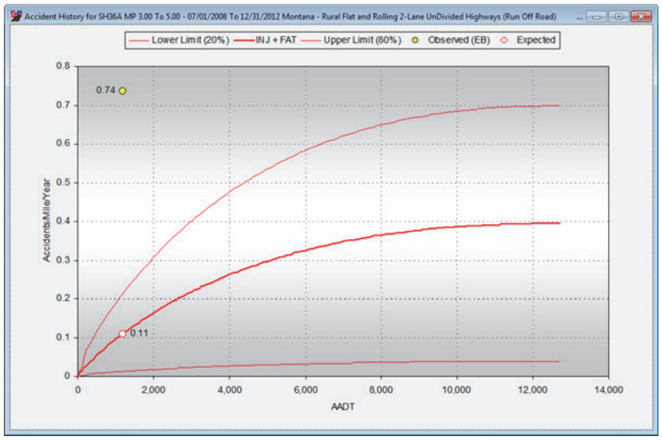

Figure 20 EB Corrected Inj+Fat ROR SPF

Corridor 52 - MP 24.00-27.00

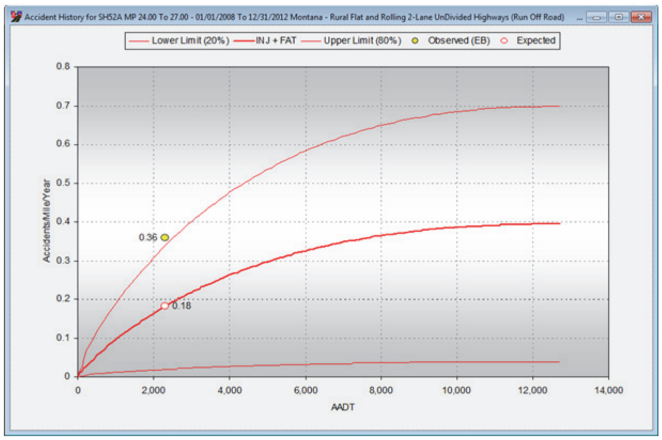

Figure 21 EB Corrected Inj+Fat ROR SPF

Corridor 52 - MP 24.00-27.00

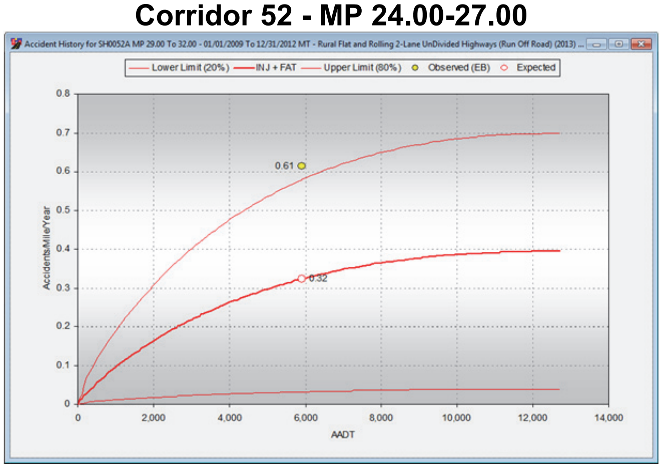

Figure 22 EB Corrected Inj+Fat ROR SPF

Corridor 86 - MP 2.70-5.20

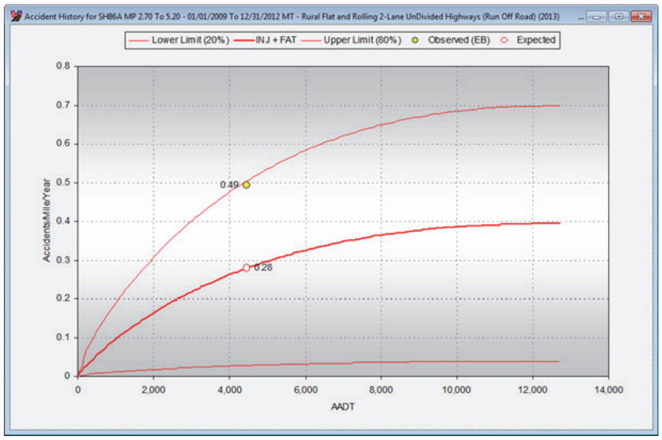

Figure 23 EB Corrected Inj+Fat ROR SPF

Corridor 93 - MP 8.50-12.00

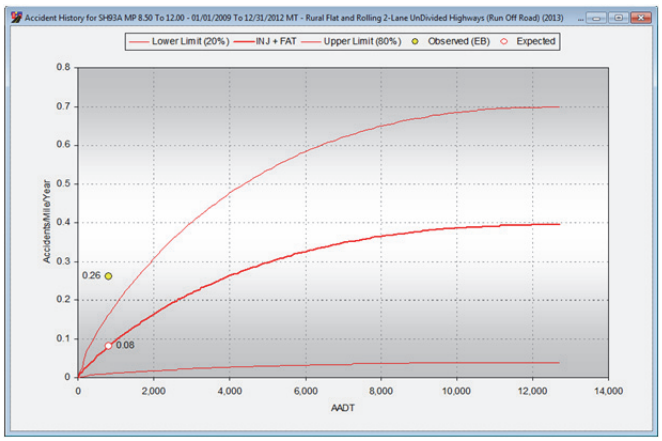

Figure 24 EB Corrected Inj+Fat ROR SPF

Corridor 93 - MP 25.00-30.00

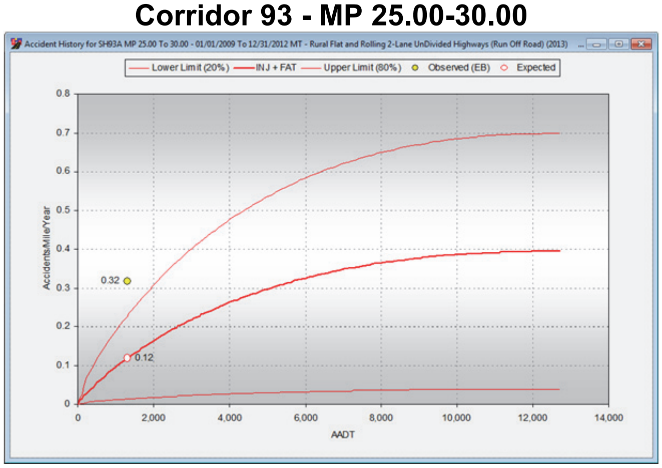

Figure 25 EB Corrected Inj+Fat ROR SPF

Corridor 269 - MP 12.00-18.00

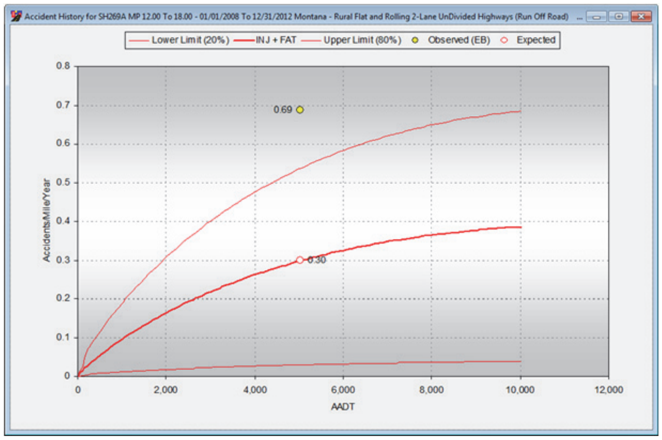

Figure 26 EB Corrected Inj+Fat ROR SPF

SH 279 - MP 2.00-5.00

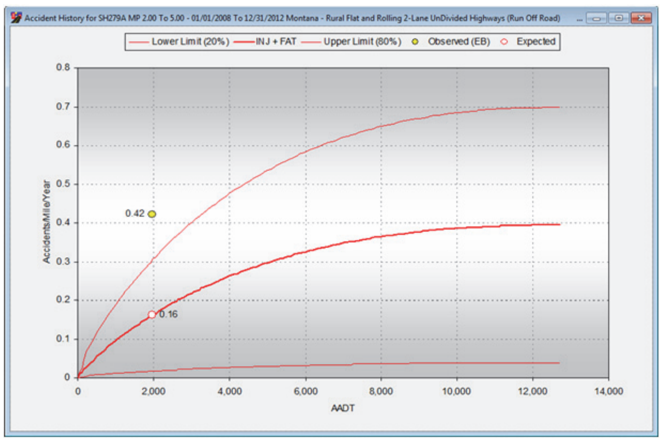

Figure 27 EB Corrected Inj+Fat ROR SPF

SH 279 - MP 5.50-7.50

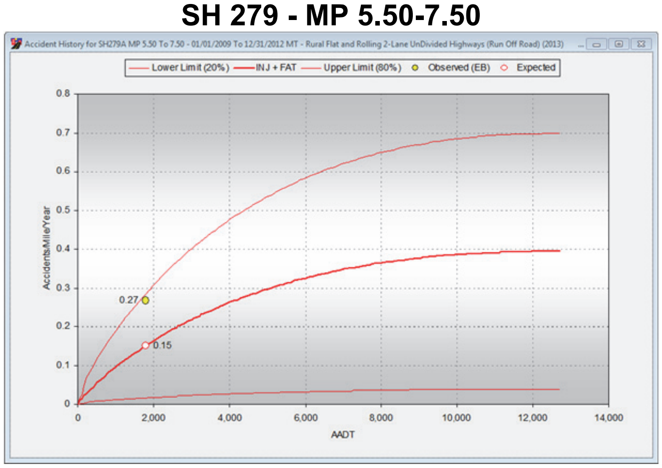

Figure 28 EB Corrected Inj+Fat ROR SPF

Corridor 308 - MP 1.90-3.00

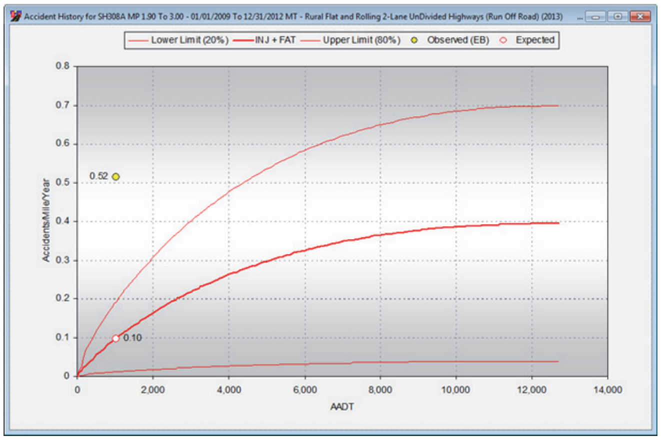

Figure 29 EB Corrected Inj+Fat ROR SPF

Corridor 354 - MP 1.00-3.00

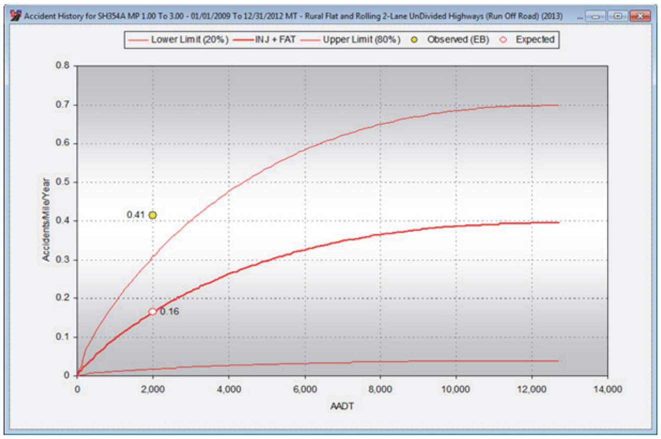

Figure 30 EB Corrected Inj+Fat ROR SPF

Corridor 532 - MP 7.50-10.00

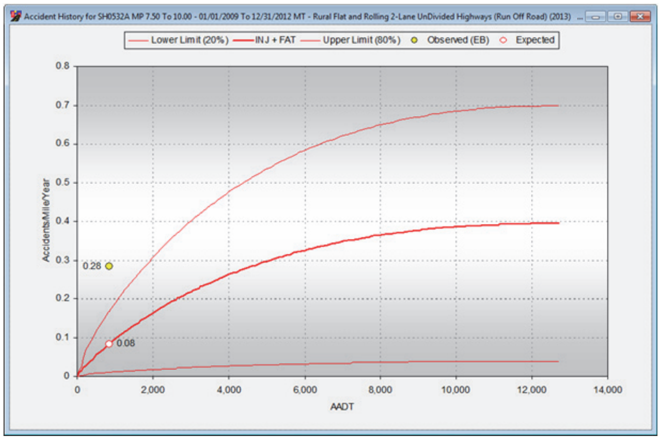

Figure 31 EB Corrected Inj+Fat ROR SPF

Rural 2-Lane Highways in Mountainous Terrain

Corridor 29 - MP 74.00-78.00

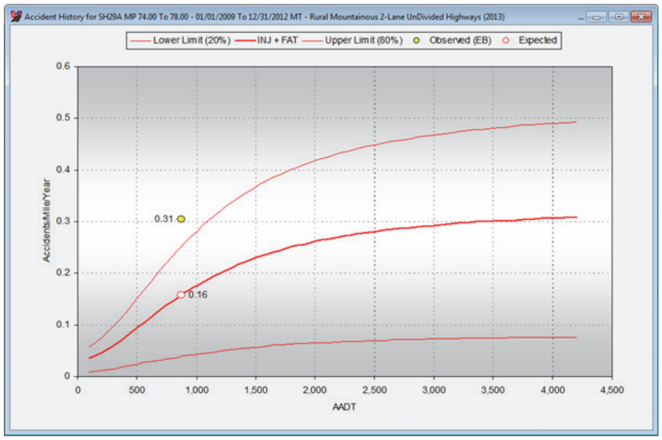

Figure 32 EB Corrected Inj+Fat SPF

Corridor 35 - MP 15.80-17.10

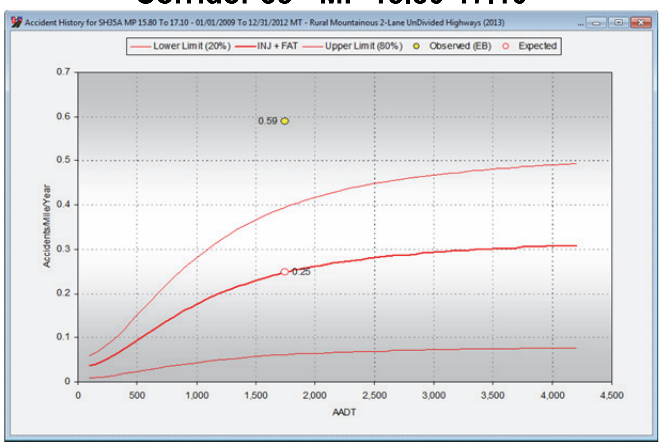

Figure 33 EB Corrected Inj+Fat SPF

Corridor 56 - MP 26.50-30.50

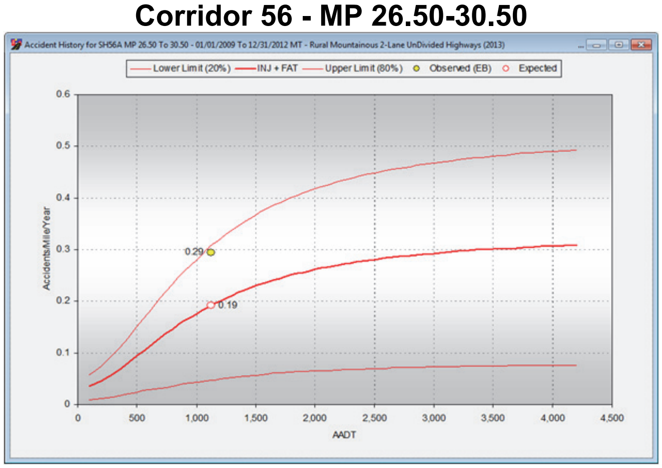

Figure 34 EB Corrected Inj+Fat SPF

Corridor 60 - MP 30.00-35.00

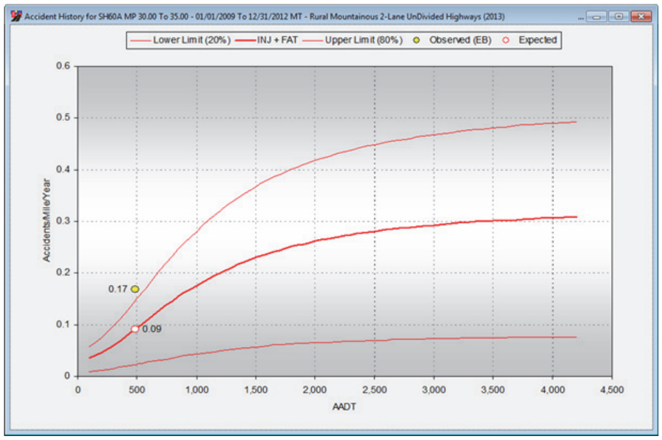

Figure 35 EB Corrected Inj+Fat SPF

Corridor 280 - MP 12.00-15.00

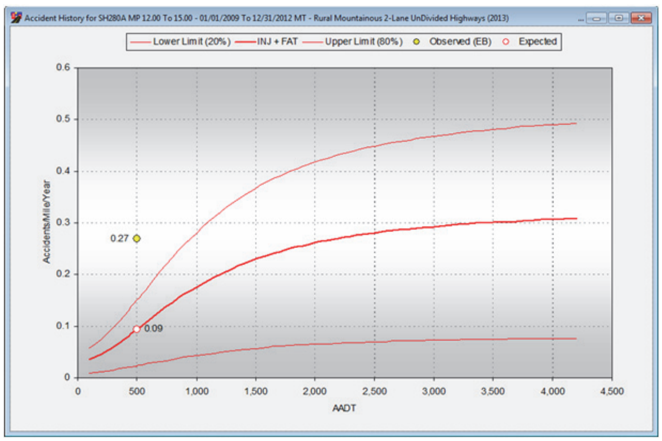

Figure 36 EB Corrected Inj+Fat SPF

<u>**Rural 4-Lane Divided Freeways in Flat and Rolling Terrain**</u>

I-15 - MP 280.00-285.00

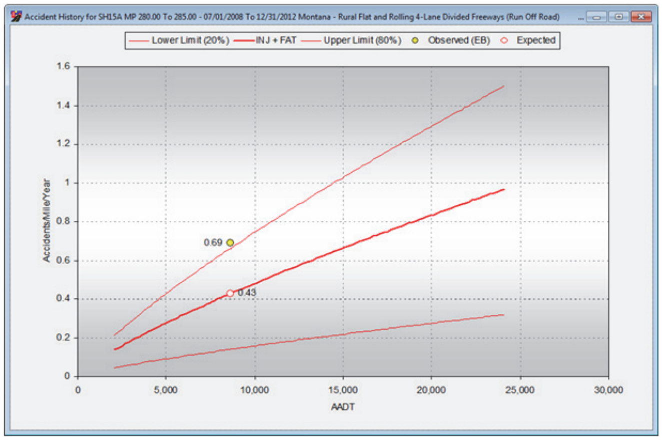

Figure 37 EB Corrected Inj+Fat ROR SPF

I-90 - MP 209.00-212.00

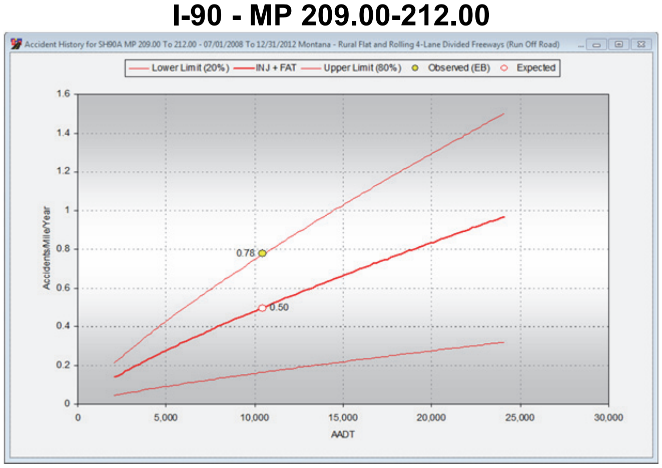

Figure 38 EB Corrected Inj+Fat ROR SPF

I-90 - MP 307.00-310.00

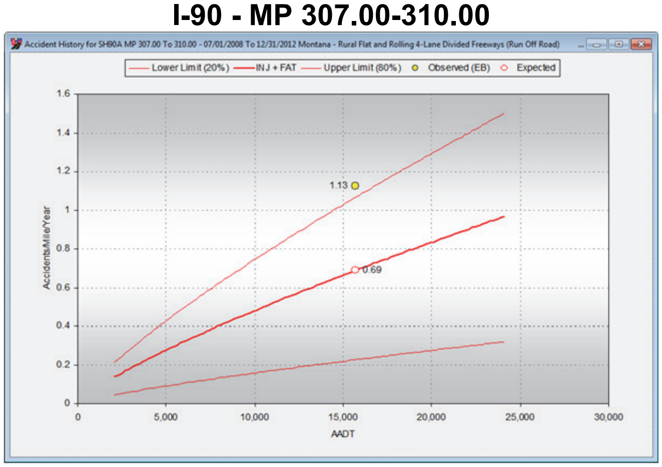

Figure 39 EB Corrected Inj+Fat ROR SPF

I-90 - MP 314.00-320.00

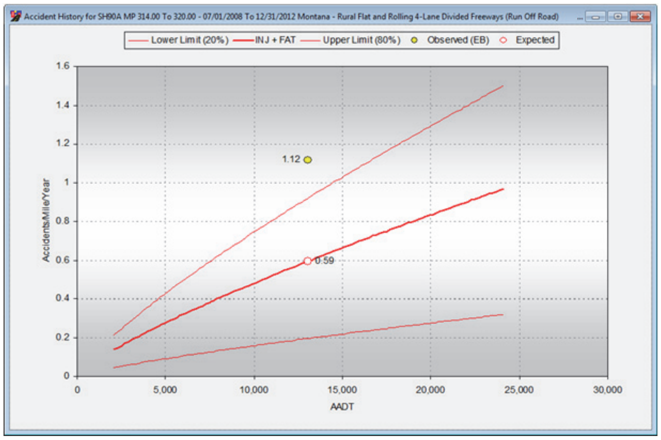

Figure 40 EB Corrected Inj+Fat ROR SPF

Rural 4-Lane Divided Freeways in Mountainous Terrain

I-15 - MP 143.80-144.80

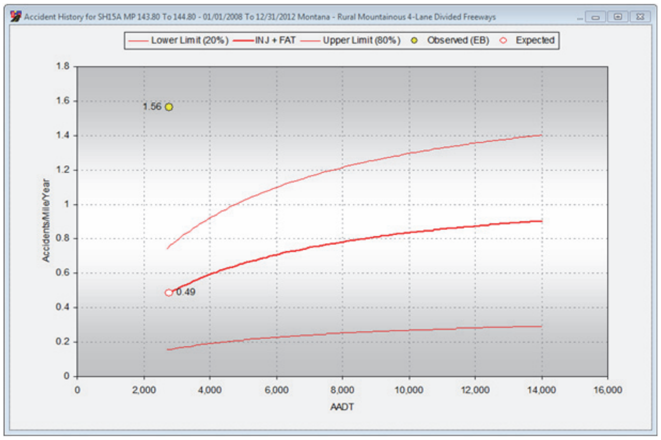

Figure 41 EB Corrected Inj+Fat SPF

I-90 - MP 5.40-7.50

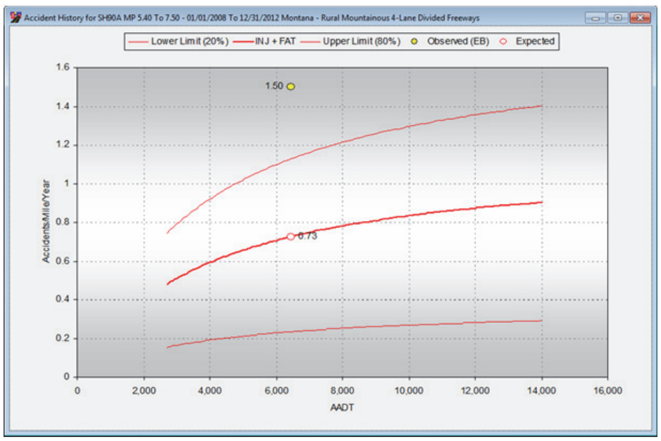

Figure 42 EB Corrected Inj+Fat SPF

I-90 - MP 230.00-240.00

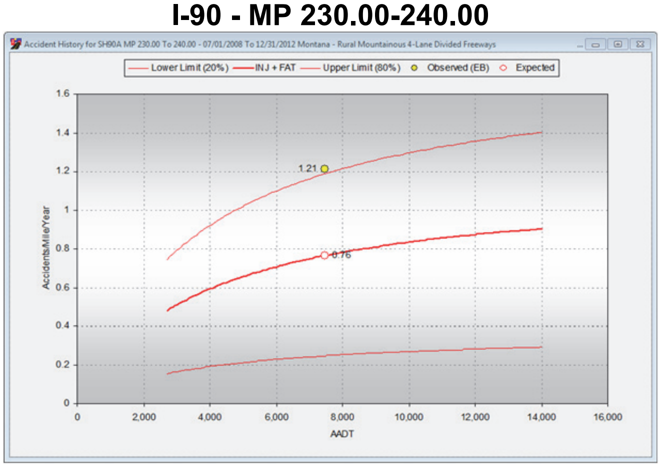

Figure 43 EB Corrected Inj+Fat SPF

ABBREVIATED SAFETY ASSESSMENT REPORT

SITE LOCATION

This study addresses Corridor 29 between MP 74.00 and MP 78.00 in Silver Bow and Jefferson Counties southeast of Butte **(Figure 44)**. The included distance is about 4 miles.

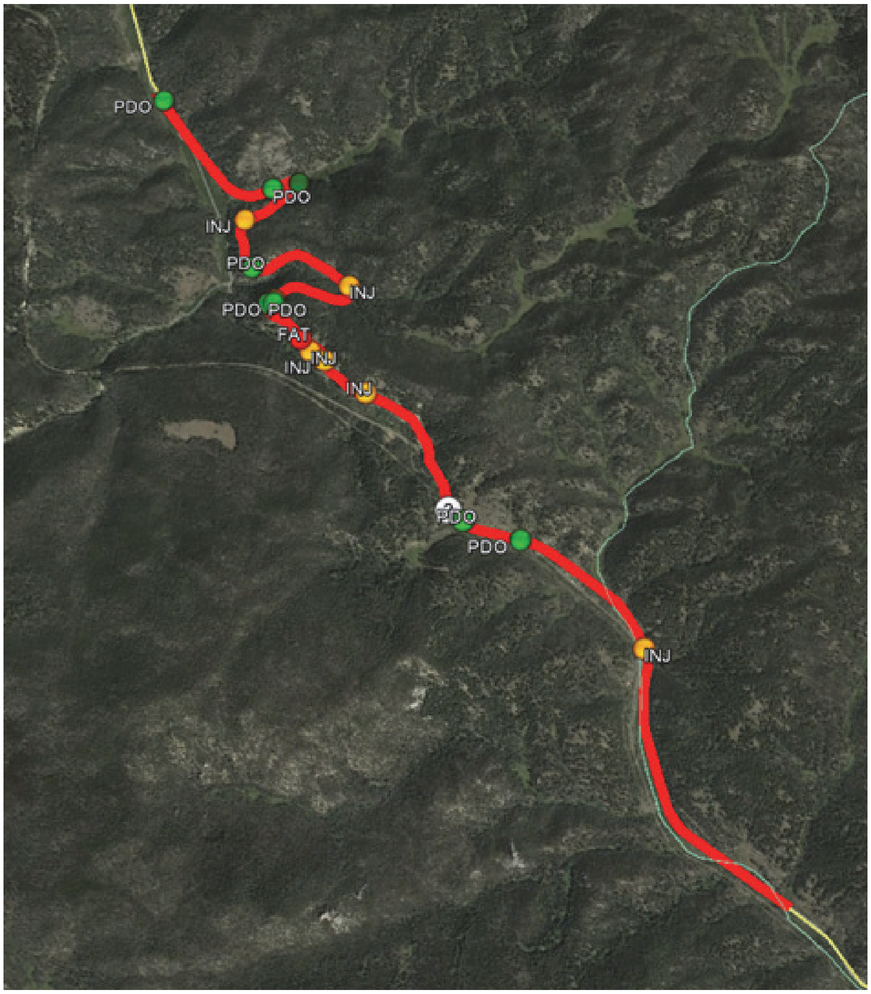

Figure 44 Project Location Map

SITE CONDITIONS

Corridor 29 is classified as a minor rural Arterial through the study section. It is a 2-lane facility with 11.5' lanes and little to no shoulders in the mountainous terrain traversing rural environment. The Average Annual Daily Traffic (AADT) was about 840 vehicles per day. The posted speed limit is 70 mph throughout the study section with curve advisory speeds ranging from 35 to 15 mph.

SAFETY PERFORMANCE ANALYSIS WITHIN PROJECT LIMITS

Figure 45 Shows typical view of Corridor 29 within study limits. **Table 11** provides a listing of the roadway features and of the changes in traffic. **Figures 46** shows corridor level SPF analysis reflecting changes in safety performance along the corridor from the frequency and severity stand point. **Figures 47 and 48** represent segment level EB corrected safety performance of Corridor 29 within the study limits. **Figure 47** shows safety performance from the total crash frequency stand point. **Figure 48** represents safety performance from the stand point of severity and considers injury and fatal crashes only. **Table 12** provides a detailed listing of segment safety performance related parameters.

Figure 45 Typical View

Highway	Milepoint	Descriptin	Rucode	Func_class	Adt	Adt_year	County	Terrain	Lanes
0029A	74.03	ENT/LV SILVER BOW/JEFFERSON CO	Rural	Minor Arterial	910	2012	SILVER BOW	Mountainous	2
0029A	74.23	ENT/LV JEFFERSON/SILVER BOW CO	Rural	Minor Arterial	910	2012	JEFFERSON	Mountainous	2
0029A	75.05	ENT/LV SILVER BOW/JEFFERSON CO	Rural	Minor Arterial	910	2012	SILVER BOW	Mountainous	2
0029A	75.59	PROJECT CHANGE	Rural	Minor Arterial	910	2012	SILVER BOW	Mountainous	2
0029A	77.88	AADT VOLUME CHANGE ADDED	Rural	Minor Arterial	980	2012	SILVER BOW	Mountainous	2
0029A	77.89	PROJECT CHANGE	Rural	Minor Arterial	980	2012	SILVER BOW	Mountainous	2

Table 11 Listing of Roadway Features and Related Information

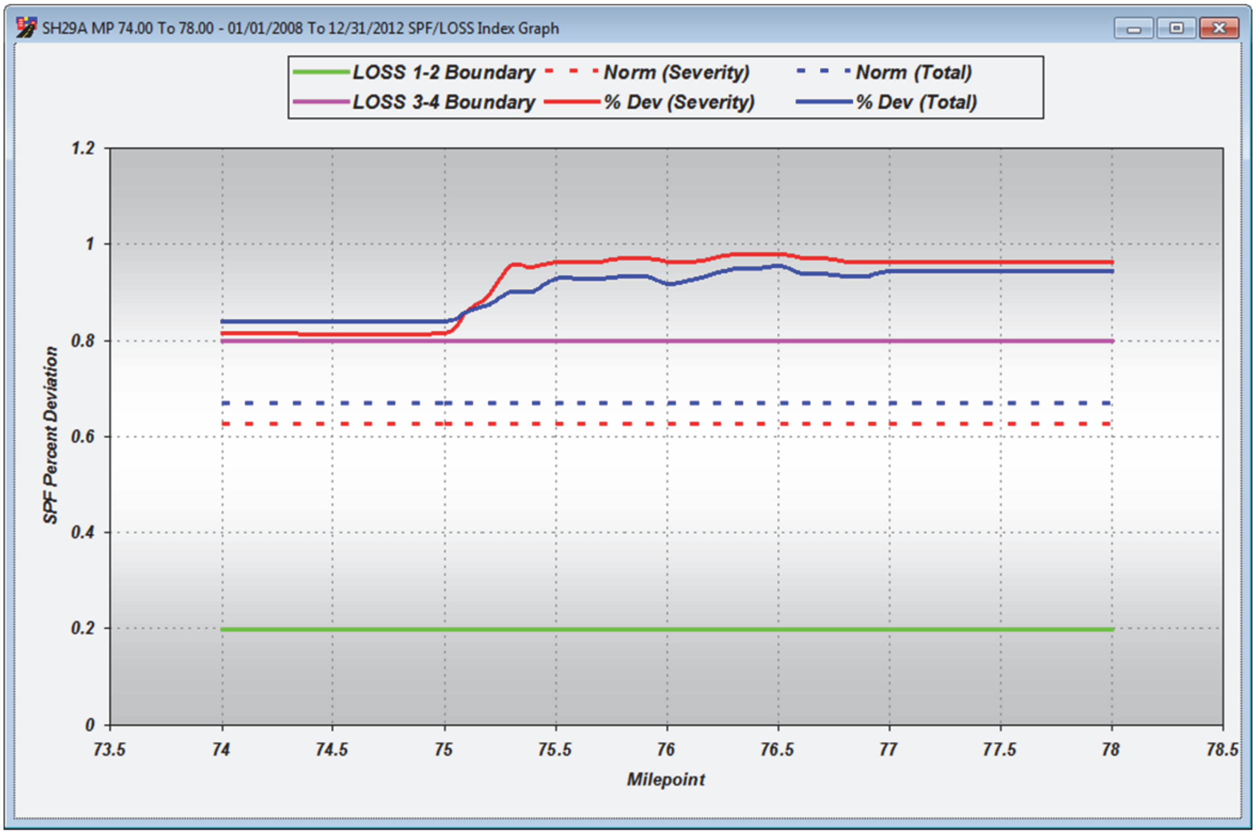

Figure 46 Corridor 29 MP 74.00-78.00 EB Corrected Corridor Level SPF Analysis

Corridor and segment level analyses of the frequency and severity of crashes observed on the Corridor 29 within study area are in the *LOSS-IV category, which reflects high potential for crash reduction from the frequency and severity stand point.* The entire corridor will be examined for the presence of crash patterns susceptible to cost-effective correction.

Aadt	Pdo	Inj	Fat	Length	Years	Spfmean_if	Spfmean_t	Obseb_if	Obseb_t	Spf_loc
841	14	13	1	3.990	5.000	0.1523	0.3796	0.3776	1.1638	SH29A : MP 74.00 to 78.00

Table 12 Corridor 29 MP 74.00-78.00 SPF Parameters

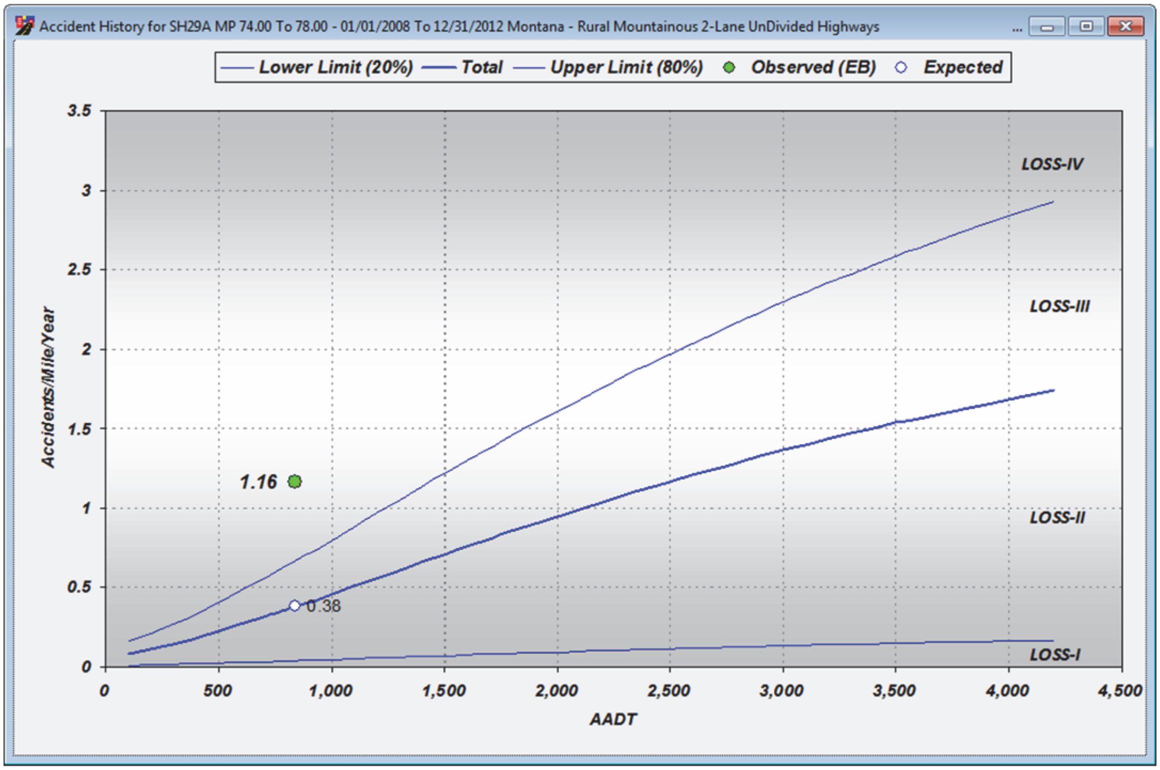

Figure 47 SPF for Total Crashes on Corridor 29 MP74.00-78.00

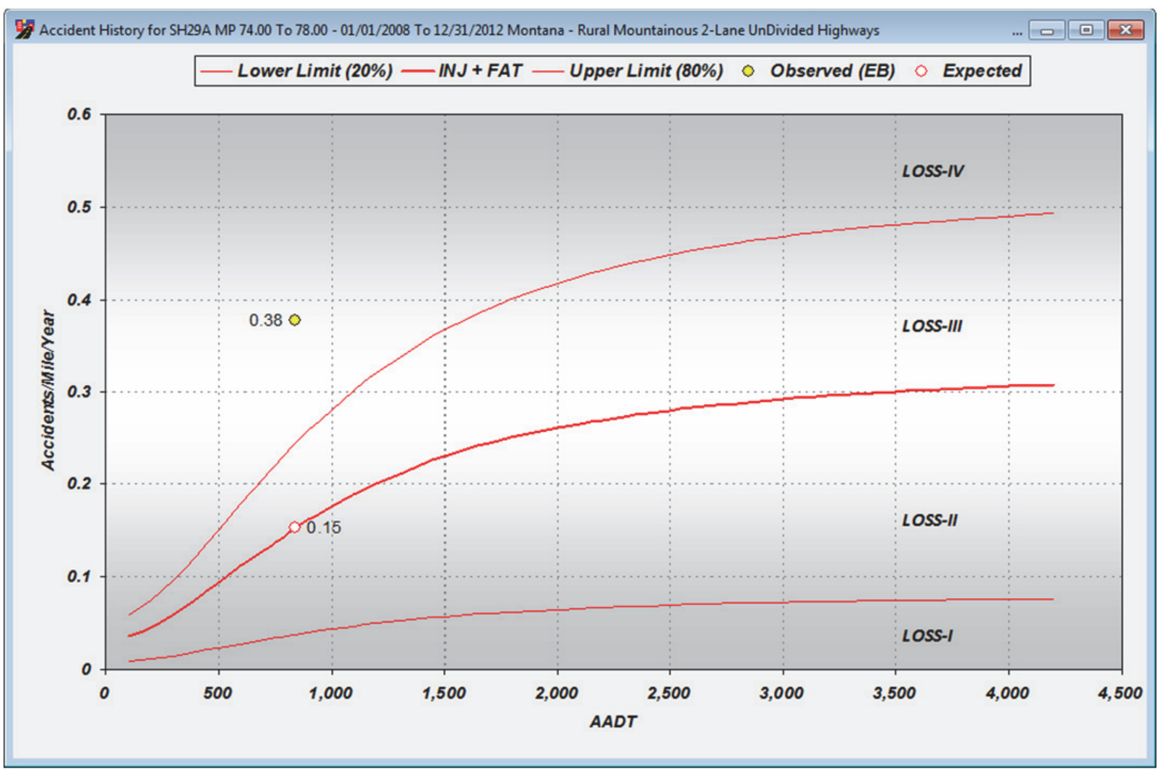

Figure 48 SPF for Injury + Fatal Crashes on Corridor 29 MP74.00-78.00

PATTERN RECOGNITION and DIAGNOSTIC ANALYSIS

The listing of observed cash patterns on Corridor 29 between MP 74.00 and MP 78.00 is provided in **Table 13**. Distribution of non-intersection related crashes by type is shown on **Figure 49.**

MONTANA

Montana Department of Transportation
DiExSys™ Roadway Safety Systems
Pattern Recognition Listing

06/06/2014
Job #: 20140606104946

Comparing: SH0029A MP 74.00 To 78.00 | **Min # of Accidents:** 5 | **Probability Confidence:** 95%

Pattern Recognition Listing

ACCIDENT PATTERN	%
Injury (INJ)	97.64%
Unknown Road Location	98.14%
Embankment	99.74%
Total Fixed Objects	98.88%
Daylight	97.07%
No Adverse Weather	97.65%
Dry Road	98.65%

Table 13 Listing of Observed Crash Patterns Corridor 29 MP 74.00-78.00

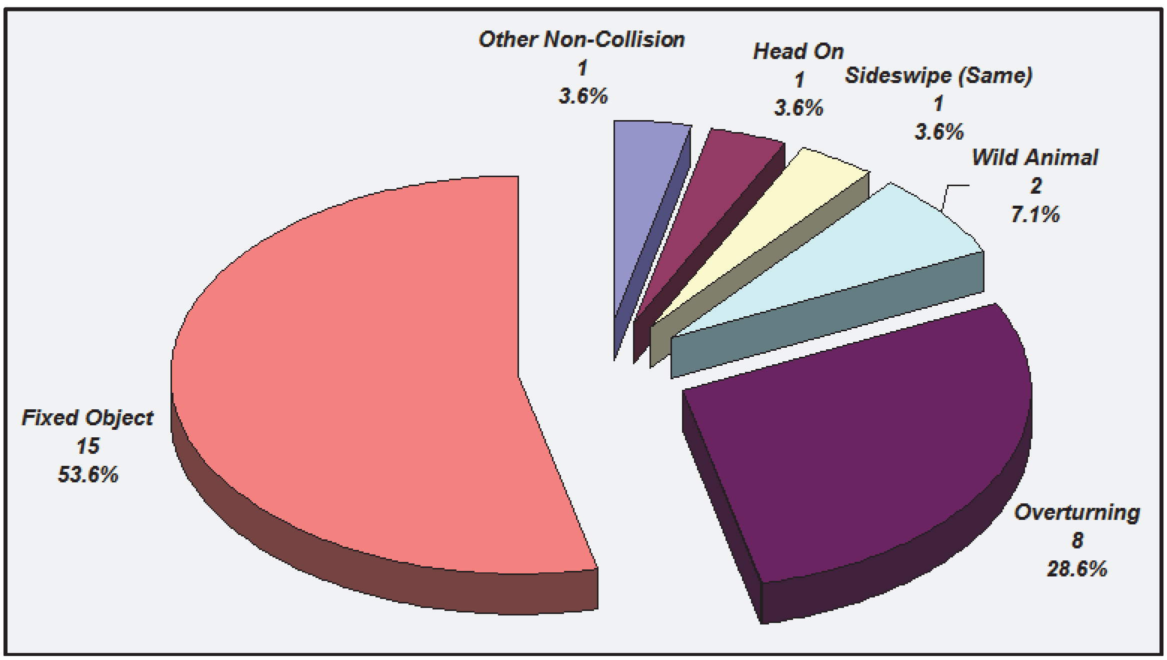

Figure 49 Corridor 29 MP 74.00-78.00 Distribution of Crashes by Type

Results of the crash pattern recognition analysis show that injury and collisions with fixed objects are over-represented. Distribution of crashes by type illustrates that roadway departure crashes account for 85.8% of the total (15 Fixed Objects, 8 Overturnings and 1 Head On). **Figure 50** shows locations of the roadway departure crashes in the straight line diagram format.

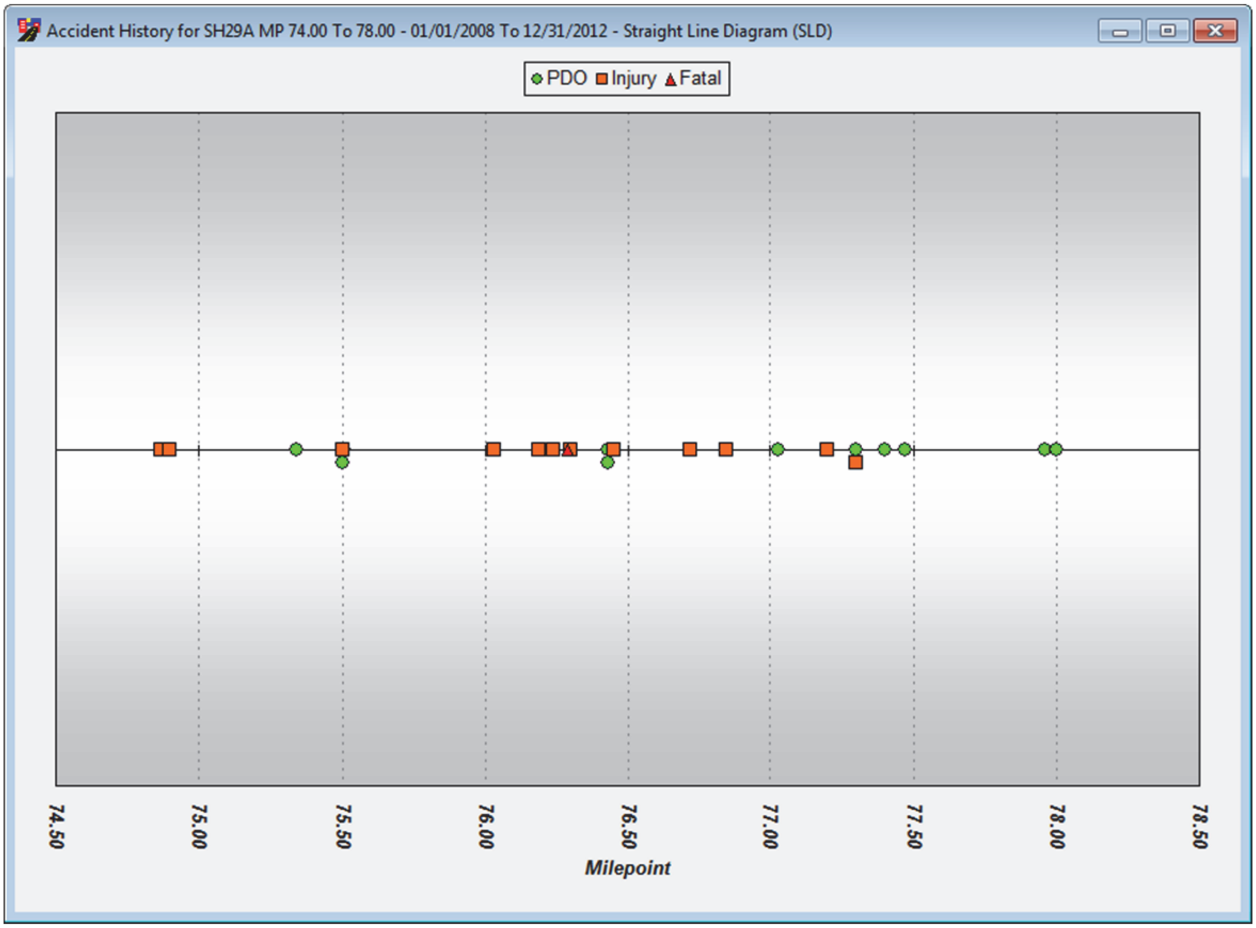

Figure 50 Corridor 29 MP 74.00-78.00 Roadway Departure Crashes Straight Line Diagram

It is relevant to note **(Figure 51)** that only one of the fixed object crashes involved a collision with guard rail, which in concert with elevated injury pattern and observed overturning crashes suggests that additional guard rail construction has a potential for injury reduction. A concentration of the roadway departure crashes between MP 76.00 and 77.50 presents an opportunity for the effective guard rail installation. **Figure 52** shows roadside slopes along Corridor 29 at approximately MP 76.00 looking northwest.

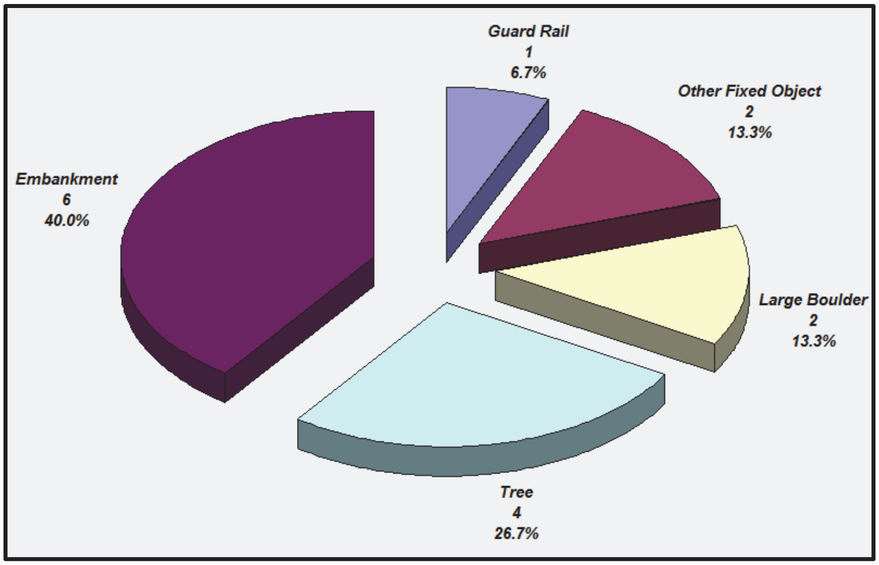

Figure 51 Corridor 29 74.00-78.00 Distribution of Fixed Object Crashes by Object Type

Figure 52 Corridor 29 Approx. MP 76 Looking Northwest

The benefits of constructing new guard rail between MP 76.00 and 77.50 are quantified by the Benefit/Cost (B/C) analysis **(Table 14)** as a guide to construction expenditures and anticipated safety improvements. **Table 14** shows that guard rail construction between MP 76.00 and 77.50 is highly cost effective even under very conservative assumptions about the cost of construction.

Montana Department of Transportation
DiExSys™ Roadway Safety Systems
Economic Analysis Report

07/23/2014
Job #: 20140723112841

Location: 29A | **Begin:** 76.00 | **End:** 77.50 | **From:** 01/01/2008 | **To:** 12/31/2012

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	6		Weighted PDO:	1.47	0% :ARF for PDO	Cost of PDO:	$ 9,100
INJ:	8	8 :Injured	Weighted INJ:	1.97	40% :ARF for INJ	Cost of INJ:	$ 78,700
FAT:	1	1 :Killed	Weighted FAT:	0.25	60% :ARF for FAT	Cost of FAT:	$ 1,420,000
			B/C Weighted Year Factor:	5.00	25% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
		Cost: $ 250,000				Service Life:	20
		From: 01/01/2008				Capital Recovery Factor:	0.080
		To: 12/31/2012	Days: 1827			Annual Maintenance Cost:	$ 2,000

Benefit Cost Ratio: 12.29 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: GUARDRAIL - INSTALLATION
Special Notes: RUN OFF THE ROAD ACCIDENTS ONLY AND RELATED ACCIDENTS

Table 14 Detailed Life Cycle B/C Analysis

Approximately 20% of crashes involved motorcyclists **(Figure 53)**, which is likely far greater than the share of their presence in the traffic stream. We recommend constructing centerline rumble strips to moderate reckless driving around curves. Additionally centerline rumble strips is very effective countermeasure to reduce head-on/sideswipe opposite crashes (observed 4 in 10 years in this low AADT environment).

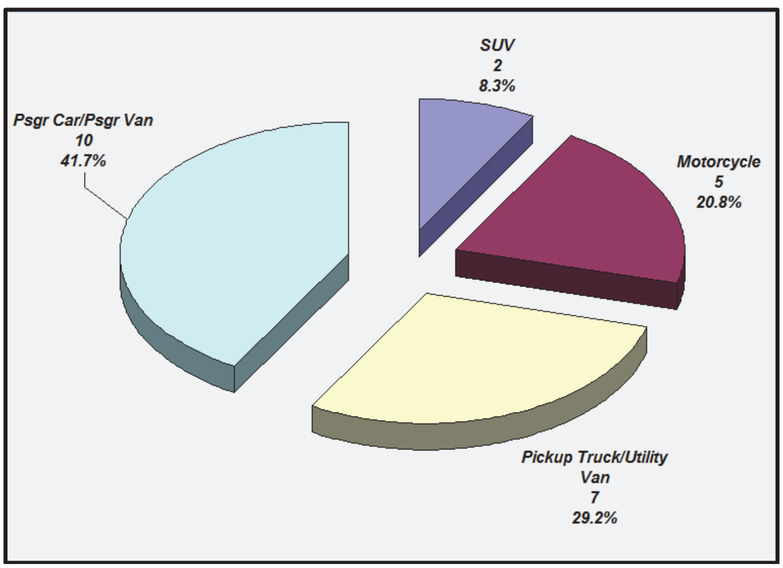

Figure 53 Corridor 29 MP 74.00-78.00 Distribution of Crashes by Vehicle Type

General Observations

Regulatory posted speed within study limits is 70 mph and the advisory speed around curves ranges between 35 mph and 15 mph. Even though curve warning signs with advisory plaques are intended to improve safety by alerting the driver to a change in geometry that may not be expected, it is possible that 70 mph speed limit does not fully prepare the driver to encounter the sharpest curves in this mountainous terrain. Drivers may not expect differences between the posted speed limit and advisory curve speed exceeding 25 mph, and in one case 55 mph.

CONCLUSIONS AND RECOMMENDATIONS

Frequency and severity of crashes on Corridor 29 experienced within study area are in the LOSS-IV category, which reflects high potential for crash reduction from the frequency and severity standpoint. Our recommendations aimed at reducing frequency and severity of the roadway departure crashes includes the following:

Construct new guard rail between MP 76.00 and 77.50

MDT may consider completing an engineering and traffic speed study focusing on the difference between posted and advisory speeds to better prepare drivers for the demands of the driving task within study limits, thereby improving design consistency and likely, as a result, safety.

If resurfacing project is planned, the following features typically associated with a resurfacing project should be provided:

- Good skid resistance and drainage of the roadway surface.
- Adjustment, repair and upgrade of all existing guardrail and bridge rail to meet current Montana standards.
- Replace all delineator reflector buttons and guard rail reflector tabs to maximize delineation in the corridor.
- Elimination of pavement edge drop-offs.
- Superelevation and crown correction where required.
- Appropriate pavement markings, signing and delineation.

IMPAIRED DRIVING RELATED PROBLEMS

According to the National Highway Traffic Safety Administration (NHTSA) Assessment of the Montana's Impaired Driving Program[5] Montana continues to have one of the highest rates of alcohol impaired fatalities in the nation. Its rate of alcohol related fatal crashes is twice the national average. Montana has a widely dispersed population, with the majority of residents living around Billings, Butte, Missoula and Helena. Many of the Montana Counties are comprised of thousands of square miles populated by only a few thousand people. Demographic characteristics of Montana are thought to have contributed to the widely divergent approaches to law enforcement in general and impaired driving enforcement in particular[5].

At the same time Montana is one of the few states in the country which, by law, assesses a portion of fee revenue to impaired driving programs. Montana has Interagency Coordination Council (ICC) comprised of state agencies and organizations that work together to create and sustain a comprehensive system of prevention services across the state. Additionally in Montana there are 32 County-level Driving Under the Influence (DUI) Task Forces representing 36 counties. Of the seven Indian tribes, only the Apsaalooke Nation (Crow Tribe) maintains an active DUI Task Force. Similar multi-disciplinary activities, however, aimed at prevention of impaired driving crashes exist among other tribal governments.

Priority recommendations in the area of Program Management of the NHTSA Assessment of Montana's Impaired Driving Program emphasize the need for the project selection and program efforts to be:

- Data-driven and evidence-based
- Focused on populations and locals that are most at risk.

Toward this goal RDSIP provides a GIS map of locations where alcohol-related crashes are over-represented. These maps were developed on the basis of statewide pattern recognition analysis and can be used to target enforcement and possibly education efforts. In some cases behavioral intervention on selected corridors can be combined with engineering countermeasures to produce Enforcement-Education-Engineering (3E) projects. In the process of developing Montana-specific Safety Knowledge Base the percent of alcohol related crashes for each road type was calibrated and further stratified by the degree of congestion. These normative percentages were then used to identify and delineate boundaries of abnormally high concentrations of alcohol related crashes using a pattern recognition algorithm[6]. Because traffic crashes can be viewed as random Bernoulli trials it is possible to detect deviations from the random statistical process by computing the observed cumulative probability for each of the normative parameters; in this case the percent of alcohol related crashes. A reference framework for the continuous pattern recognition analysis for the deviation from the Montana –

---

[5] Assessment of the Impaired Driving Program, STATE OF MONTANA, National Highway Traffic Safety Administration, May 5-10, 2013

[6] Kononov, J., (2003) Identifying Locations with Potential for Accident Reduction: Use of Direct Diagnostics and Pattern Recognition Methodologies. In Transportation Research Record No. 1840, TRB, National Research Council, Washington, D.C. 2002, pp 57-66

specific norms for the alcohol-related crashes is provided in **Figure 54.** The pattern recognition process can be described as follows:

Select scanning interval $\Delta_i = \Delta_1 = \Delta_2 = ...\Delta_n$

Scanning interval is generally 1 mile for the analysis of roadway segments in rural areas. Selection of the scanning interval is data driven and can be extended beyond 1 mile in areas with low AADT or reduced in the areas of high AADT.

Select a scanning increment $\delta_i = \delta_1 = \delta_2 = ...\delta_n$

The scanning increment is generally 0.10 miles and was found adequate for most Montana highways.

Identify the number of total crashes (*n*) and the number of crashes involving alcohol (*x*).

Select the appropriate *p* reflecting the Bernoulli probability/diagnostic norm of alcohol related crashes.

Select critical value P_α for making classification decisions $P_\alpha = 0.95$, for most cases.

Compute cumulative probability of observing *x* or fewer alcohol related crashes out of n

$$P(X \leq x) = B(x,n,p) = \sum_{i=0}^{x} \frac{n!}{(n-i)!i!} p^i (1-p)^{n-i}$$

Where:

n – Total number of crashes

x – Number of observed crashes alcohol-related crashes

p – Expected % alcohol-related crashes based on statewide statistics

P – Cumulative probability of observing x alcohol-related crashes or fewer

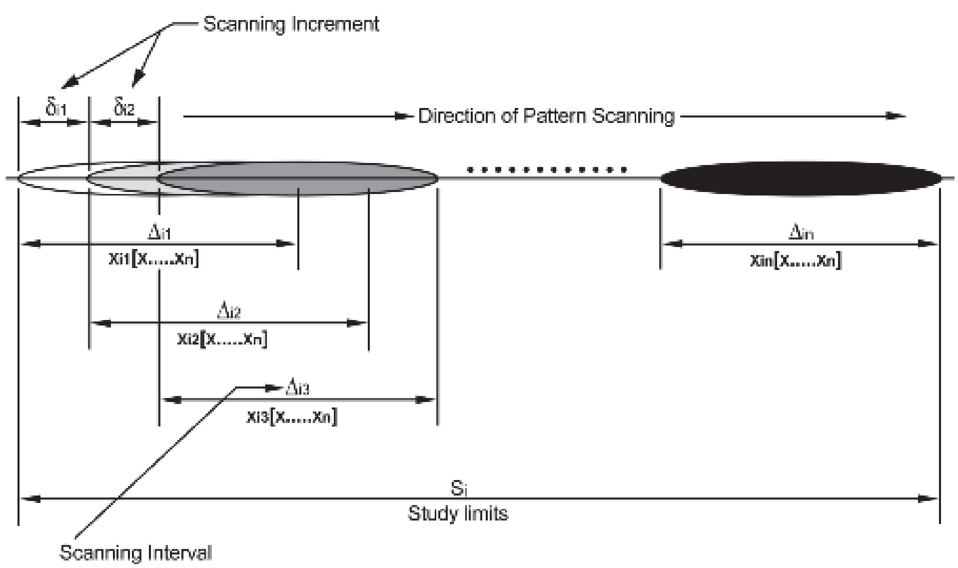

Figure 54 – Reference Framework for Continuous Pattern Recognition

For instance if total (n) of 16 crashes are observed, 6 (x) of them involved use of alcohol, when Montana state average p for 2-Lane Rural Roads is 10.3% the cumulative probability of observing 6 or fewer crashes can be computed as follows:

$P(X \leq 6, n = 16, p = 10.3\%) \approx 100\%$

Which suggests that frequency of alcohol related crashes at this location is abnormally high.

Following the completion of the first pattern recognition cycle, the scanning interval is shifted a predetermined incremental distance and the process is repeated again. In this incremental fashion the entire distance S representing study limits is tested for the presence of abnormally high frequency of alcohol-related crashes.

Figure 55 provides a statewide GIS map of locations where alcohol-related crashes are over-represented. To further illustrate the utility of using this map, an enlarged detail map of alcohol-related crashes of the area northeast Helena (**Figure 56**) is also included. To illustrate practical application of these maps a case history addressing a pattern of alcohol-related crashes on Corridor 280 in the Hauser Lake area is provided in this report (Pages 55-57) including how the analysis is performed and how cost-effectiveness of potential counter-measures is evaluated.

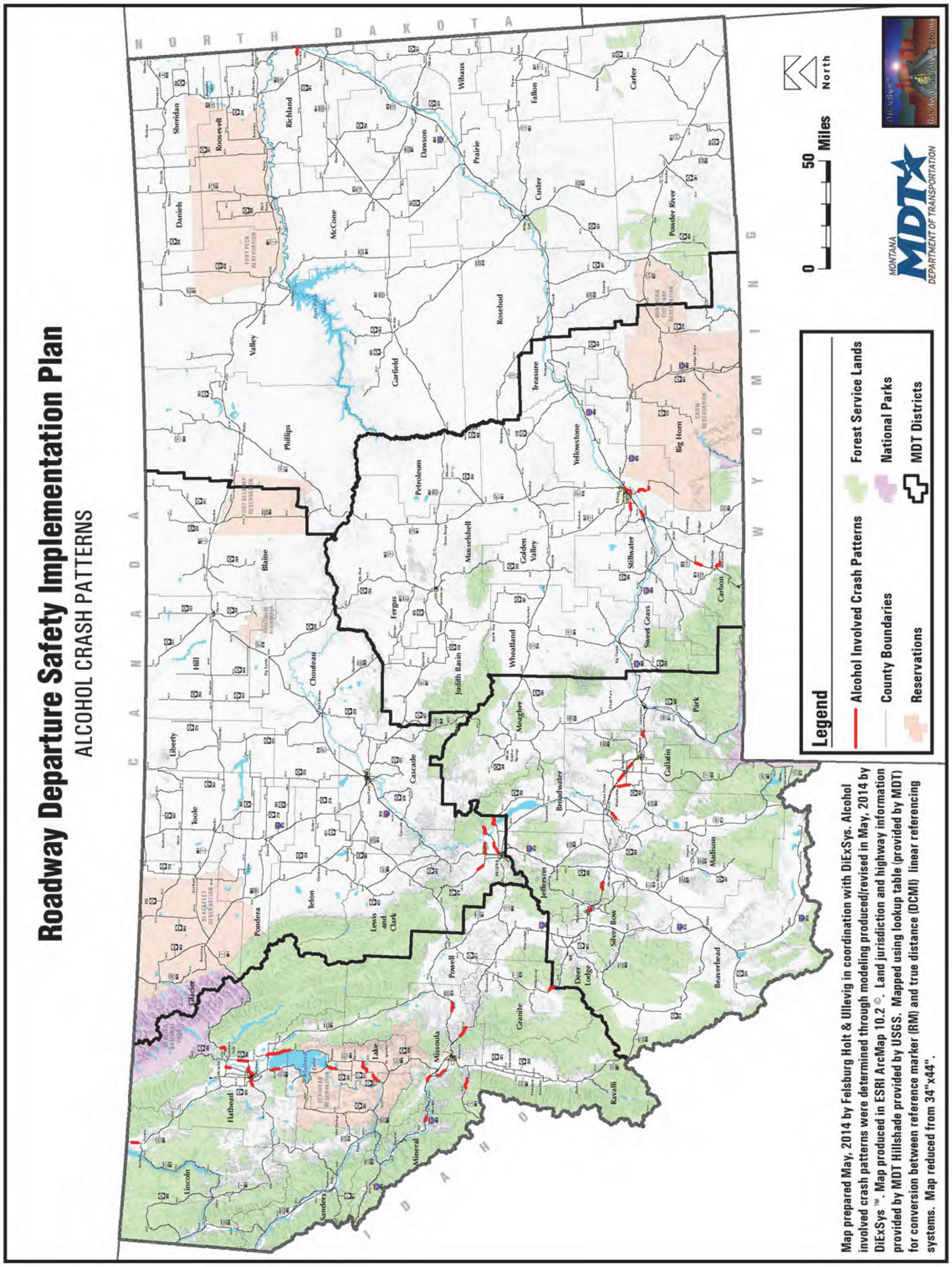

Figure 55 Statewide Map of Alcohol-related Crash Patterns

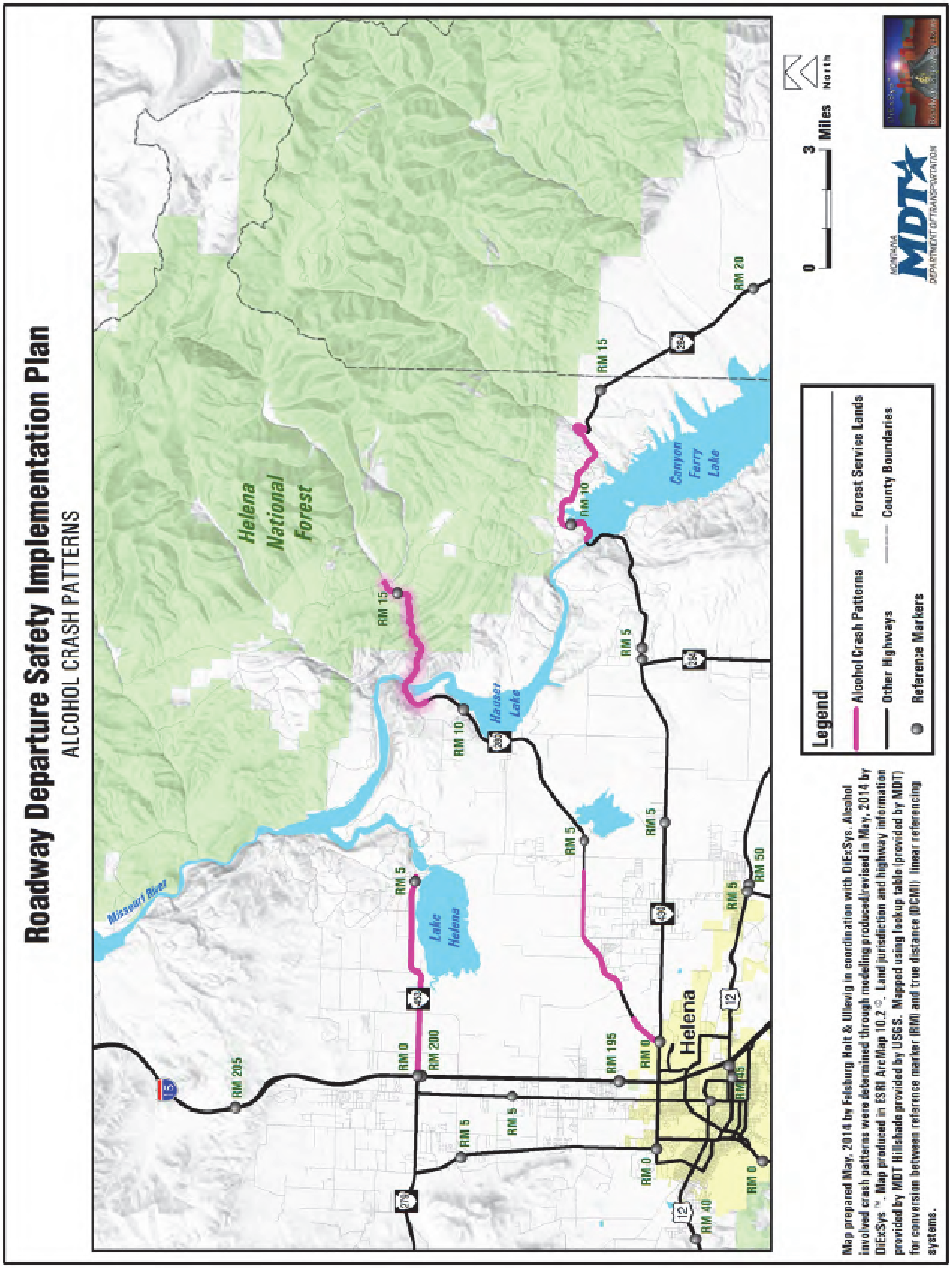

Figure 56 Enlarged Map of Alcohol-related Crash Patterns Northeast of Helena

Using Alcohol-related Crash Pattern Maps to Target Impaired Driving Programs

Alcohol-related crash pattern map **(Figure 57)** shows a pattern of impaired driving crashes on Corridor 280 approximately between MP 11.00 and 15.44.

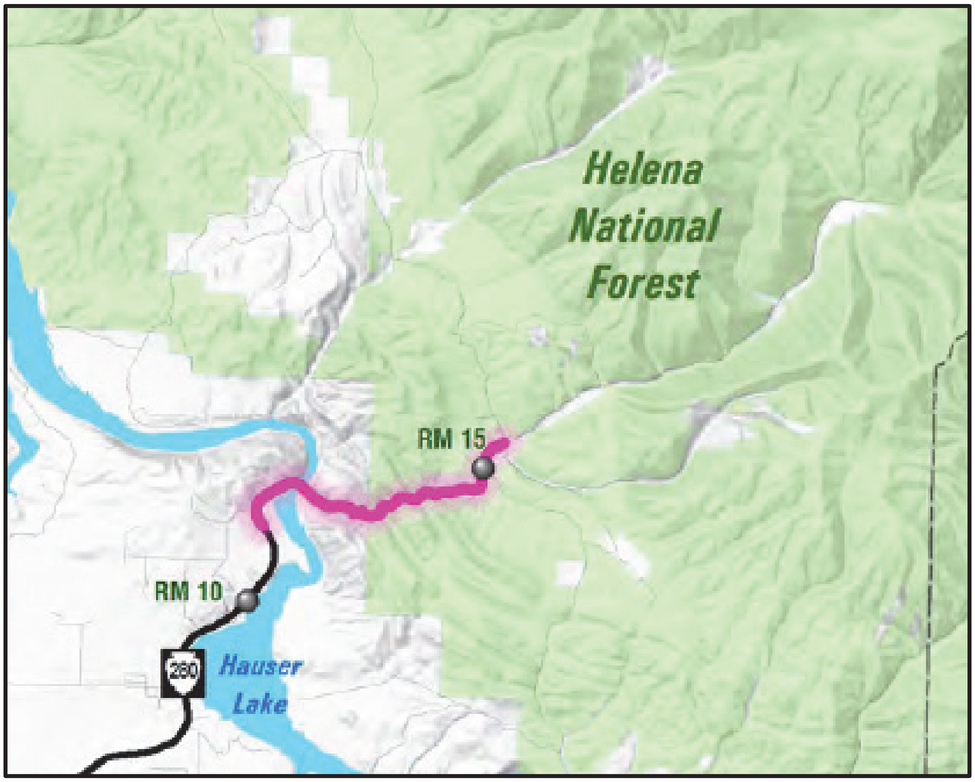

Figure 57 Alcohol Crash Pattern Map (Enlarged) Corridor 280 MP 11.00-15.44

Out of 48 crashes total 15 involved alcohol **(Figure 58). T**his suggests a very strong (100% cumulative probability) pattern of impaired driving crashes (see analysis below). Additionally "driver not observed" designation, in our experience, is often associated with the impaired driver abandoning his or her vehicle and leaving the scene of the crash.

$$P(X \leq x) = B(x, n, p) = \sum_{i=0}^{x} \frac{n!}{(n-i)!i!} p^i (1-p)^{n-i}$$

Where:

n – Total number of crashes (48)

x – Number of observed crashes alcohol-related crashes (15)

p – Expected % alcohol-related crashes based on statewide statistics (12.06% Mountainous 2-Lane)

P – Cumulative probability of observing x alcohol-related crashes or fewer

$P(X \leq 15, n = 48, p = 12.06\%) \approx 100\%$

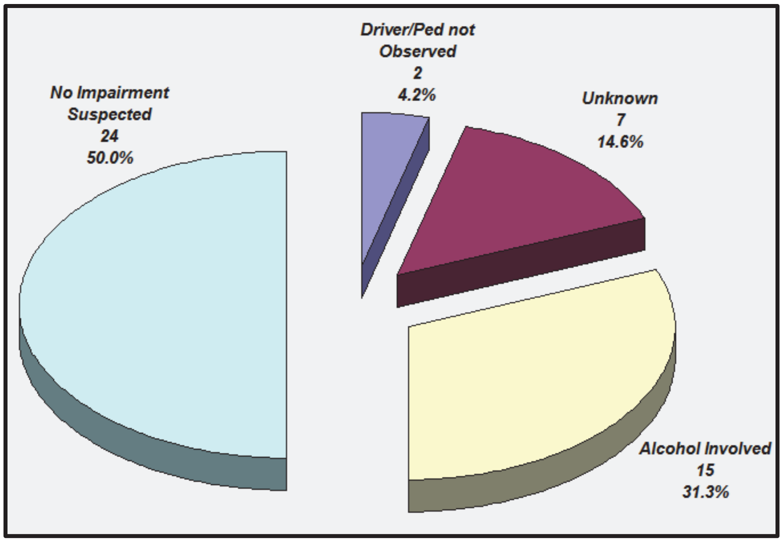

Figure 58 Distribution of Crashes by Driver Condition

Although there is no specific evidence to that effect, the fact that most of alcohol-related crashes occurred in the west or southbound direction suggests that the problem may possibly be related to York Bar located at the end of Corridor 280 at approximately MP 15.40 (Figure 59).

Figure 59 York Bar Corridor 280 approx. MP 15.40

A possible counter-measure strategy to address this problem may include a combination of increased enforcement in concert with cooperation with York Bar management to institute a designated driver or a safe ride program. The benefits of enforcement combined with designated driver/safe ride programs are quantified by Benefit/Cost (B/C) analysis as a guide to program expenditures and anticipated safety improvements. **Table 15** provides the B/C ratio relating $20,000 of annual combined program cost with anticipated benefits of a 20% reduction in the alcohol-related crashes. It shows that a combination of enforcement and designated driver/safe ride program can be cost-effective.

MONTANA

Montana Department of Transportation
DiExSys™ Roadway Safety Systems
Economic Analysis Report

01/09/2015

Job #: 20150109194229

Location: 280A **Begin:** 11.00 **End:** 15.44 **From:** 01/01/2003 **To:** 12/31/2012

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	3		Weighted PDO:	0.30	20% :ARF for PDO	Cost of PDO:	$ 8,900
INJ:	13	18 :Injured	Weighted INJ:	1.80	20% :ARF for INJ	Cost of INJ:	$ 78,900
FAT:	1	1 :Killed	Weighted FAT:	0.10	20% :ARF for FAT	Cost of FAT:	$ 1,410,000
			B/C Weighted Year Factor:	10.00	20% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
	Cost: $ 0					Service Life:	1
	From: 01/01/2003					Capital Recovery Factor:	1.050
	To: 12/31/2012		Days: 3653			Annual Maintenance Cost:	$ 20,000

Benefit Cost Ratio: 2.86 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: COMBINATION OF ENFORCEMENT/DESIGNATED DRIVER AND SAFE RIDE PROGRAMS

Special Notes:

Table 15 B/C Analysis of Combined Behavioral Countermeasures

HOW TO CONDUCT OBSERVATIONAL BEFORE AND AFTER STUDIES TO ESTIMATE CRASH MODIFICATION FACTORS

This chapter of the RDSIP represents a brief summary of the methodology described in the Federal Highway Administration's (FHWA) Guide to Developing Quality Crash Modification Factors[7]. It will first examine Before-After methodology using Comparison Group method followed by the review of the empirical Bayes Before-After methodology.

BEFORE-AFTER WITH COMPARISON GROUP METHOD

A before-after with Comparison Group study uses an untreated comparison group of sites similar to the treated ones to account for changes in crashes unrelated to the treatment such as time and traffic volume changes. The Comparison Group is used to calculate the ratio of observed crash frequency in the after period to that in the before period. The observed crash frequency in the before period at a treatment site group is multiplied by this comparison ratio to provide an estimate of expected crashes at the treatment group if no treatment been applied. This is then compared to the observed crashes in the after period at the treatment site group to estimate the safety effect of the treatment. This method does not correct for regression-to-the mean bias, but it represents a simple alternative to the more complex empirical Bayes approach. It can be a useful strategy to evaluate the effectiveness of safety countermeasures when Safety Performance Functions for specific crash types are not available. The following example illustrates its application. **Table 16** provides before and after crash counts for the treatment and comparison groups.

Time Period	Treatment Group	Comparison Group
Before	100	84
After	65	80

Table 16 Example Crash Count for before-After Comparison Group Study

The following terminology will be used:

$N_{obs,T,B}$ = the observed number of crashes in the before period for the treatment group

$N_{obs.T.A.}$= the observed number of crashes in the after period for the treatment group

$N_{obs.C.B}$ = the observed number of crashes in the before period for the comparison group

$N_{obs.C.A}$ = the observed number of crashes in the after period for the comparison group

The Comparison Ratio (CR) = $N_{obs.C.A}/ N_{obs.C.B.}$ It indicates how crash counts are expected to change in the absence of treatment. In this case CR = 80/84 = 0.9524

$N_{exp.\ TA}$ = the expected number of crashes in the after period in the absence of treatment

$N_{exp.\ TA} = N_{obs,T,B}$ CR = 100 (0.9524) = 95.24

Var($N_{exp.\ TA}$) = variance of the expected number of crashes in the after period

[7] Gross, Persaud and Lyon, *Guide to Developing Quality Crash Modification Factors,* Report No. FHWA-SA-10-032, December 2010.

$Var(N_{exp.\,TA})$ = $N_{exp.\,TA}^{2}(1/N_{obs,T,B} + 1/N_{obs.C.B} + 1/N_{obs.C.B})$ = $95.24^2\left(\frac{1}{100}+\frac{1}{84}+\frac{1}{80}\right) = 312.06$

CMF = Crash Modification Factor

CMF = $\frac{N_{obs,T,A}/N_{exp,T,A}}{1+Var(N_{exp,T,A})/(N_{exp,T,A}^2)} = \frac{65/95.24}{1+312.06/95.24^2} =$ 0.660

Var(CMF) = variance of the CMF

Var(CMF) = $\frac{CMF^2[(1/N_{obs,T,A})+(Var(N_{exp,T,A}/N_{exp,T,A}^2)]}{[1+Var(N_{exp,T,A})/N_{exp,T,A}^2]^2} = \frac{0.660^2[(1/65)+(312.06)/(95.24^2)]}{[1+(312.06)/(95.24)^2]^2} =$ 0.0203

Standard Error (σ) = $\sqrt{Var(CMF)}$ = $\sqrt{0.0203}$ = 0.1424

The cumulative probability factors for common confidence intervals are provided in **Table 17**.

Confidence Interval	Cumulative Probability
99%	2.576
95%	1.960
90%	1.645

Table 17 Cumulative Probability Factors

95% Confidence Interval = 0.660 $\pm$ 1.960(0.1424), which translates into a confidence interval of 0.381 to 0.939. Note that that confidence interval does not contain 1 and therefore the results are statistically significant at the 95% confidence level.

EMPIRICAL BAYES BEFORE-AFTER METHOD

Similar to the comparison group method, the effect of the safety treatment is estimated by comparing the sum of the estimates of $N_{exp. TA}$ for all treated sites with the number of crashes actually observed after treatment. The advantage of the empirical Bayes approach is that it correctly accounts for the changes in crash history that may be due to the regression-to-the-mean (RTM) phenomenon. RTM phenomenon reflects the tendency for random events, such as vehicle crashes to move toward the average during the course of an experiment or over time. The existence of the RTM bias has been long recognized and is now effectively addressed by using the Empirical Bayes (EB) method[8]. Additionally it provides a better approach than the comparison group method for accounting for changes in safety performance due to traffic volumes. The application of the empirical Bayes method requires the use of the Safety Performance Functions (SPF) and related over-dispersion parameters provided in the Montana-specific safety knowledge base. **Table 18** provides information to support example calculations using the empirical Bayes Before-After Method. For this simplified example, a weight (W) of 0.25 is assumed for the SPF prediction for all sites and there are no traffic volume changes at the treated sites.

Time Period	Treatment Group	SPF Estimates for Treatment Group
Before	100	81.08
After	65	81.08

Table 18 Example Data for Empirical Bayes Before-After Study

Weight (W) provided in the problem statement is computed as follows:

$W = \frac{1}{1+(\mu \times n)\alpha} = 0.25$

Where

μ = Mean predicted by the SPF, here $N_{pred,B} = N_{pred,A}$ (no changes in traffic volume in this example)

n = number of years in the before or after period

α = Over-dispersion Parameter derived from SPF

The empirical Bayes estimate, $N_{exp, T,B}$, is computed as:

$N_{exp,T,B} = W\ N_{pred} + (1 – W)\ N_{obs,T,B} = 0.25(81.08) + (1-0.25)\ 100 = 95.27$

Since there was no changes in volume $N_{pred,B} = N_{pred,A}$

$N_{exp,T,A} = 95.27$

The variance of $N_{exp,T,A}$ is estimated as:

[8] Hauer et al. Estimating Safety by the Empirical Bayes Method. In *Transportation Research Record 1174,* TRB, National Research Council, Washington, D.C., 2002, pp 126-131.

$Var(N_{exp,T,A}) = N_{exp,T,A}\ (1 - W) = 95.27(1\text{-}0.25) = 71.45$

$$CMF = \frac{N_{obs,T,A}/N_{exp,T,A}}{1+Var(N_{exp,T,A})/(N^2_{exp,T,A})} = \frac{65/95.27}{1+71.45/95.27^2} = 0.677$$

$$Var(CMF) = \frac{CMF^2[(1/N_{obs,T,A})+(Var(N_{exp,T,A})/N^2_{exp,T,A})]}{[1+Var(N_{exp,T,A})/N^2_{exp,T,A}]^2} = \frac{0.677^2[(1/65)+(71.45)/(95.27^2)]}{[1+(71.45)/(95.27)^2]^2} =$$

=0.0104

Standard Error (σ) = $\sqrt{Var(CMF)}$ = $\sqrt{0.0104}$ = 0.102

In this case the results are statistically significant at the 99% confidence level.

99% Confidence Interval = 0.677 $\pm$ 2.576 (0.102), which translates into 0.414 to 0.940.

CONCLUSIONS

Data-driven and evidence based Montana RDSIP described in this report was enabled by the development of the Montana-specific Safety Knowledge Base. The Montana-Specific Safety Knowledge Base is intended to serve as an analytical engine to assist Montana Department of Transportation (MDT) staff with maximizing safety improvements on Montana roads. It is comprised of predictive tools in the form of Safety Performance Functions (SPF) and diagnostic tools in the form of diagnostic menus and pattern recognition algorithms.

RDSIP developed a planning level estimate of $73 million per year necessary to meet MDT's goal of reducing Montana roadway departure crashes by 5% annually. Even though the expenditure of $73 Million annually is well beyond the current annual allocation of HSIP funds this ambitious goal can become a reality when all branches of MDT are working in concert.

To aid MDT with identification of locations with potential for crash reduction RDSIP includes GIS maps with Level of Service of Safety (LOSS)-categories and with roadway departure-related crash patterns. These maps were developed on the basis of the statewide SPF and Pattern Recognition Analysis using newly developed Montana-specific predictive and diagnostic tools. To demonstrate how locations for crash reduction can be selected RDSIP includes a list of 30 sites exhibiting elevated number of the roadway departure injury crashes or roadway departure-related crash patterns. Each potential site was examined further through diagnostic examination, followed by countermeasure development and the B/C analysis.

Additionally RDSIP developed requisite 5 year threshold of the number of injury crashes per mile (10 miles for rumble strips) *to produce* B/C Ratios of 2:1 or greater for the following selected countermeasures:

- Improvements of signing and delineation
- Center-line Rumble Strips
- Shoulder Rumble Strips
- Guardrail Installation
- Intensification of Snow and Ice Removal above Standard Levels of Maintenance

Using these thresholds enables MDT to identify future Roadway Departure Safety Improvement (RDSI) projects by considering how cost and safety benefits can be anticipated at the time of initial screening.

RDSIP provides a GIS map of locations where alcohol-related crashes are over-represented. These maps were developed on the basis of statewide pattern recognition analysis and can be used to target enforcement and possibly education efforts. In some cases behavioral intervention on selected corridors can be combined with engineering countermeasures to produce Enforcement-Education-Engineering (3E) projects.

To assist with the evaluation of effectiveness of constructed safety improvements using Montana-specific Safety Knowledge Base the RDSIP provides technical guidance and examples.