BEFORE/AFTER
SAFETY ANALYSES

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INTRODUCTION

The purpose of this study was to determine the effects of safety improvements on safety performance at locations chosen by the Colorado Department of Transportation (CDOT). This report discusses the results at 12 locations that were analyzed and the methodology used in the process. In addition, this report discusses the need to institutionalize the process of evaluating safety outcomes of constructed projects.

An overview of the methodology used in the before/after analysis for each location is provided in **Appendix A**.

ANALYSIS AND RESULTS

Fifteen locations were chosen by CDOT for analysis for this study. Those locations included state highways and non-state highways covering a variety of safety improvements. Analyzed roadway improvements included: guard rail, cable rail, concrete median, a weather warning system, and deer fencing. Intersection improvements analyzed included: a new signal, additional turn lanes, improving geometry to get rid of split phases, adding protected left-turn phasing, and signal upgrades such as larger signal heads and replacing old span-wire signals.

Three of the non-state highway study locations had poor data availability, and we were unable to accurately analyze them without implementing unified street naming convention and manual quality control for the off system crashes. The remaining 12 projects were analyzed and are provided in **Table 1** with the location, type of project, and resulting benefit/cost (B/C) ratio. As shown, many of the B/C ratios were greater than anticipated at the time of application for funding. Of the 12 safety projects analyzed, 3 showed no improvement or deterioration in safety performance in the after period and may not have been justified. The 3 projects with little to no improvement included:

- #15505 - Deer fencing and cattle guards on US 550. The number of wild animal crashes was reduced following construction as would be expected. However, the crashes were more severe in the after period causing the B/C ratio to be below one.
- #16006 - Intersection improvements at SH 45 and Red Creek Springs. The number of crashes in the before and after period were approximately the same, but the severity of crashes increased in the after period. It is unclear why the severity of crashes increased following this improvement project.
- #16010 - New signal at Industrial and Purcell. The number of broadside crashes decreased after the signal was constructed, but several other crash types saw an increase in number of crashes including approach turns, rear-ends, and sideswipes. In addition, the severity of crashes increased. The signal was warranted, but the results suggest that an intersection with volumes that just meet warrants might have better safety outcomes with a roundabout.

Table 1. Summary of Safety Analyses Locations

Def.	Region	Highway/Intersection	MP	Improvement Type	Initial Predicted B/C	Final Observed B/C
#15505	5	US 550	107.00 - 111.00	Deer Fencing/Cattle Guards	1.81	0.24
#15645	6	SH 83	69.39 - 70.57	Concrete Median	2.11	5.91
#15748	6	I-76	1.77 - 5.78	Cable Rail	14.36	6.16
#15770	2	I-25	102.50 - 107.50	Median Cable Rail	2.65	2.26
#15771	2	SH 165	18.65 - 23.90	Guard Rail	4.97	12.67
#15828	6	SH 93 / SH 72	7.57	Signal Upgrade	1.72	14.93
		SH 93	7.47 - 11.83	Weather Related Road Closure System	1.17	1.42
#15861	4	SH 52 / 95th Street	3.16	Intersection Improvements	2.52	13.37
#15862	4	US 34 / 11th Avenue	112.23	Intersection Improvements	2.03	9.69
#15900	3	SH 133	46.00 - 51.50	Guard Rail	4.89	21.54
#16005	2	US 50 / Purcell Boulevard	309.78	Intersection Improvements	1.77	4.00
#16006	2	SH 45 / Red Creek Springs	3.95	Intersection Improvements	1.18	0.08
#16010	2	Industrial / Purcell	-	New Signal	1.12	-

Appendix B provides a detailed report for each study location providing all the analyses and results.

All the barrier improvements including guard rail, cable rail, and concrete barrier showed significant improvement with B/C ratios ranging from 2.26 to 21.54, indicating that these are excellent safety improvements when crash data indicates there is a run-off-the-road pattern. The primary goal of these roadway barriers is to reduce the risk of severe crashes that can occur when a vehicle leaves the roadway. The barrier helps to reduce severe crash types such as head-on, overturning, or tree crashes. In the two guard rail studies (#15771, #15900), it was found that not only did the severity of crashes decrease, but the number of vehicles leaving the roadway also decreased. It has been theorized that perhaps the guard rail not only acts as a barrier to help reduce severe crashes, but it also provides additional delineation helping to keep drivers aware of curves in the roadway and as a result reduces the frequency of run-off-the-road crashes.

There were several projects that involved improving existing intersections and upgrading signals that had B/C ratios greater than one. These improvements including upgrading old signal heads to 12 inch heads, fixing geometry so split phasing is not required, adding turn lanes, and adding channelization and protected left-turn phasing. The B/C ratios varied from 4.00 to 14.93 for these projects, indicating that these improvements had a significant impact on the safety of the intersections. As mentioned earlier, there were two intersection improvement projects that did not have a B/C ratio greater than one.

The wide range in the resulting B/C ratios following construction of improvements demonstrates that CDOT should continue conducting the observational before/after safety studies for safety projects. It is important to gather data to learn what safety improvements are the most effective so that CDOT can make improved decisions regarding safety projects in the future.

SUMMARY AND RECOMMENDATIONS

It is important for CDOT to continue to do these Before/After Safety Analyses to understand what safety improvements are most effective. While many of the projects analyzed in the study have shown significant safety benefits, some showed deterioration in safety. It is essential to complete these studies in order to understand the impacts of different improvements types and why sometimes the anticipated safety improvements are not observed following construction. It is recommended that CDOT institutionalize this process and complete a before/after safety analysis for all safety projects constructed. Analyzing safety performance of projects before and after completion will allow CDOT to make better and more informed decisions for future projects.

APPENDIX A. STATEWIDE METHODOLOGY

Development of Methodology for Evaluating Changes in Safety Performance on Completed Construction Projects

By

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Introduction

The intent of this report is to describe a methodology for evaluating safety outcomes of constructed projects. One of the main sources of factual knowledge about the effect of highway and traffic engineering measures is the 'observational Before-After study'. The term observational in this context is used to distinguish between a randomized experiment designed to answer a research question and observing the safety consequences of some treatment that has been constructed for purposes other than answering a research question. Two kinds of evaluation methods is described here; the first will address safety evaluation methodology applied to the individual project and the second one will be used when estimating Crash Modification Factors (CMF) of a specific safety countermeasure applied to a group of sites.

Methodology to Evaluate Changes in Safety Performance at an Individual Site or Project

The use of this methodology will be illustrated using a specific example describing safety improvement resulting from constructing a median barrier on I-76 (MP 1.77 to MP 5.78). In this case, a Safety Performance Function (SPF) representing Urban 4-Lane Freeway is available.

Step 1

Identify scope and dates/duration of the construction period, in this case median barrier construction 7/9/2007-10/19/2007.

Step 2

Using Vision Zero Suite (VZS) collect safety performance data and AADT for 3-5 years of the before period, in this case the 5 years of before period used was 1/1/2002-12/31/2006.

Step 3

Using VZS evaluate safety performance in the before period following correction for the Regression to the Mean (RTM) bias using Empirical Bayes method. 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. This is addressed effectively by using the Empirical Bayes (EB) method[1]. The EB method for the estimation of safety increases the precision of estimation and corrects for the regression to the mean bias. It

[1] 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.

is based on combining the information contained in accident counts (known crash history) with the information contained in knowing the safety of similar entities. The information about safety of similar entities is brought into the EB procedure by the SPF through use of expected mean value and over-dispersion parameter associated with the specific SPF. Correcting for the RTM is a default setting in VZS. **Figure 1** shows safety performance of I-76 (MP 1.77 to MP 5.78) from the severity standpoint in the before period 1/1/2002-12/31/2006 EB corrected for RTM.

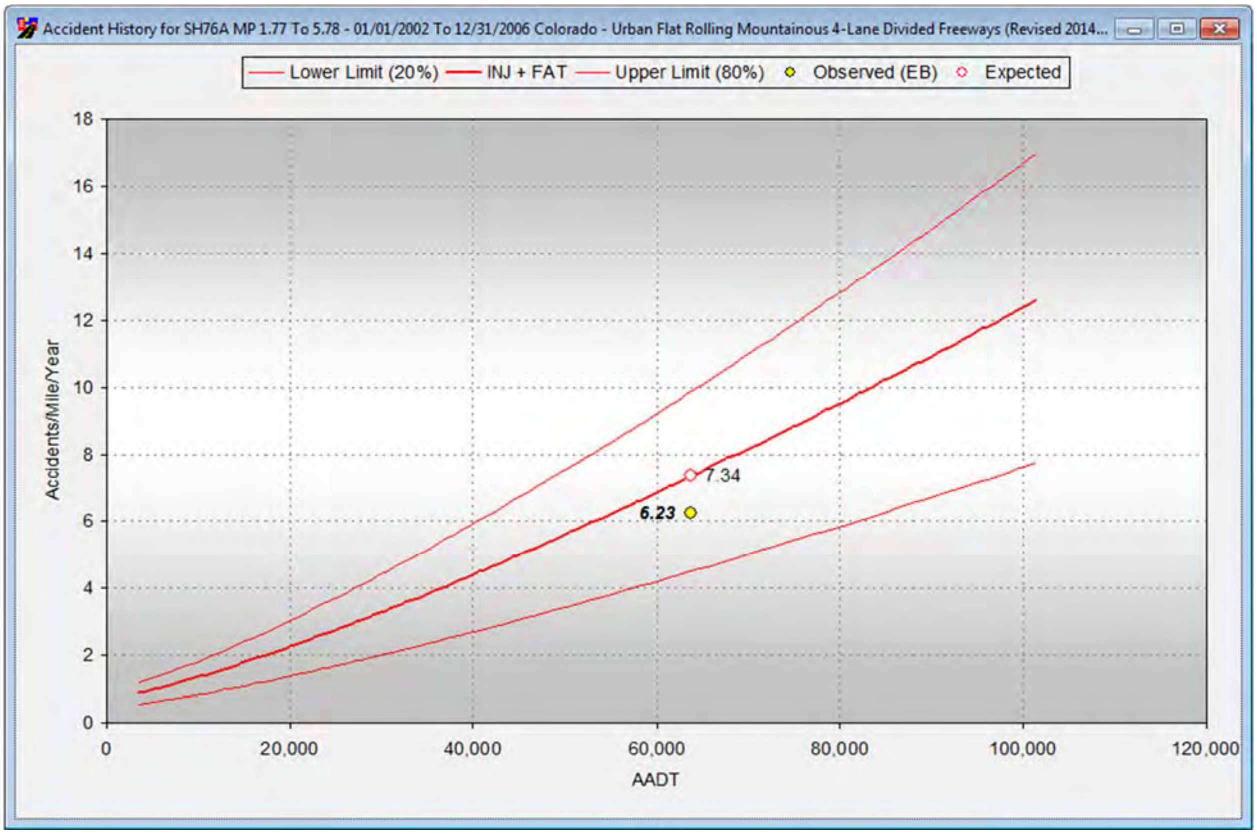


Figure 1 EB Corrected SPF Inj+Fat - I-76 (MP 1.77 to MP 5.78)
(Before Period - 1/1/2002-12/31/2006)

Step 4

Evaluate safety performance of I-76 (MP 1.77 to MP5.78) [1/1/2008-12/31/2012] in the after period. According to Hauer[2], the crash count in the after period is not subject to the EB correction for the RTM bias. **Figure 2** shows how to turn off EB correction in the VZS and **Figure 3** shows safety performance in the after period without the EB correction (***4.49*** crash/mi/year) and the before period corrected for RTM (***6.23*** crash/mi/year) on the same graph.

[2] Hauer, E. Observational Before-After Studies in Road Safety. Pergamon, Elsevier Science Ltd, 1997.

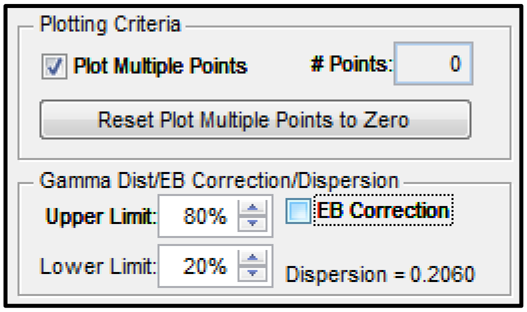


Figure 2 EB Correction Turned Off

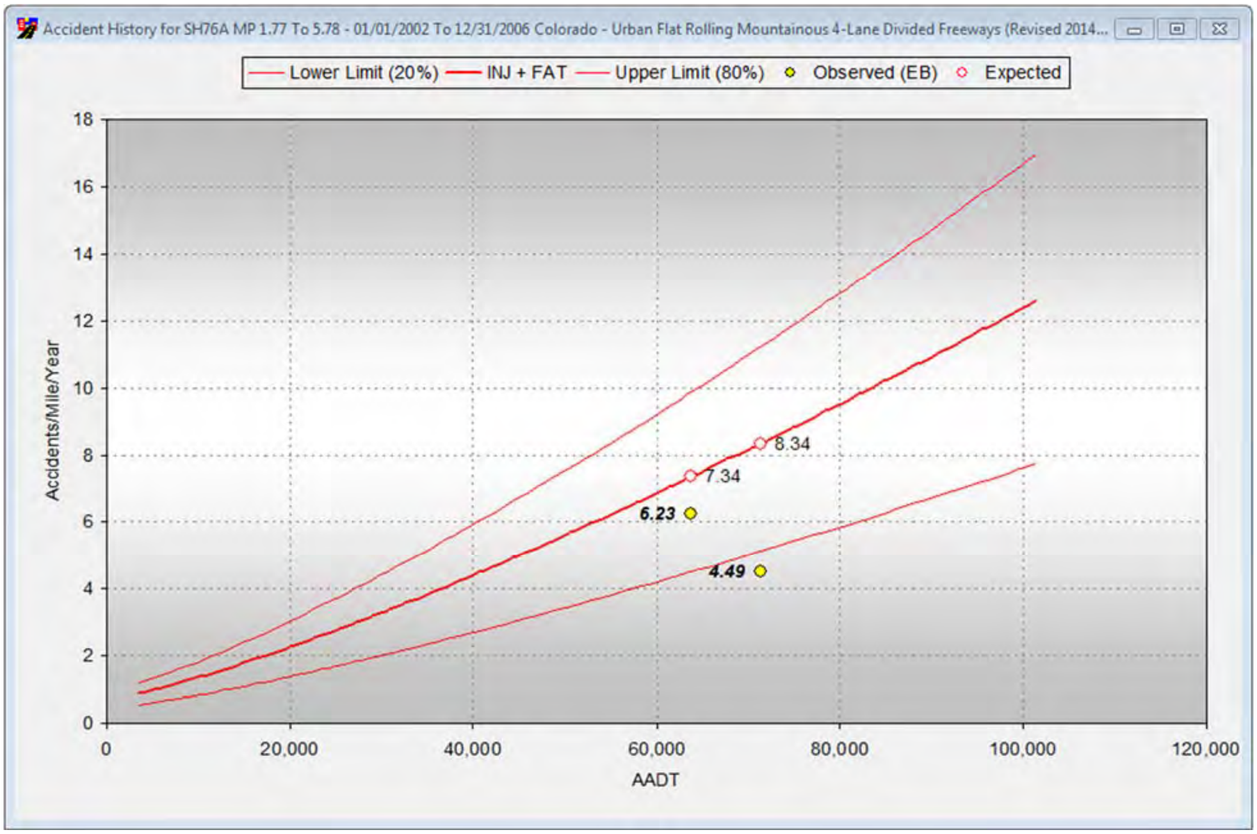


Figure 3 SPF Inj+Fat - I-76 (MP 1.77 to MP 5.78)
(EB Corrected Before Period- 1/1/2002-12/31/2006) and
(After Period - 1/1/2008-12/31/2012)

Step 5

Establish what the safety of the site in the after period would have been had safety improvement not been constructed and compare it with the after period. This is accomplished by first computing the percentile of the EB corrected safety performance within reference population in the before period using the gamma distribution and then extrapolating it for the AADT in the after period. It is assumed that if AADT changes in the after period and no safety improvements are constructed, the percentile of safety performance within reference population of similar facilities will be preserved.

The percentile within reference population of the EB corrected safety performance is computed using the gamma distribution probability density function as follows:

$$f(u) = \frac{a^b u^{b-1} e^{-au}}{\Gamma(b)}$$

u – The mean for the facility

μ - The mean predicted by the SPF

α – Over-dispersion parameter estimated from the regression

b – shape parameter ($b = 1/\alpha$)
a– b/μ (Scale parameter)
Γ– Gamma Function

For instance if u = 6.23 crash/mi per year after correcting for the RTM in the before period and
$\mu = 7.33 \frac{crash}{mi}\ per\ year$, predicted by SPF
Gamma (Γ) Function percentile (cumulative probability) can be computed as follows:

$$\int_{u=0}^{u=6.23} \frac{a^b u^{b-1} e^{-au}}{\Gamma(b)} du = 42.2\%$$

This computation is performed using Gamm Function (GAMMA.DIST) in the Excel spreadsheet (**Figure 4**) where

Alpha = b (here 1/ α = 1/0.205= 4.88) and Beta = μ/b (here 7.33/4.88 = 1.502)

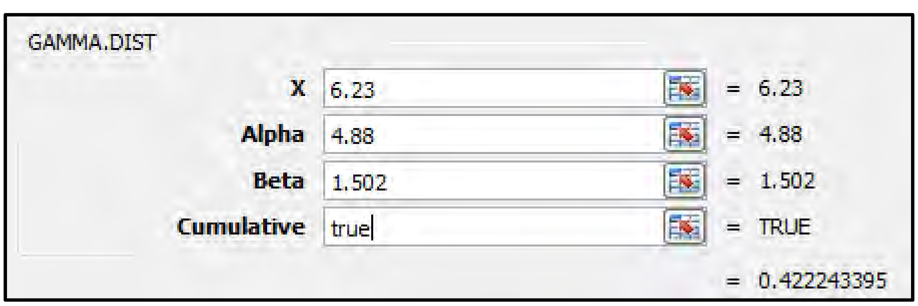


Figure 4 Cumulative Probability of Gamma Function in Excel

Safety performance in the before period is represented by the 42.22 percentile of the reference population of similar facilities. AADT in the after period has increased to 71,366 which corresponds to the SPF mean $\mu = 8.34 \frac{crash}{mi}\ per\ year.$ Using Inverse Gamma Function (GAMMA.INV) in the Excel (**Figure 5**) we can now compute 42.22 percentile for the new mean of 8.34. The return of the Inverse Gamma Function at 42.22 percentile represents what safety performance would have been had safety improvement not been constructed, in this case 7.09 $\frac{crash}{mi}\ per\ year$.

Alpha = b (here 1/0.205= 4.88) and Beta = μ/b (here 8.34/4.88 = 1.709)

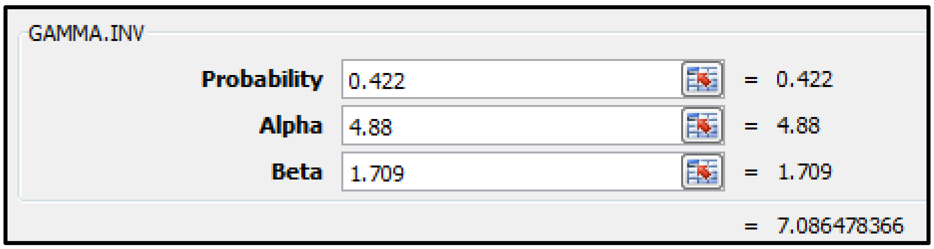


Figure 5 Inverse Gamma Function for a Specified Percentile in Excel

6.23 crash/mile per year is what safety was in the before period and **7.08** crash/mi per year is what safety would have been had safety improvement not been constructed. Following construction observed safety performance in the after period resulted in **4.49** crash/mile per year. When compared with the **7.08** crash/mile per year it represents **36.58%** reduction in injury and fatal crashes. **Figure 6** shows safety performance of I-76, MP 1.77-5.78 before (**6.23**), before without construction (**7.09**) and after (**4.49**) following construction on the same graph.

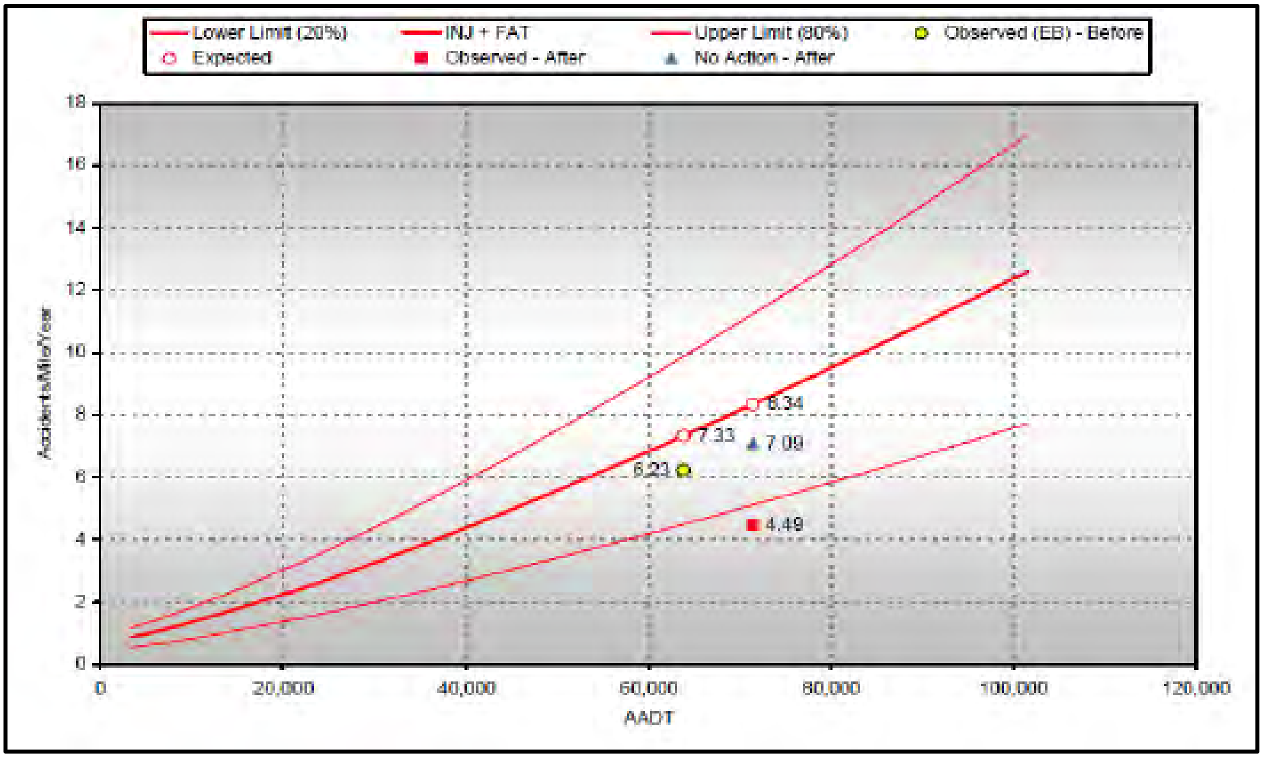


Figure 3 SPF Inj+Fat - I-76 (MP 1.77 to MP 5.78)
(EB Corrected Before Period, Before Without Construction, and After Period)

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

This section of the report represents a brief summary of the methodology described in the Federal Highway Administration's (FHWA) Guide to Developing Quality Crash Modification Factors[3]. 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 1** 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 1 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

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

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

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 2**.

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

Table 2 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[4]. 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 Colorado-specific safety knowledge base. **Table 3** 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 3 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

[4] 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.

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:

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

APPENDIX B. SAFETY REPORTS

- #15505 – US 550 Deer Fencing/Cattle Guards (MP 107.00 – 111.00)
- #15645 – SH 83 Concrete Median (MP 69.39 – 70.57)
- #15748 – I-76 Cable Rail (MP 1.77 – 5.78)
- #15770 – I-25 Median Cable Rail (MP 102.50 – 107.50)
- #15771 – SH 165 Guard Rail (MP 18.65 – 23.90)
- #15828 – SH 93 / SH 72 Signal Upgrade
  – SH 93 Weather Related Road Closure System (MP 7.47 – 11.83)
- #15861 – SH 52 / 95th Street Intersection Improvements (MP 3.16)
- #15862 – US 34 / 11th Avenue Intersection Improvements (MP 112.23)
- #15900 – SH 133 Guard Rail (MP 46.00 – 51.50)
- #16005 – US 50 / Purcell Boulevard Intersection Improvements (MP 309.78)
- #16006 – SH 45 / Red Creek Springs Intersection Improvements (MP 3.95)
- #16010 – Industrial / Purcell New Signal

Project Information

Project Name: US 550 near Ridgway State Park

Project Description: Install Double Cattle Guards and Extend Deer Fencing

CDOT Region: 5 Project Def: 15505 County: Ouray

Location: US 550 Mile Points: from 107 to 111 Length: 4 miles

Schedule: Work Start Date: 3/20/2007 Completion Date: 5/16/2008

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the ten-year crash history (1994 – 2003) showed that there were a total of 18 injury crashes (31 injuries), 50 PDO crashes, but no fatalities. This total included 23 wildlife related crashes. Much of the highway right of way (ROW) has deer fencing from approximately MP 106 to MP 113. The main entrance to Ridgway State Park is near MP 107, and it did not have any means to prevent wildlife from entering the ROW and being caught between the fencing along the corridor.

Improvement Description: Between March 20, 2007 and May 16, 2008, a double wildlife (cattle) guard was installed across the main entrance to the park and the existing deer fencing was extended to meet the new wildlife guard. It was anticipated that this would eliminate a primary entry point for wildlife to enter the highway ROW. The cost of construction was $295,155.

The HSIP application anticipated that a 30% reduction in all types of crashes might be realized by the improvement. The initial benefit/cost ratio was estimated to be 1.81.

Summary and Findings

The analysis of safety before and after the double wildlife (cattle) guard was installed as a barrier across the main entrance to the Ridgway State Park from US 550 showed an overall reduction in the wildlife type of crash that a wildlife guard is designed to mitigate. For this segment of 2-lane arterial highway, there were 44 total crashes during the five-year period before the wildlife guard was installed (2002 – 2006). In the five years after construction (2009 – 2013), the number of crashes decreased to 28. This decrease in crashes was accompanied by a modest increase in AADT reflected by the frequency SPF. In addition, the number fatal crashes also diminished although the number of injury crashes (and injuries) remained the same.

A comparison of wildlife type crashes before and after the double wildlife (cattle) guard barrier improvement was installed showed that there was an increase in injury crashes (from 1 INJ in 5 years before to 2 INJ in the 5 years after). The number of PDO crashes was reduced from 19 to 12. The ratio of benefits and cost for this project shows that benefits are outweighed by costs as the B/C ratio is 0.24 to one. The result is an improvement that might not have been justified from an economic standpoint since the decrease in the number of PDO crashes is outweighed by the unfortunate increase in injury crashes, although the total number of wildlife crashes did decrease.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decrease from 44 during the five-year period (2002 to 2006) before the wildlife barrier project was constructed (see **Table 1** and **Exhibit 1**) to 28 during the five-year after period (2009 to 2013) (see **Table 1** and **Exhibit 2**). The number of serious crashes showed a decrease in that there was no fatality during the after period:

- Before (2002 – 2006) – 1 fatal crash with 1 fatality (sideswipe opposite) and 9 injury crashes with 13 injuries
- After (2009 – 2013) – no fatal crashes and 9 injury crashes with 13 injuries

This decrease in the total number of crashes occurred in spite of a modest increase in traffic volumes on US 550: 6,500 vehicles per day (vpd) for the before period and 7,140 vpd in the after period reflected by the SPF analysis.

Table 1 - Results of Overall Crash Analyses

SH 550 MP 107 - 111	**Before**	**After**
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
AADT	6,488 vpd	7,140 vpd
Filters:	None	None
Total Crashes	**44**	**28**
Fatal Crashes (Fatalities)	1 (1)	0
Injury Crashes (Injuries)	9 (13)	9 (13)
Property Damage Only	34	19
Crash Types: # (%) [significance]		
Wild Animal	19 (43.2%) [99.96]	14 (50.0%) [99.26%]
Fixed Objects	10 (22.7%) [97.02%]	8 (28.6%)
Overturning	5 (11.4%)	1 (3.6%)
Rear End	3 (6.8%)	2 (7.1%)
Sideswipe Same	3 (6.8%)	1 (3.6%)
Sideswipe Opposite	2 (4.5%)	0
Fixed Object Crashes: # (% of FO) [significance]		
Fence	4 (40.0%)	0
Tree	4 (40.0%)	2 (25.0%)
Sign	1 (10.0%)	1 (12.5%)
Large Boulder/Rock	1 (10.0%)	3 (37.5%)
Embankment	0	2 (25.0%)

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. A SPF reflects the complex relationship between exposure (measured in ADT) and the crash count for a section of roadway measured in crashes per mile per year (CPMPY) or for an intersection, measured in crashes per year. The SPF models provide an estimate for the expected crash frequency and severity for a range of ADT among similar facilities. This allows for an assessment of the magnitude of the safety problem from a frequency standpoint.

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

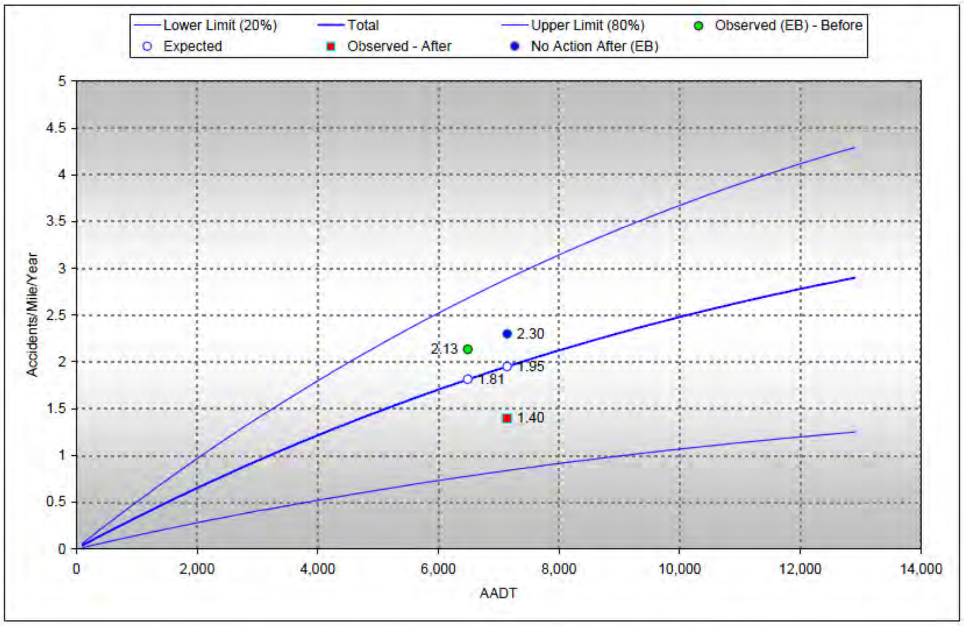
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

LOSS boundaries are calibrated by computing the 20^{th} and the 80^{th} percentiles using the Gamma Distribution Probability Density Function. Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT increases. LOSS reflects how a segment of roadway or intersection is performing in regard to its expected crash frequency at a specific level of ADT.

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect this improvement in the crash record. LOSS improved from the LOSS III range for total crashes in the before period to LOSS II in the after period. Injury/Fatal crashes improved in the after period, although still within the LOSS II range (see **Table 2**), due to the absence of a fatal crash. However, it is difficult to conclude that the overall decrease in almost all types of crashes (except wildlife) can be attributed solely to the installation of the double wildlife (cattle) guard at the main park entrance. **Figures 1** and **2** also show that the number of crashes during the period after construction was much improved in comparison to what it could have been without the project.

Figure 1 - SPF for Total Crashes

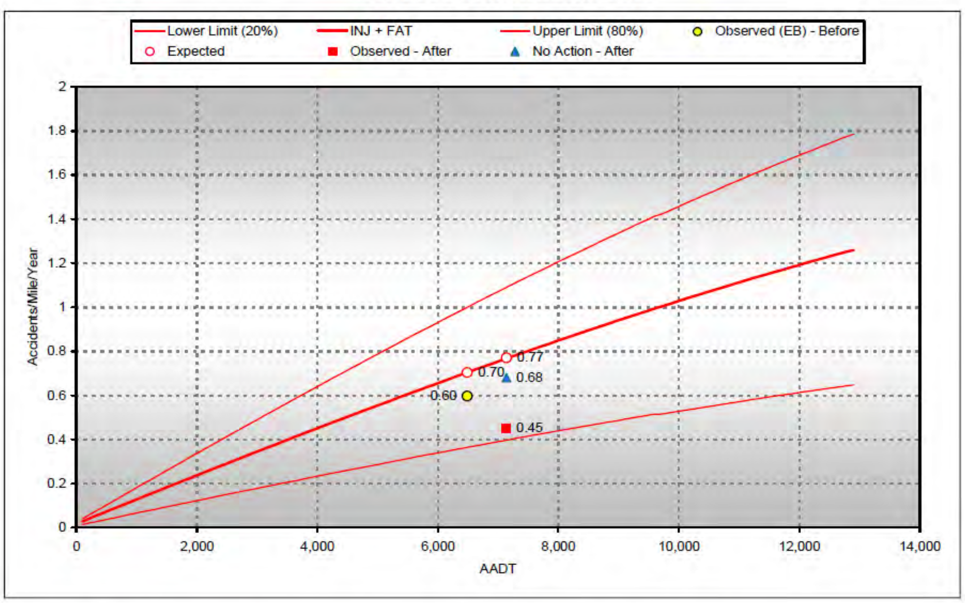
US 550 (MP 107 to MP 111)
Before: 2002 to 2006 After: 2009 to 2013



Note: Safety Performance Function (SPF) Model: Colorado - Rural Flat and Rolling 2-Lane Undivided Highway

Figure 2 - SPF for Injury and Fatal Crashes

US 550 (MP 107 to MP 111)
Before: 2002 to 2006 After: 2009 to 2013



Note: Safety Performance Function (SPF) Model: Colorado - Rural Flat and Rolling 2-Lane Undivided Highway

Table 2 – Safety Performance Function (SPF)

SH 550 MP 107 - 111	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Rural, Flat & Rolling, 2-lane Undivided Highway	Rural, Flat & Rolling, 2-lane Undivided Highway	Rural, Flat & Rolling, 2-lane Undivided Highway
Total Crashes:			
LOSS	LOSS III	LOSS II	LOSS III
CPMPY	2.13	1.40	2.30
Mean CPMPY	1.81	1.95	1.95
Proportion of Mean	1.177	0.718	1.177
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS II	LOSS II
CPMPY	0.60	0.45	0.68
Mean CPMPY	0.70	0.77	0.77
Proportion of Mean	0.857	0.584	0.857

A more detailed review of the before and after crash record reveals that a somewhat mixed improvement in safety can be attributed to the installation of the double wildlife (cattle) guard. **Table 3** provides a comparison of the wildlife type crash that is most directly affected by the new guard installation. The No Build After crashes were estimated using the increase in the median of the SPF for total crashes found in **Table 2** (increase is 1.077 = 1.95/1.81). **Table 3** shows an increase in injury crashes (from 1 in 5 years before to 2 in the 5 years after). The number of PDO crashes was reduced from 19 to 12.

Table 3 – Results of Wildlife Crash Analyses

SH 550 MP 107 - 111	Before	After	No Build After
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
Crash Types:			
Wildlife – Total	**19**	**14**	**20**
Injury (injuries)	1 (1)	2 (2)	1 (1)
PDO	18	12	19
% Reduction in Total			

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Exhibit 3** for wildlife type crashes. The increase in injury crashes in the after period was factored into the analysis by increasing the cost of construction for the wildlife (cattle) guard. Over the design life of 10 years for the guard, the increased cost of crashes would be $161,400 (2 INJ = 2X$80,700). **Exhibit 3** shows the result of the Benefit/Cost calculation is a B/C ratio of 0.24. This result shows that the project might not have been justified from an economic standpoint since the decrease in the number of PDO crashes is outweighed by the unfortunate increase in injury crashes, although the total number of wildlife crashes did decrease.

Exhibit 3 – Benefit Cost Analysis – Wildlife Crashes Only

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

06/24/2015

Job #: 20150624075513

Location: 550B **Begin:** 107.00 **End:** 111.00 **From:** 01/01/2002 **To:** 12/31/2006

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	19		Weighted PDO:	4.17	37% :ARF for PDO	Cost of PDO:	$ 9,300
INJ:	1	1 :Injured	Weighted INJ:	0.22	0% :ARF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	100% :ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	35% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
	Cost:	$ 456,555				Service Life:	10
	From:	01/01/2009				Capital Recovery Factor:	0.129
	To:	12/31/2013	Days:	1826		Annual Maintenance Cost:	$ 500

Benefit Cost Ratio: 0.24 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Wildlife Crashes only

Special Notes: Latest NSC Crash Costs - Cost of 2 INJ ($80,700X2) over 10 yrs. added $161,400 to const. cost

Location: 550B **Begin:** 107.00 **End:** 111.00 **From:** 01/01/2002 **To:** 12/31/2006

No Filters

Severity

PDO:	34		
INJ:	9	13	:Injured
FAT:	1	1	:Killed
Total:	**44**		

Number of Vehicles

One Vehicle:	34
Two Vehicles:	8
Three or More:	2
Unknown:	0
Total:	**44**

Location

On Road:	30
Off Road Left:	5
Off Road Right:	9
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**44**

Lighting Conditions

Daylight:	22
Dawn or Dusk:	5
Dark - Lighted:	0
Dark - Unlighted:	16
Unknown:	1
Total:	**44**

Weather Conditions

None:	36
Rain:	2
Snow/Sleet/Hail:	5
Fog:	0
Dust:	0
Wind:	0
Unknown:	1
Total:	**44**

Crash Rates

PDO:	0.72	*
INJ:	0.19	*
FAT:	2.12	**
Total:	**0.93**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	5	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	0
Head On:	0	Curb:	0
Rear End:	3	Delineator Post:	0
Sideswipe (Same):	3	Fence:	4
Sideswipe (Opposite):	2	Tree:	4
Approach Turn:	1	Large Boulders or Rocks:	1
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	10
Wild Animal:	19	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**44**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	44
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**44**

Road Description

At Intersection:	3
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	41
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**44**

Road Conditions

Dry:	32
Wet:	2
Muddy:	0
Snowy:	3
Icy:	6
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	1
Total:	**44**

ADT: 6,488 **Length:** 3.97

Location: 550B **Begin:** 107.00 **End:** 111.00 **From:** 01/01/2002 **To:** 12/31/2006

No Filters

Vehicle Type

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	23	6	2
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	14	1	0
Pickup Truck/Utility Van w/Trl:	2	1	0
SUV:	0	0	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	2	2	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	1	0	0
Motorcycle:	2	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**44**	**10**	**2**

Vehicle Movement

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	37	6	1
Slowing:	2	1	0
Stopped in Traffic:	0	2	1
Making Right Turn:	0	0	0
Making Left Turn:	1	0	0
Making U-Turn:	0	0	0
Passing:	3	1	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**44**	**10**	**2**

Contributing Factor

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	35	10	2
Asleep at the Wheel:	1	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	3	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	3	0	0
Driver Unfamilar with Area:	2	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	0	0	0
Total:	**44**	**10**	**2**

Direction

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	19	6	1
Southeast:	0	0	0
South:	3	0	0
Southwest:	0	0	0
West:	22	4	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**44**	**10**	**2**

Condition of Driver

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	43	10	2
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**44**	**10**	**2**

ADT: 6,488 **Length:** 3.97

Location: 550B **Begin:** 107.00 **End:** 111.00 **From:** 01/01/2009 **To:** 12/31/2013

No Filters

Severity

PDO:	19		
INJ:	9	13	:Injured
FAT:	0	0	:Killed
Total:	**28**		

Number of Vehicles

One Vehicle:	23
Two Vehicles:	5
Three or More:	0
Unknown:	0
Total:	**28**

Location

On Road:	19
Off Road Left:	5
Off Road Right:	4
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**28**

Lighting Conditions

Daylight:	17
Dawn or Dusk:	1
Dark - Lighted:	0
Dark - Unlighted:	10
Unknown:	0
Total:	**28**

Weather Conditions

None:	20
Rain:	1
Snow/Sleet/Hail:	7
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**28**

Crash Rates

PDO:	0.36	*
INJ:	0.17	*
FAT:	0.00	**
Total:	**0.54**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	2
Head On:	1	Curb:	0
Rear End:	2	Delineator Post:	0
Sideswipe (Same):	1	Fence:	0
Sideswipe (Opposite):	0	Tree:	2
Approach Turn:	0	Large Boulders or Rocks:	3
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	8
Wild Animal:	14	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	1
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	1
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**28**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	28
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**28**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	28
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**28**

Road Conditions

Dry:	20
Wet:	2
Muddy:	0
Snowy:	6
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**28**

ADT: 7,140 **Length:** 3.99

Location: 550B **Begin:** 107.00 **End:** 111.00 **From:** 01/01/2009 **To:** 12/31/2013

No Filters

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	9	1	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	12	1	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	6	3	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**28**	**5**	**0**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	23	5	0
Asleep at the Wheel:	1	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	0	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	1	0	0
Total:	**28**	**5**	**0**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	26	5	0
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**28**	**5**	**0**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	22	4	0
Slowing:	0	0	0
Stopped in Traffic:	0	1	0
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	2	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	3	0	0
Unknown:	0	0	0
Total:	**28**	**5**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	6	1	0
Northeast:	1	0	0
East:	10	2	0
Southeast:	0	0	0
South:	4	1	0
Southwest:	0	0	0
West:	7	1	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**28**	**5**	**0**

ADT: 7,140 **Length:** 3.99

Project Information

Project Name: SH 83A (Parker Road) from Lehigh Avenue to I-225A

Project Description: Install Concrete Median Barrier

CDOT Region: 6 Project Def: 15645 County: Arapahoe

Location: SH 83A Mile Points: from 69.39 to 70.57 Length: 1.18 miles

Schedule: Work Start Date: 9/11/2006 Completion Date: 1/17/2007

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history (2000 – 2004) showed a number of head-on, sideswipe in opposite direction, median crossover, and off median/left type crashes. The number of head-on crashes (9) was higher than expected. These crashes occurred with a high severity (1 fatal and 10 injury crashes).

Improvement Description: Between September 11, 2006 and January 17, 2007, a concrete median barrier (1.18 miles) was constructed between the intersection at Lehigh Avenue and the intersection at I-225. (There may have been short segments of concrete median barrier in place before this project). This barrier was installed to reduce the potential for head-on and sideswipe (opposite direction) crashes. The cost of construction was $1,320,726.

The HSIP application anticipated that the following reductions in crashes might be realized by the improvement anticipated: fatal crashes – 60%, injury crashes – 40%, and property damage only – 0%. The initial benefit/cost ratio was estimated to be 2.21.

Summary and Findings

The analysis of safety before and after the concrete median barrier was installed along SH 83A between Lehigh Avenue and I-225 showed reductions in the types of crashes that a median barrier is designed to mitigate. For this segment of limited access highway, there were 229 total crashes (mainline, non-intersection) during the five-year period before the concrete barrier was installed (2001 – 2005). In the five years after construction (2008 – 2012), the number of crashes increased slightly to 240. Since daily volumes continued to increase throughout the study period, the crash rate was reduced. In addition, the number of injury and fatal crashes also diminished.

The concrete median barrier improvement was directly responsible for decreases in the number and severity of head-on, overturning and sideswipe (opposite) crashes. During the before period, there was one fatal head-on collision and two injury crashes that involved injuries to 4 people. The after period experienced no fatal or injury crashes of these three types. The number of crashes involving the concrete median barrier remained the same in the before and after periods, although the number of injury crashes was reduced.

The ratio of benefits derived from crash reduction to the cost of construction for this project shows that benefits outweigh costs by a ratio of 5.91 to one. The result is an improvement that was certainly justified, especially since there were no fatal crashes in the period after construction.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records shows a slight increase in the number of crashes; the total number of crashes increased from 229 during the five-year period (2001 to 2005) before the concrete median barrier project was constructed (see **Table 1** and **Exhibit 1**) to 240 during the five-year after period (2008 to 2012) (see **Table 1** and **Exhibit 2**). As identified in **Table 1**, these crashes were not at either of the intersections in the study area and involved the mainline of SH 83A only. The number of serious crashes showed a more significant decrease:

- Before (2001 – 2005) – 2 fatal crashes with 2 fatalities (1 head-on and 1 involving a pedestrian) and 74 injury crashes with 98 injuries
- After (2008 – 2012) – no fatal crashes and 68 injury crashes with 90 injuries

This decrease in severe crashes occurred in spite of a modest increase in traffic volumes on SH 83A: 68,600 vehicles per day (vpd) estimated for the before period and 73,750 vpd in the after period. This combination of increased traffic and decreased number of crashes also resulted in a decrease in the accident rates:

- Before (2001 – 2005): 1.55 crashes per million vehicle miles of travel (cpmvmt)
- After (2008 – 2012): 1.49 (cpmvmt)

Table 1 – SH 83A (MP 69.39 to MP 70.57) - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2001 to 12/31/2005 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)
AADT	68,579 vpd	73,749vpd
Filters:	Non-Intersection / Mainline Only	Non-Intersection / Mainline Only
Total Crashes	**229**	**240**
Fatal Crashes (Fatalities)	2(2)	0
Injury Crashes (Injuries)	74 (98)	68 (90)
Property Damage Only	153	172
Crash Types: # (%)		
Rear End	122 (53.3%)	156 (65.0%)
Sideswipe Same	45 (19.7%)	43 (25.3%)
Fixed Objects	37 (16.2%)	27 (11.2%)
Head-On	6 (2.6%)	0
Overturning	2(0.9%)	3 (1.2%)
Sideswipe Opposite	4 (1.7%)	0
Other Objects	3(1.3%)	5 (2.0%)
Fixed Object Crashes: # (% of FO)		
Concrete Barrier	7 (18.9%)	16 (59.6%)
Guard Rail	16 (43.2%)	4 (14.8%)
Curb	3 (8.1%)	0
Crash Cushion	3 (8.1%)	2 (7.4%)
Tree	1 (2.7%)	2 (7.4%)

Normally, the magnitude of safety problems on highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. However in the case of SH 83A which is an urban arterial, no SPF can be developed. Additionally, no crash pattern norms for diagnostic analyses are available for the same reason.

A more detailed review of the before and after crash record reveals that a significant improvement in safety can be attributed to the installation of the concrete median barrier. **Table 2** shows a comparison of four types of crashes (all off-road left or off median) that are most directly affected by the barrier: head-on, sideswipe (opposite), overturning, and hitting the concrete barrier itself. The No Build After crashes were estimated using the increase in the average daily traffic volumes found in **Table 1** (increase is 1.075 = 73,749 / 68,579).

Table 2 – SH 83A (MP 69.39 to MP 70.57) - Results of Concrete Median Barrier Crash Analyses

	Before	**After**	**No Build After**
Time Period:	1/1/2001 to 12/31/2005 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)
Crash Types:			
Head-On – Total	**6**	**0**	**6**
Fatal (fatalities)	1 (1)	0	1 (1)
Injury (injuries)	3 (6)	0	3 (6)
PDO	1	0	1
% Reduction in Total		100%	
Sideswipe (Opp.)– Total	**4**	**0**	**4**
Injury (injuries)	2 (4)	0	2 (4)
PDO	2	0	2
% Reduction in Total		100%	
Overturning – Total (off-left/off-median only)	**1**	**0**	**1**
Injury (injuries)	0	0	0
PDO	1	0	1
% Reduction in Total		100%	
Concrete Barrier – Total (off-left/off-median only)	**7**	**7**	**7**
Injury (injuries)	4 (4)	1 (1)	4 (4)
PDO	3	6	3

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Exhibit 3** for head-on, sideswipe (opposite), and overturning crashes and **Exhibit 4** for concrete barrier crashes. The increase in property damage only crashes from hitting the concrete barrier was factored into the analysis by increasing the cost of construction for concrete median barrier crashes. During the 5-year after period, there were 6 PDO concrete median barrier crashes, up from the 3 PDO crashes that occurred in the before period. Over the design life of 20 years for the concrete barrier, the increased cost of crashes would be $111,600 (12 PDO = 12X$9,300). Since there were concrete barrier crashes in the before period, it can be speculated that the study section of SH 83A had short segments of concrete median barrier that caused a higher level of injury crashes. The barrier does not eliminate new crashes since it creates a barrier near the roadway, but the result is a trade-off of less serious crashes (PDOs primarily) instead of more serious injury crashes.

Exhibits 3 and 4 provide the Benefit/Cost calculations. The B/C ratio for eliminating head-on, sideswipe (opposite), and overturning crashes is 5.40, and the B/C ratio for concrete barrier crashes is 0.51. Therefore, the resulting B/C ratio for the cable rail project is 5.91 (5.40 + 0.51), showing that the improvement was certainly justified, especially since there were no fatal crashes in the period after construction.

Exhibit 3 – Benefit Cost Analysis – SH 83A (MP 69.39 to MP 70.57) - Head-on, Sideswipe (Opposite), and Overturning Crashes Only

COLORADO Department of Transportation

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

06/16/2015

Job #: 20150616142552

Location: 83A **Begin:** 69.39 **End:** 70.57 **From:** 01/01/2001 **To:** 12/31/2005

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	5		Weighted PDO:	1.23	100% :ARF for PDO	Cost of PDO:	$ 9,300
INJ:	5	10 :Injured	Weighted INJ:	2.46	100% :ARF for INJ	Cost of INJ:	$ 80,700
FAT:	1	1 :Killed	Weighted FAT:	0.25	100% :ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	100% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance Cost:	$ 1,000

Cost: $ 1,320,726
From: 01/01/2001
To: 12/31/2005 Days: 1826

Benefit Cost Ratio: 5.40 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Head-on, Sideswipe (opposite), and Overturning Crashes Only
Special Notes: Latest NSC Crash Costs

Exhibit 4 – Benefit Cost Analysis – SH 83A (MP 69.39 to MP 70.57) - Concrete Barrier Only

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

06/16/2015

Job #: 20150616143133

Location: 83A **Begin:** 69.39 **End:** 70.57 **From:** 01/01/2001 **To:** 12/31/2005

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors				Other Information	
PDO:	3		Weighted PDO:	0.74	0%	:ARF for PDO	Cost of PDO:	$ 9,300
INJ:	4	4 :Injured	Weighted INJ:	0.98	75%	:ARF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0%	:ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	42%	:Weighted ARF	Interest Rate:	5%
							ADT Growth Factor:	2.0%
							Service Life:	20
							Capital Recovery Factor:	0.080
							Annual Maintenance Cost:	$ 1,000

Cost: $ 1,432,326
From: 01/01/2001
To: 12/31/2005 Days: 1826

Benefit Cost Ratio: 0.51 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Concrete Barrier Crashes Only
Special Notes: Latest NSC Crash Costs - Cost of 12 PDO ($9,300X12) added to construction cost

Location: 83A **Begin:** 69.39 **End:** 70.57 **From:**01/01/2001 **To:**12/31/2005

Severity

PDO:	153	
INJ:	74	98 :Injured
FAT:	2	2 :Killed
Total:	**229**	

Number of Vehicles

One Vehicle:	37
Two Vehicles:	148
Three or More:	44
Unknown:	0
Total:	**229**

Location

On Road:	184
Off Road Left:	16
Off Road Right:	25
Off Road at Tee:	0
Off in Median:	4
Unknown:	0
Total:	**229**

Lighting Conditions

Daylight:	146
Dawn or Dusk:	7
Dark - Lighted:	58
Dark - Unlighted:	13
Unknown:	5
Total:	**229**

Weather Conditions

None:	193
Rain:	11
Snow/Sleet/Hail:	19
Fog:	0
Dust:	0
Wind:	1
Unknown:	5
Total:	**229**

Crash Rates

PDO:	1.04 *
INJ:	0.50 *
FAT:	1.35 **
Total:	**1.55** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	2	Bridge Abutment:	0
Other Non Collision:	2	Column/Pier:	0
Pedestrians:	1	Culvert/Headwall:	0
Broadside:	1	Embankment:	1
Head On:	6	Curb:	3
Rear End:	122	Delineator Post:	0
Sideswipe (Same):	45	Fence:	1
Sideswipe (Opposite):	4	Tree:	1
Approach Turn:	1	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	2	Wall/Building:	1
Railway Vehicle:	0	Crash Cushion:	3
Bicycle:	1	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	37
Wild Animal:	2	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	3	Involving Other Object:	3
Bridge Rail:	1	Total Other Objects:	3
Guard Rail:	16	Unknown:	0
Cable Rail:	0	**Total:**	**229**
Concrete Barrier:	7		

Mainline/Ramps/Frontage Roads

Mainline:	229
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**229**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	229
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**229**

Road Conditions

Dry:	175
Wet:	17
Muddy:	0
Snowy:	2
Icy:	24
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	3
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	6
Total:	**229**

ADT: 68,579 **Length:** 1.18

Location: 83A **Begin:** 69.39 **End:** 70.57 **From:** 01/01/2001 **To:** 12/31/2005

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	159	138	32
Passenger Car/Van w/Trl:	0	3	0
Pickup Truck/Utility Van:	43	37	9
Pickup Truck/Utility Van w/Trl:	1	2	0
SUV:	0	0	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	9	4	0
School Bus < 15 People:	0	1	0
Non School Bus < 15 People:	1	0	0
Motorhome:	1	0	0
Motorcycle:	3	2	0
Bicycle:	1	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	5	0	0
Other:	1	0	0
Unknown:	5	5	3
Total:	**229**	**192**	**44**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	128	162	35
Asleep at the Wheel:	2	0	0
Illness:	3	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	20	2	2
Driver Fatigue:	1	0	0
Driver Preoccupied:	28	2	1
Driver Unfamilar with Area:	5	0	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	1	0	0
Physical Disability:	0	0	0
Unknown:	38	26	6
Total:	**229**	**192**	**44**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	213	192	44
Alcohol Involved:	14	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	2	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**229**	**192**	**44**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	143	88	16
Slowing:	11	31	5
Stopped in Traffic:	3	62	21
Making Right Turn:	1	1	0
Making Left Turn:	0	0	0
Making U-Turn:	2	0	0
Passing:	1	1	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	2	0
Changing Lanes:	44	3	0
Avoiding Object/Veh in Road:	5	1	0
Weaving:	3	0	0
Other:	11	1	0
Unknown:	5	2	2
Total:	**229**	**192**	**44**

Direction	Veh 1	Veh 2	Veh 3
North:	73	66	10
Northeast:	0	0	0
East:	30	23	3
Southeast:	1	0	0
South:	67	56	14
Southwest:	0	0	0
West:	43	38	8
Northwest:	11	9	2
Unknown:	4	0	7
Total:	**229**	**192**	**44**

ADT: 68,579 **Length:** 1.18

Location: 83A **Begin:** 69.39 **End:** 70.57 **From:**01/01/2008 **To:**12/31/2012

Severity

PDO:	172		
INJ:	68	90	:Injured
FAT:	0	0	:Killed
Total:	**240**		

Number of Vehicles

One Vehicle:	28
Two Vehicles:	155
Three or More:	57
Unknown:	0
Total:	**240**

Location

On Road:	212
Off Road Left:	9
Off Road Right:	19
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**240**

Lighting Conditions

Daylight:	159
Dawn or Dusk:	19
Dark - Lighted:	53
Dark - Unlighted:	8
Unknown:	1
Total:	**240**

Weather Conditions

None:	201
Rain:	6
Snow/Sleet/Hail:	32
Fog:	0
Dust:	0
Wind:	0
Unknown:	1
Total:	**240**

Crash Rates

PDO:	1.07	*
INJ:	0.42	*
FAT:	0.00	**
Total:	**1.49**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	3	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	1	Culvert/Headwall:	0
Broadside:	1	Embankment:	0
Head On:	0	Curb:	0
Rear End:	156	Delineator Post:	0
Sideswipe (Same):	43	Fence:	0
Sideswipe (Opposite):	0	Tree:	2
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	2
Parked Motor Vehicle:	1	Wall/Building:	1
Railway Vehicle:	0	Crash Cushion:	2
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	27
Wild Animal:	2	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	3
Traffic Signal Pole:	0	Road Maintenance Equipment:	1
Sign:	0	Involving Other Object:	1
Bridge Rail:	0	Total Other Objects:	5
Guard Rail:	4	Unknown:	0
Cable Rail:	0	**Total:**	**240**
Concrete Barrier:	16		

Mainline/Ramps/Frontage Roads

Mainline:	240
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**240**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	240
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**240**

Road Conditions

Dry:	186
Wet:	13
Muddy:	0
Snowy:	10
Icy:	18
Slushy:	4
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	4
Snowy w/Icy Road Treatment:	1
Icy w/Icy Road Treatment:	1
Slushy w/Icy Road Treatment:	0
Unknown:	3
Total:	**240**

ADT: 73,749 **Length:** 1.19

Location: 83A **Begin:** 69.39 **End:** 70.57 **From:** 01/01/2008 **To:** 12/31/2012

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	138	118	28
Passenger Car/Van w/Trl:	1	0	0
Pickup Truck/Utility Van:	28	23	9
Pickup Truck/Utility Van w/Trl:	1	0	2
SUV:	61	62	17
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	3	1	0
School Bus < 15 People:	1	2	0
Non School Bus < 15 People:	0	1	0
Motorhome:	0	0	0
Motorcycle:	2	3	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	4	0	0
Other:	1	2	0
Unknown:	0	0	1
Total:	**240**	**212**	**57**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	129	64	12
Slowing:	25	47	7
Stopped in Traffic:	5	87	36
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	1	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	0
Changing Lanes:	45	4	0
Avoiding Object/Veh in Road:	4	2	1
Weaving:	1	0	0
Other:	28	5	0
Unknown:	1	2	1
Total:	**240**	**212**	**57**

Direction	Veh 1	Veh 2	Veh 3
North:	62	57	17
Northeast:	0	0	0
East:	2	3	2
Southeast:	25	22	3
South:	59	53	13
Southwest:	0	0	0
West:	14	12	3
Northwest:	77	64	18
Unknown:	1	1	1
Total:	**240**	**212**	**57**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	98	202	56
Asleep at the Wheel:	1	0	0
Illness:	1	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	30	1	0
Driver Fatigue:	0	1	0
Driver Preoccupied:	32	1	0
Driver Unfamilar with Area:	5	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	2	0	0
Unknown:	71	7	1
Total:	**240**	**212**	**57**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	234	212	57
Alcohol Involved:	5	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**240**	**212**	**57**

ADT: 73,749 **Length:** 1.19

Project Information

Project Name: I-76 – Sheridan to I-25

Project Description: Install Tensioned Cable Barrier

CDOT Region: 6	Project Def: 15748	County: Adams
Location: I-76	Mile Points: from: 1.77 to 5.78	Length: 4.01 miles
Schedule:	Work Start Date: 7/9/2007	Completion Date: 10/19/2007

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history showed a higher than expected number of head-on, sideswipe in opposite direction, and overturning type crashes. These crashes were occurring off-left and in the median. These crashes occurred with a higher than expected severity (5 fatal and 3 injury crashes).

Improvement Description: In 2007, cable guard rail (2.58 miles) was installed at locations where vehicles have the potential to leave the road to the left and perhaps cause head-on, sideswipe, or overturning-type crashes. The cost of construction was $521,450.

The HSIP application anticipated that three crash types would be impacted by this improvement: off median head-on, off left overturning, and sideswipe opposite. The following reductions in crashes were anticipated: fatal crashes – 60%, injury crashes – 40%, and property damage only – 20%. The initial benefit/cost ratio was estimated to be 14.36.

Summary and Findings

The analysis of safety before and after the cable guard rail was installed along I-76 between Sheridan Boulevard and I-25 showed significant safety improvements. For this segment of freeway, there were 355 total crashes during the five-year period before the rail was installed (2002 – 2006). In the five years after construction (2008 – 2012), the number of crashes was decreased to 348. Since daily volumes continued to increase throughout the study period, the crash rate was reduced. In addition, the number of injury and fatal crashes also diminished.

The cable rail improvement was directly responsible for decreases in the number and severity of head-on and overturning crashes. During the before period, there was one fatal head-on collision and a number of injury crashes. The after period experienced no fatal crashes and a reduction in the number of injury crashes. Cable rail causes new crashes since it creates a barrier near the roadway, but the result is a trade-off of less serious crashes (PDOs primarily) instead of more serious fatal and injury crashes.

The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 6.16 to one. The result is an improvement that was certainly justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a slight decrease in the number of crashes; the total number of crashes decreased from 355 during the five-year period (2002 to 2006) before the cable rail project was constructed (see **Table 1** and **Exhibit 1**) to 348 during the five-year after period (2008 to 2012) (see **Table 1** and **Exhibit 2**). The number of serious crashes showed a more significant decrease:

- Before (2002 – 2006) – 3 fatal crashes with 4 fatalities (1 head-on and 2 involving guard rail) and 122 injury crashes with 166 injuries
- After (2008 – 2012) – no fatal crashes and 92 injury crashes with 112 injuries

This decrease in severe crashes occurred in spite of a modest increase in traffic volumes on I-76: 63,800 vehicles per day (vpd) estimated for the before period and 71,400 vpd in the after period. This combination of increased traffic and decreased number of crashes also resulted in a decrease in the accident rates:

- Before (2002 – 2006): 0.74 crashes per million vehicle miles of travel (cpmvmt)
- After (2008 – 2012): 0.65 (cpmvmt)

Table 1 – I-76 (MP 1.77 to MP 5.78) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)
AADT	63,800 vpd (est.)	71,366 vpd
Filters:	Mainline Only/Non-Intersection	Mainline Only/Non-Intersection
Total Crashes	**355**	**348**
Fatal Crashes (Fatalities)	3 (4)	0
Injury Crashes (Injuries)	122 (166)	92 (112)
Property Damage Only	230	256
Crash Types: # (%) [significance]		
Fixed Objects	114 (32.1%)	121 (34.8%)
Rear End	104 (29.3%)	78 (22.4%)
Sideswipe Same	67 (18.9%) [99.60%]	88 (25.3%) [100.00%]
Overturning	27 (7.6%)	18 (5.2%)
Head-On	6 (1.7%)	2 (0.6%)
Other Objects	22 (6.2%)	33 (9.5%)
Fixed Object Crashes: # (%) [significance]		
Concrete Barrier	50 (43.9%) [100.00%]	53 (43.8%) [99.99%]
Cable Rail	n/a	26 (21.5%) [100.00%]
Guard Rail	18 (15.8%)	16 (13.2%)
Fence	15 (13.2%) [100.00%]	6 (5.0%)
Bridge Rail	6 (5.3%)	0
Light/Utility Pole	8 (7.0%) [99.86%]	6 (5.0%)

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. A SPF reflects the complex relationship between exposure (measured in ADT) and the crash count for a section of roadway measured in crashes per mile per year (CPMPY) or for an intersection, measured in crashes per year. The SPF models provide an estimate for the expected crash frequency and severity for a range of ADT among similar facilities. This allows for an assessment of the magnitude of the safety problem from a frequency standpoint.

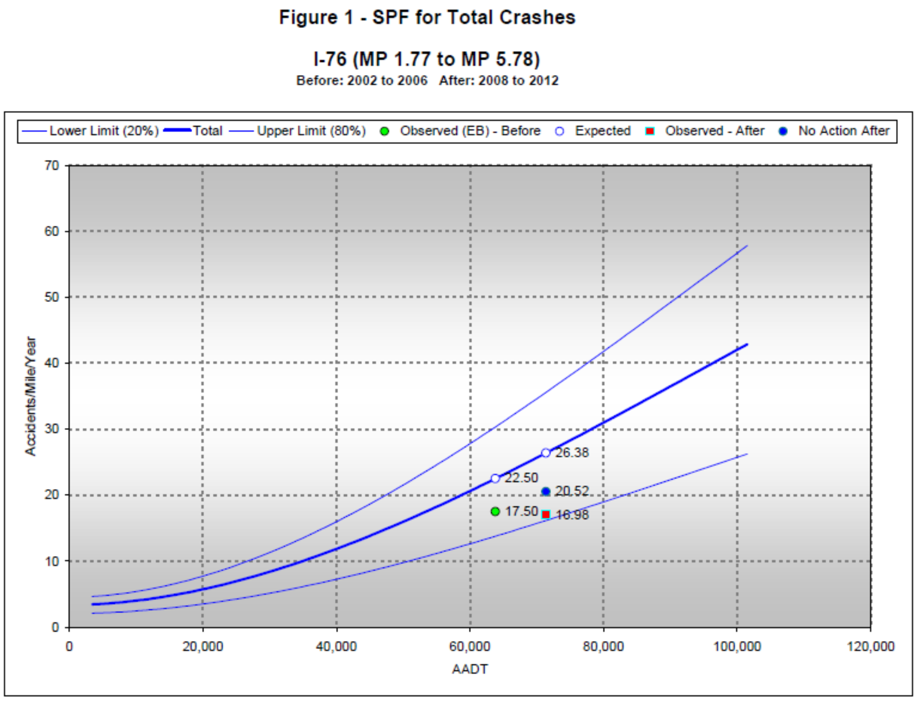
Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be 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

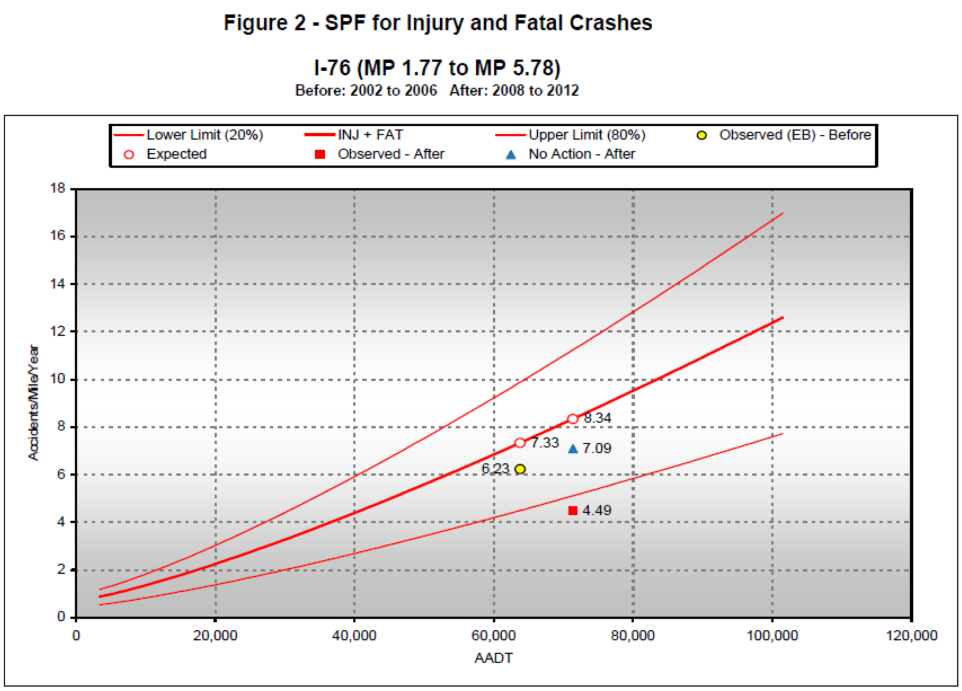
Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT increases. LOSS reflects how a segment of roadway or intersection is performing in regard to its expected crash frequency at a specific level of ADT.

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect this improvement in the crash record. LOSS improved within the LOSS II range for total crashes in the after period, and Injury/Fatal crashes improved to LOSS I in the after period (see **Table 2**), due to the decrease in both types of severe crashes. However, it is difficult to conclude that the overall decrease in almost all types of crashes (except cable rail) can be attributed solely to the installation of the cable rail in the median of I-76 during 2007. However, as will be discussed in the following section, the cable rail has significantly reduced certain types of crashes.

A more detailed review of the before and after crash record reveals that a significant improvement in safety can be attributed to the installation of the median cable rail. **Table 3** shows a comparison of three types of crashes that are most directly affected by the cable rail: head-on, overturning (off-road left and off median), and hitting the cable rail. The No Build After crashes were estimated using the increase in the median of the SPF for total crashes found in **Table 2** (increase is 1.173 = 26.38/22.49). **Figures 1** and **2** also show that the number of crashes after construction was much better than it could have been without the project.



Note: Safety Performance Function (SPF) Model: Colorado - Urban Flat Rolling Mountainous 4-Lane Divided Freeways (Revised



Note: Safety Performance Function (SPF) Model: Colorado - Urban Flat Rolling Mountainous 4-Lane Divided Freeways (Revised)

Table 2 – I-76 (MP 1.77 to MP 5.78) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane Freeway	Urban, 4-lane Freeway	Urban, 4-lane Freeway
Total Crashes:			
LOSS	LOSS II	LOSS II	LOSS II
CPMPY	17.49	16.98	20.52
Mean CPMPY	22.49	26.38	26.38
Proportion of Mean	0.778	0.644	0.778
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS I	LOSS II
CPMPY	6.23	4.49	7.09
Mean CPMPY	7.33	8.34	8.34
Proportion of Mean	0.850	0.538	1.275

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Exhibit 3** for overturning crashes and **Exhibit 4** for head-on crashes. The increase in cable rail crashes was factored into the analysis by increasing the cost of construction for head-on crashes. During the 5-year after period, there were 2 injury and 22 PDO cable rail crashes. Over the design life of 20 years for the cable rail system, the increased cost of crashes would be $1,936,000 (88 PDO = $783,000 and 8 injuries = $631,000). Cable rail causes new crashes since it creates a barrier near the roadway, but the result is a trade-off of less serious crashes (PDOs primarily) instead of more serious fatal and injury crashes.

Exhibits 3 and 4 provide the Benefit/Cost calculations. The B/C ratio for overturning crashes is 3.53 and the B/C ratio for head-on crashes is 2.53. Therefore, the resulting B/C ratio for the cable rail project is 6.16 (3.63 + 2.53), showing that the improvement was certainly justified.

Table 3 – I-76 (MP 1.77 to MP 5.78) - Results of Off-Road Left and Off-Median Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)
Crash Types:			
Overturning – Total	**12**	**2**	**14**
Injury (injuries)	7 (8)	1 (1)	8 (9)
PDO	5	1	6
% Reduction in Total – (INJ / PDO)		89 / 83%	
Head-On – Total	**5**	**0**	**6**
Fatal (fatalities)	1 (1)	0	1 (1)
Injury (injuries)	2 (2)	0	2 (2)
PDO	2	0	3
% Reduction in Total		100%	
Cable Rail – Total	**n/a**	**24**	**n/a**
Injury (injuries)	n/a	2 (2)	n/a
PDO	n/a	22	n/a

Exhibit 3 – Benefit Cost Analysis – I-76 (MP 1.77 to MP 5.78) - Overturning Crashes Only

CDOT
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Colorado Department of Transportation
DiExSys™ Roadway Safety Systems
Economic Analysis Report

06/30/2015

Job #: *20150630091637*

Location: 76A **Begin:** 1.77 **End:** 5.78 **From:** 01/01/2002 **To:** 12/31/2006

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	6		Weighted PDO:	1.47	83% :ARF for PDO	Cost of PDO:	$ 9,300
INJ:	8	9 :Injured	Weighted INJ:	2.21	89% :ARF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	100% :ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	86% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance Cost:	$ 5,000

Cost: $ 521,450
From: 01/01/2008
To: 12/31/2012 Days: 1827

Benefit Cost Ratio: 3.63 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Overturning Crashes Only
Special Notes: 2015 NSC crash costs

Exhibit 4 – Benefit Cost Analysis – I-76 (MP 1.77 to MP 5.78) - Head-On and Cable Rail Crashes

COLORADO Department of Transportation

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

06/08/2015

Job #: 20150608115519

Location: 76A **Begin:** 1.77 **End:** 5.78 **From:** 01/01/2002 **To:** 12/31/2006

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	3		Weighted PDO:	0.74	100% :ARF for PDO	Cost of PDO:	$ 9,300
INJ:	2	2 :Injured	Weighted INJ:	0.49	100% :ARF for INJ	Cost of INJ:	$ 80,700
FAT:	1	1 :Killed	Weighted FAT:	0.25	100% :ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	100% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance Cost:	$ 5,000

Cost: $ 1,985,450
From: 01/01/2008
To: 12/31/2012 Days: 1827

Benefit Cost Ratio: 2.53 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Head-On Crashes Only
Special Notes: Cable Rail: Cost of 88 PDO ($9,300X88) and 8INJ ($80,700X8) added to $521,450 const. cost

Exhibit 1

05/27/2015

Job #: 20150527121208

Location: 76A **Begin:** 1.77 **End:** 5.78 **From:** 01/01/2002 **To:** 12/31/2006

Severity

PDO:	230		
INJ:	122	166	:Injured
FAT:	3	4	:Killed
Total:	**355**		

Number of Vehicles

One Vehicle:	145
Two Vehicles:	185
Three or More:	25
Unknown:	0
Total:	**355**

Location

On Road:	206
Off Road Left:	78
Off Road Right:	64
Off Road at Tee:	0
Off in Median:	7
Unknown:	0
Total:	**355**

Lighting Conditions

Daylight:	216
Dawn or Dusk:	13
Dark - Lighted:	103
Dark - Unlighted:	8
Unknown:	15
Total:	**355**

Weather Conditions

None:	284
Rain:	26
Snow/Sleet/Hail:	29
Fog:	0
Dust:	0
Wind:	2
Unknown:	14
Total:	**355**

Crash Rates

PDO:	0.70	*
INJ:	0.37	*
FAT:	0.91	**
Total:	**1.07**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	27	Bridge Abutment:	0
Other Non Collision:	10	Column/Pier:	0
Pedestrians:	1	Culvert/Headwall:	1
Broadside:	0	Embankment:	2
Head On:	6	Curb:	2
Rear End:	104	Delineator Post:	4
Sideswipe (Same):	67	Fence:	15
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	1	Barricade:	0
Parked Motor Vehicle:	3	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	1
Domestic Animal:	0	Total Fixed Objects:	114
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	8	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	7	Involving Other Object:	22
Bridge Rail:	6	Total Other Objects:	22
Guard Rail:	18	Unknown:	0
Cable Rail:	0	**Total:**	**355**
Concrete Barrier:	50		

Mainline/Ramps/Frontage Roads

Mainline:	355
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**355**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	355
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**355**

Road Conditions

Dry:	258
Wet:	44
Muddy:	0
Snowy:	9
Icy:	17
Slushy:	7
Foreign Material:	1
With Road Treatment:	0
Dry w/Icy Road Treatment:	3
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	1
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	14
Total:	**355**

ADT: 44,095 **Length:** 4.10

Location: 76A	Begin: 1.77	End: 5.78	From:01/01/2002	To:12/31/2006

Vehicle Type

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	194	125	15
Passenger Car/Van w/Trl:	2	0	0
Pickup Truck/Utility Van:	74	48	6
Pickup Truck/Utility Van w/Trl:	10	2	0
SUV:	0	0	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	29	19	2
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	1	0	0
Motorhome:	2	0	0
Motorcycle:	7	2	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	24	4	1
Other:	0	0	0
Unknown:	12	10	0
Total:	**355**	**210**	**25**

Vehicle Movement

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	243	128	13
Slowing:	6	41	5
Stopped in Traffic:	5	25	4
Making Right Turn:	3	0	0
Making Left Turn:	1	0	0
Making U-Turn:	0	0	0
Passing:	5	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	2	1
Changing Lanes:	61	4	0
Avoiding Object/Veh in Road:	7	7	2
Weaving:	6	0	0
Other:	6	3	0
Unknown:	11	0	0
Total:	**355**	**210**	**25**

Direction

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	176	110	16
Southeast:	0	0	0
South:	0	0	0
Southwest:	0	0	0
West:	168	100	9
Northwest:	0	0	0
Unknown:	11	0	0
Total:	**355**	**210**	**25**

Contributing Factor

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	274	196	24
Asleep at the Wheel:	12	0	0
Illness:	2	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	17	0	0
Driver Fatigue:	2	0	0
Driver Preoccupied:	22	1	0
Driver Unfamilar with Area:	3	0	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	1	0	0
Unknown:	20	13	1
Total:	**355**	**210**	**25**

Condition of Driver

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	332	210	25
Alcohol Involved:	19	0	0
RX, Medication, or Drugs Involved:	3	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**355**	**210**	**25**

ADT: 44,095 **Length:** 4.10

Location: 76A **Begin:** 1.77 **End:** 5.78 **From:** 01/01/2008 **To:** 12/31/2012

Severity

PDO:	256		
INJ:	92	112	:Injured
FAT:	0	0	:Killed
Total:	**348**		

Number of Vehicles

One Vehicle:	139
Two Vehicles:	182
Three or More:	27
Unknown:	0
Total:	**348**

Location

On Road:	208
Off Road Left:	77
Off Road Right:	63
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**348**

Lighting Conditions

Daylight:	219
Dawn or Dusk:	16
Dark - Lighted:	95
Dark - Unlighted:	18
Unknown:	0
Total:	**348**

Weather Conditions

None:	287
Rain:	7
Snow/Sleet/Hail:	49
Fog:	0
Dust:	0
Wind:	5
Unknown:	0
Total:	**348**

Crash Rates

PDO:	0.48 *
INJ:	0.17 *
FAT:	0.00 **
Total:	**0.65** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	18	Bridge Abutment:	0
Other Non Collision:	5	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	1
Broadside:	0	Embankment:	1
Head On:	2	Curb:	0
Rear End:	78	Delineator Post:	6
Sideswipe (Same):	88	Fence:	6
Sideswipe (Opposite):	0	Tree:	1
Approach Turn:	1	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	1	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	1
Domestic Animal:	0	Total Fixed Objects:	121
Wild Animal:	1	Rocks in Roadway:	0
Light/Utility Pole:	6	Vehicle Cargo/Debris:	26
Traffic Signal Pole:	0	Road Maintenance Equipment:	2
Sign:	4	Involving Other Object:	5
Bridge Rail:	0	Total Other Objects:	33
Guard Rail:	16	Unknown:	0
Cable Rail:	26	**Total:**	**348**
Concrete Barrier:	53		

Mainline/Ramps/Frontage Roads

Mainline:	348
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**348**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	348
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**348**

Road Conditions

Dry:	245
Wet:	21
Muddy:	0
Snowy:	15
Icy:	55
Slushy:	6
Foreign Material:	1
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	3
Icy w/Icy Road Treatment:	2
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**348**

ADT: 71,366 **Length:** 4.09

Location: 76A **Begin:** 1.77 **End:** 5.78 **From:** 01/01/2008 **To:** 12/31/2012

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	160	106	16
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	70	35	7
Pickup Truck/Utility Van w/Trl:	9	0	0
SUV:	58	43	4
SUV w/Trl:	1	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	23	20	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	1	0	0
Motorhome:	1	1	0
Motorcycle:	5	1	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	20	0	0
Other:	0	3	0
Unknown:	0	0	0
Total:	**348**	**209**	**27**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	200	204	27
Asleep at the Wheel:	6	0	0
Illness:	7	0	0
Distracted by Passenger:	5	0	0
Driver Inexperience:	26	0	0
Driver Fatigue:	2	0	0
Driver Preoccupied:	21	0	0
Driver Unfamilar with Area:	5	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	76	5	0
Total:	**348**	**209**	**27**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	322	209	27
Alcohol Involved:	21	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	5	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**348**	**209**	**27**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	171	132	16
Slowing:	8	33	7
Stopped in Traffic:	0	23	3
Making Right Turn:	1	0	0
Making Left Turn:	1	0	0
Making U-Turn:	1	0	0
Passing:	5	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	1	0	0
Starting in Traffic:	0	0	0
Parked:	0	2	0
Changing Lanes:	67	4	0
Avoiding Object/Veh in Road:	7	9	1
Weaving:	9	0	0
Other:	75	6	0
Unknown:	1	0	0
Total:	**348**	**209**	**27**

Direction	Veh 1	Veh 2	Veh 3
North:	4	0	0
Northeast:	17	11	2
East:	145	84	12
Southeast:	0	0	0
South:	0	2	0
Southwest:	18	10	2
West:	164	102	11
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**348**	**209**	**27**

ADT: 71,366 **Length:** 4.09

Project Information

Project Name: I-25 Median Cable Rail

Project Description: Install cable rails along I-25 N/O Pueblo

CDOT Region: 2 Project Def: 15770 County: Pueblo

Location: I-25 Mile Points: 102.5 – 107.5 Length: 5.0 miles

Schedule: Work Start Date: 6/25/2007 Completion Date: 1/23/2008

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history showed a higher than expected number of off-road type crashes. I-25 southbound and northbound lanes are separated by a median width of 22 feet or less. The median is grass and has very little depression. The clear zone recommendation is 26 feet which would mean a 52 foot median. Also in this stretch, the frontage road is close to the highway with some locations having grade separation.

Improvement Description: In 2007, cable rail was installed along the entire stretch of median and on the shoulder between I-25 and the frontage road in select locations. The cost of construction was $1,042,820.

The HSIP application anticipated that off-road crash types would be impacted by this improvement. The following reductions in crashes were anticipated: fatal crashes – 60%, injury crashes – 40%, and property damage only – 20%. The initial benefit/cost ratio was estimated to be 2.65.

Summary and Findings

The analysis of safety performance of I-25 MP 102.5-107.5 before and after the cable rail was installed showed some safety improvements. For this segment of highway, there were 163 total crashes during the five-year period before the rail was installed (2002 – 2006). In the five years after construction (7/2008 – 6/2013), the number of crashes was decreased to 151. In addition, the number of injury and fatal crashes also diminished.

The cable rail improvement was directly responsible for decreases in the number and severity of off-road crashes. During the before period, there was 4 fatal crashes and a number of injury crashes. The after period experienced 3 fatal crashes and a reduction in the number of injury crashes. Cable rail causes new crashes since it creates a barrier near the roadway, but the result is a trade-off of less serious crashes (PDOs primarily) instead of more serious fatal and injury crashes.

The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 2.26 to one. The result is an improvement that was justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 163 during the five-year period (2002 to 2006) before the cable rail was installed (see **Table 1** and **Exhibit 1**) to 151 during the five-year after period (7/2008 to 6/2013) (see **Table 1** and **Exhibit 2**). The number of serious crashes also showed a decrease:

- Before (2002 – 2006) – 4 fatal crashes with 4 fatalities (2 overturning, head-on, embankment) and 45 injury crashes with 74 injuries
- After (7/2008 – 6/2013) – 3 fatal crashes with 3 fatalities (2 pedestrian, overturning) and 42 injury crashes with 61 injuries

This decrease in crashes occurred along with an increase in traffic volumes on I-25: 29,000 vehicles per day (vpd) for the before period and 30,100 vpd in the after period is reflected by the SPF analysis.

Table 1 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	7/1/2008 to 6/30/2013 (5 yr.)
AADT	28,989 vpd	30,109 vpd
Filters:	Mainline- Only Non-Intersection	Mainline Only Non-Intersection
Total Crashes	**163**	**151**
Fatal Crashes (Fatalities)	4 (4)	3 (3)
Injury Crashes (Injuries)	45 (74)	42 (61)
Property Damage Only	114	106
Crash Types: # (%) [significance]		
Fixed Objects	47 (28.8%) [99.32%]	76 (50.3%) [100.00%]
Overturning	25 (15.3%) [100.00%]	17 (11.3%) [99.93%]
Rear End	23 (14.1%)	11 (7.3%)
Other Objects	22 (13.5%) [100.00%]	9 (6.0%)
Sideswipe Same	17 (10.4%)	24 (15.9%) [99.85%]
Head-On	2 (1.2%)	1 (0.7%)
Fixed Object Crashes: # (%) [significance]		
Guard Rail	13 (27.7%) [99.78%]	29 (38.2%) [100.00%]
Fence	10 (21.3%) [100.00%]	7 (9.2%)
Delineator Post	9 (19.1%) [99.97%]	3 (3.9%)0
Embankment	5 (10.6%)	4 (5.3%)
Sign	3 (6.4%)	9 (11.8%)
Cable Rail	n/a	21 (27.6%) [100.00%]

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. A SPF reflects the complex relationship between exposure (measured in ADT) and the crash count for a section of roadway measured in crashes per mile per year (CPMPY) or for an intersection,

measured in crashes per year. The SPF models provide an estimate for the expected crash frequency and severity for a range of ADT among similar facilities. This allows for an assessment of the magnitude of the safety problem from a frequency standpoint.

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

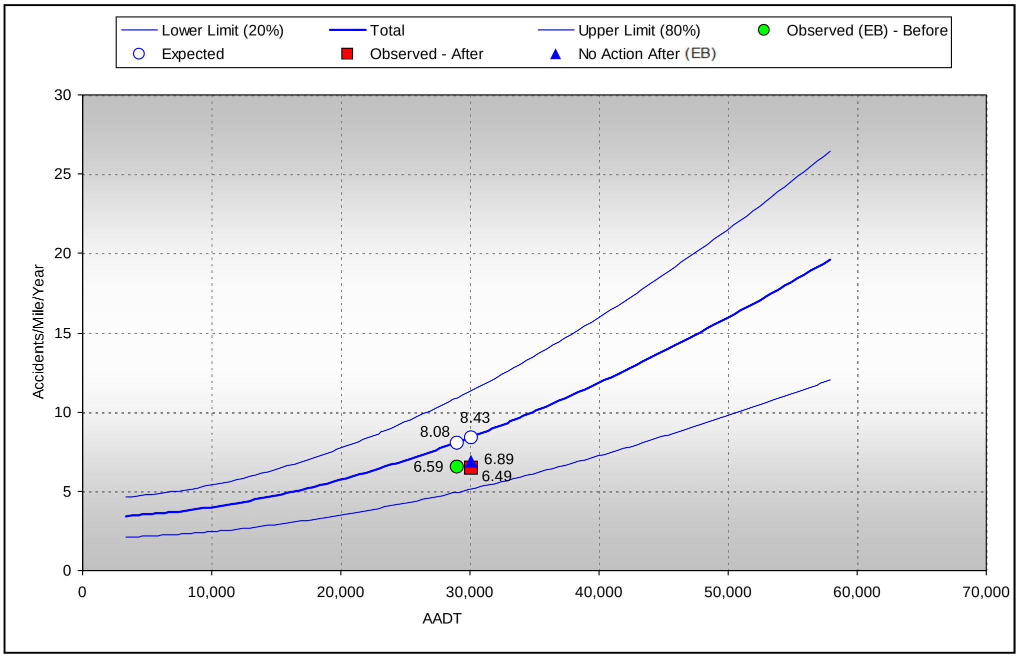
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

LOSS boundaries are calibrated by computing the 20^{th} and the 80^{th} percentiles using the Gamma Distribution Probability Density Function. Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT increases. LOSS reflects how a segment of roadway or intersection is performing in regard to its expected crash frequency at a specific level of ADT.

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect this improvement in the crash record. LOSS improved within the LOSS II range for total crashes in the after period, and Injury/Fatal crashes improved to LOSS I in the after period (see **Table 2**), due to the decrease in both types of severe crashes. However, it is difficult to conclude that the overall decrease in some types of crashes can be attributed solely to the installation of the cable rail on the curves. However, as will be discussed in the following section, the cable rail has significantly reduced certain types of crashes.

Figure 1 – SPF for Total Crashes

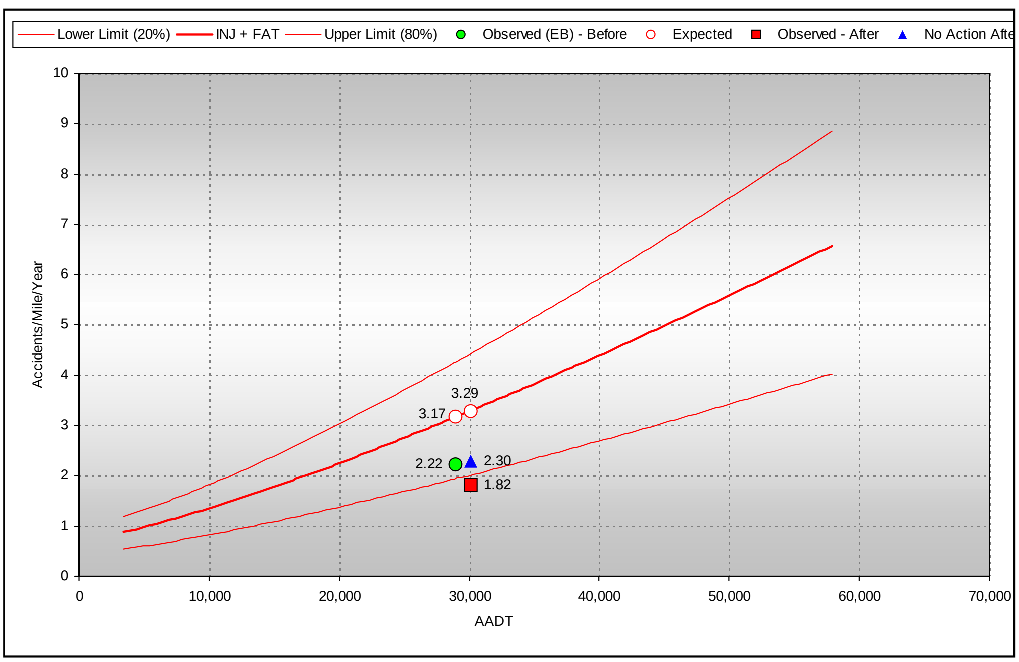
I-25 (MP 102.50 – MP 107.50)
Before: 2002 to 2006 After: 7/2008 to 6/2013



Note: Safety Performance Function (SPF) Model – Urban Flat Rolling Mountainous 4-Lane Divided Freeway (Revised)

Figure 2 – SPF for Injury and Fatal Crashes

I-25 (MP 102.50 – MP 107.50)
Before: 2002 to 2006 After: 7/2008 to 6/2013



Note: Safety Performance Function (SPF) Model rban Flat Rolling Mountainous 4-Lane Divided Freeway (Revised)

Table 2 – Safety Performance Function (SPF)

I-25 MP 102.5 – 107.5	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane Freeway	Urban, 4-lane Freeway	Urban, 4-lane Freeway
Total Crashes:			
LOSS	LOSS II	LOSS II	LOSS II
CPMPY	6.59	6.09	6.89
Mean CPMPY	8.08	8.43	8.43
Proportion of Mean	0.816	0.722	0.816
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS I	LOSS II
CPMPY	2.22	1.82	2.30
Mean CPMPY	3.17	3.29	3.29
Proportion of Mean	0.700	0.553	0.700

A more detailed review of the before and after crash record reveals that improvement in safety can be attributed to the installation of the cable rail. **Table 3** shows a comparison of types of crashes that are most directly affected by the cable rail: overturning, head-on, and cable rail. The No Build After crashes were estimated using the increase in the mean of the SPF reflecting AADT in the after period for total and injury crashes found in **Table 2** (increase is 1.04 = 8.43/8.08). **Figures 1** and **2** also show that the number of crashes after construction was much better than it could have been without the project.

Table 3 – Results of Off-Road Left and Off-Median Crash Analyses

I-25 MP 102.5 – 107.5	Before	After	No Build After
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	7/1/2008 to 6/30/2013 (5 yr.)	7/1/2008 to 6/30/2013 (5 yr.)
Crash Types: (#)			
Overturning – Total	**15**	**7**	**16**
Fatal (fatalities)	1 (1)	1 (1)	1 (1)
Injury (injuries)	13 (21)	5 (7)	14 (22)
PDO	1	1	1
% Reduction in Total		56%	
Head-On – Total	**2**	**0**	**2**
Fatal (fatalities)	1 (1)	0	1 (1)
Injury (injuries)	0	0	0
PDO	1	0	1
% Reduction in Total		100%	
Cable Rail – Total	**n/a**	**21**	**n/a**
Injury (injuries)	n/a	4 (6)	n/a
PDO	n/a	17	n/a

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Exhibit 3** for overturning, head-on, and cable rail crashes. The increase in cable rail crashes was factored into the analysis by increasing the cost of construction for the overturning and head-on crashes. During the 5-year after period, there was 17 PDO cable rail crashes and 6 injuries. Over the design life of 20 years for the cable rail system, the increased cost of crashes would be $2,569,200. Cable rail causes new crashes since it creates a barrier near the roadway, but the result is a trade-off of less serious crashes (PDOs primarily) instead of more serious fatal and injury crashes.

Exhibit 3 provides the Benefit/Cost calculations. The B/C ratio for the project is 2.26, showing that the improvement was justified.

Exhibit 3 – Benefit Cost Analysis – Overturning, Head-On, and Cable Rail Crashes Only

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

06/22/2015

Job #: 20150622233233

Location: 25A **Begin:** 102.50 **End:** 107.50 **From:** 01/01/2002 **To:** 12/31/2006

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	2		Weighted PDO:	0.49	50% :ARF for PDO	Cost of PDO:	$ 9,300
INJ:	14	22 :Injured	Weighted INJ:	5.40	68% :ARF for INJ	Cost of INJ:	$ 80,700
FAT:	2	2 :Killed	Weighted FAT:	0.49	50% :ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	64% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
	Cost:	$ 3,612,020				Service Life:	20
	From:	01/01/2002				Capital Recovery Factor:	0.080
	To:	12/31/2006	Days:	1826		Annual Maintenance Cost:	$ 5,000

Benefit Cost Ratio: 2.26 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: GUARDRAIL - INSTALLATION - Off-Road RIght Crashes Only

Special Notes: Cost of 17 PDO ($9,300*68) & 6 INJ ($80,700*24) added to $1,042,820 construction costs

Location: 25A **Begin:** 102.50 **End:** 107.50 **From:** 01/01/2002 **To:** 12/31/2006

Severity

PDO:	114	
INJ:	45	74 :Injured
FAT:	4	4 :Killed
Total:	**163**	

Number of Vehicles

One Vehicle:	102
Two Vehicles:	54
Three or More:	7
Unknown:	0
Total:	**163**

Location

On Road:	91
Off Road Left:	34
Off Road Right:	36
Off Road at Tee:	0
Off in Median:	2
Unknown:	0
Total:	**163**

Lighting Conditions

Daylight:	96
Dawn or Dusk:	7
Dark - Lighted:	5
Dark - Unlighted:	53
Unknown:	2
Total:	**163**

Weather Conditions

None:	127
Rain:	16
Snow/Sleet/Hail:	11
Fog:	0
Dust:	0
Wind:	6
Unknown:	3
Total:	**163**

Crash Rates

PDO:	0.42 *
INJ:	0.17 *
FAT:	1.49 **
Total:	**0.61** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	25	Bridge Abutment:	0
Other Non Collision:	14	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	1
Broadside:	0	Embankment:	5
Head On:	2	Curb:	0
Rear End:	23	Delineator Post:	9
Sideswipe (Same):	17	Fence:	10
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	3
Overtaking Turn:	1	Barricade:	0
Parked Motor Vehicle:	2	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	1
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	1
Domestic Animal:	2	Total Fixed Objects:	47
Wild Animal:	8	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	3	Involving Other Object:	22
Bridge Rail:	1	Total Other Objects:	22
Guard Rail:	13	Unknown:	0
Cable Rail:	0	**Total:**	**163**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	163
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**163**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	163
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**163**

Road Conditions

Dry:	130
Wet:	16
Muddy:	0
Snowy:	0
Icy:	7
Slushy:	5
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	1
Slushy w/Icy Road Treatment:	0
Unknown:	3
Total:	**163**

ADT: 28,989 **Length:** 5.08

Location: 25A **Begin:** 102.50 **End:** 107.50 **From:** 01/01/2002 **To:** 12/31/2006

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	102	40	5
Passenger Car/Van w/Trl:	2	1	0
Pickup Truck/Utility Van:	24	14	1
Pickup Truck/Utility Van w/Trl:	10	1	0
SUV:	0	0	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	17	4	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	1	0	0
Motorcycle:	3	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	2	0	0
Other:	0	0	0
Unknown:	2	1	0
Total:	**163**	**61**	**7**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	85	57	6
Asleep at the Wheel:	15	0	0
Illness:	1	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	16	1	1
Driver Fatigue:	5	0	0
Driver Preoccupied:	24	0	0
Driver Unfamilar with Area:	3	0	0
Driver Emotionally Upset:	2	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	11	3	0
Total:	**163**	**61**	**7**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	146	61	7
Alcohol Involved:	14	0	0
RX, Medication, or Drugs Involved:	3	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**163**	**61**	**7**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	130	41	5
Slowing:	1	9	0
Stopped in Traffic:	0	3	1
Making Right Turn:	0	0	0
Making Left Turn:	1	0	0
Making U-Turn:	0	0	0
Passing:	2	1	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	11	1	0
Avoiding Object/Veh in Road:	3	4	1
Weaving:	8	0	0
Other:	5	1	0
Unknown:	2	1	0
Total:	**163**	**61**	**7**

Direction	Veh 1	Veh 2	Veh 3
North:	78	27	5
Northeast:	0	0	0
East:	0	0	0
Southeast:	0	0	0
South:	84	32	2
Southwest:	0	0	0
West:	0	1	0
Northwest:	0	0	0
Unknown:	1	1	0
Total:	**163**	**61**	**7**

ADT: 28,989 **Length:** 5.08

Colorado Department of Transportation
DiExSys™ Roadway Safety Systems
Detailed Summary of Crashes Report

Exhibit 2 05/27/2015

Job #: 20150527145427

Location: 25A **Begin:** 102.50 **End:** 107.50 **From:** 07/01/2008 **To:** 06/30/2013

Severity

PDO:	106		
INJ:	42	61	:Injured
FAT:	3	3	:Killed
Total:	**151**		

Number of Vehicles

One Vehicle:	101
Two Vehicles:	46
Three or More:	4
Unknown:	0
Total:	**151**

Location

On Road:	56
Off Road Left:	61
Off Road Right:	34
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**151**

Lighting Conditions

Daylight:	95
Dawn or Dusk:	5
Dark - Lighted:	6
Dark - Unlighted:	45
Unknown:	0
Total:	**151**

Weather Conditions

None:	101
Rain:	23
Snow/Sleet/Hail:	25
Fog:	1
Dust:	0
Wind:	1
Unknown:	0
Total:	**151**

Crash Rates

PDO:	0.39 *
INJ:	0.15 *
FAT:	1.10 **
Total:	**0.55** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	17	Bridge Abutment:	0
Other Non Collision:	3	Column/Pier:	0
Pedestrians:	2	Culvert/Headwall:	0
Broadside:	0	Embankment:	4
Head On:	1	Curb:	0
Rear End:	11	Delineator Post:	3
Sideswipe (Same):	24	Fence:	7
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	1	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	76
Wild Animal:	7	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	8
Traffic Signal Pole:	1	Road Maintenance Equipment:	0
Sign:	9	Involving Other Object:	1
Bridge Rail:	0	Total Other Objects:	9
Guard Rail:	29	Unknown:	0
Cable Rail:	21	**Total:**	**151**
Concrete Barrier:	1		

Mainline/Ramps/Frontage Roads

Mainline:	151
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**151**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	151
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**151**

Road Conditions

Dry:	95
Wet:	24
Muddy:	0
Snowy:	12
Icy:	16
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	1
Icy w/Icy Road Treatment:	1
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**151**

ADT: 30,109 **Length:** 4.96

Location: 25A **Begin:** 102.50 **End:** 107.50 **From:** 07/01/2008 **To:** 06/30/2013

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	73	31	2
Passenger Car/Van w/Trl:	1	0	0
Pickup Truck/Utility Van:	23	5	0
Pickup Truck/Utility Van w/Trl:	5	2	0
SUV:	24	3	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	15	8	2
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	1	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	7	0	0
Other:	3	0	0
Unknown:	0	0	0
Total:	**151**	**50**	**4**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	74	48	4
Asleep at the Wheel:	10	0	0
Illness:	3	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	20	1	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	10	0	0
Driver Unfamilar with Area:	6	1	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	27	0	0
Total:	**151**	**50**	**4**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	141	50	4
Alcohol Involved:	6	0	0
RX, Medication, or Drugs Involved:	2	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	2	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**151**	**50**	**4**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	80	36	2
Slowing:	0	5	2
Stopped in Traffic:	1	3	0
Making Right Turn:	1	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	5	1	0
Backing:	2	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	1	0	0
Changing Lanes:	14	0	0
Avoiding Object/Veh in Road:	3	4	0
Weaving:	8	0	0
Other:	36	1	0
Unknown:	0	0	0
Total:	**151**	**50**	**4**

Direction	Veh 1	Veh 2	Veh 3
North:	58	18	3
Northeast:	0	0	0
East:	1	1	0
Southeast:	0	0	0
South:	90	31	1
Southwest:	0	0	0
West:	2	0	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**151**	**50**	**4**

ADT: 30,109 **Length:** 4.96

Project Information

Project Name: Guard rail SH 165 north of Rye

Project Description: Install guard rail along SH 165 at select locations

CDOT Region: 2	Project Def: 15771	County: Custer/Pueblo
Location: SH 165	Mile Points: 18.65 – 23.90	Length: 5.25 miles
Schedule:	Work Start Date: 6/4/2007	Completion Date: 7/26/2007

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history showed a higher than expected number of off-road type crashes. These crashes were occurring on the curves of the roadways. The roadway has tight, compound, and reverse curves. Outside curves with steep drop-off exist along the roadway. The San Isabel Lake dam is located within this stretch of roadway. Driving across the dam, a very steep embankment exists on one side and the lake on the other.

Improvement Description: In 2007, guard rail was installed on the outside of select curves for drop-off protection and along both sides of the roadway across the dam. The cost of construction was $452,429.

The HSIP application anticipated that off-road crash types would be impacted by this improvement. The following reductions in crashes were anticipated: fatal crashes – 60%, injury crashes – 40%, and property damage only – 0%. The initial benefit/cost ratio was estimated to be 4.97.

Summary and Findings

The analysis of safety before and after the guard rail was installed along SH 165 showed significant safety improvements. For this segment of highway, there were 20 total crashes during the five-year period before the rail was installed (2002 – 2006). In the five years after construction (2008 – 2012), the number of crashes was decreased to 5. In addition, the number of injury and fatal crashes also diminished.

The guard rail improvement was directly responsible for decreases in the number and severity of off-road crashes. During the before period, there was one fatal tree crash and a number of injury crashes. The after period experienced no fatal crashes and a reduction in the number of injury crashes. Guard rail causes new crashes since it creates a barrier near the roadway, but the result is a trade-off of less serious crashes (PDOs primarily) instead of more serious fatal and injury crashes.

The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 12.67 to one. The result is an improvement that was certainly justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a large decrease in the number of crashes; the total number of crashes decreased from 20 during the five-year period (2002 to 2006) before the guard rail was installed (see **Table 1** and **Exhibit 1**) to 5 during the five-year after period (2008 to 2012) (see **Table 1** and **Exhibit 2**). The number of serious crashes also showed a significant decrease:

- Before (2002 – 2006) – 1 fatal crashes with 1 fatalities (tree) and 11 injury crashes with 13 injuries
- After (2008 – 2012) – no fatal crashes and 3 injury crashes with 3 injuries

This decrease in severe crashes occurred along with a small decrease in traffic volumes on SH 165: 1,000 vehicles per day (vpd) estimated for the before period and 860 vpd in the after period. This combination of decreased traffic and decreased number of crashes also resulted in a decrease in the accident rates:

- Before (2002 – 2006): 11.04 crashes per million vehicle miles of travel (cpmvmt)
- After (2008 – 2012): 3.17 (cpmvmt)

Table 1 - Results of Overall Crash Analyses

SH 165 MP 18.65-23.90	Before	After
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)
AADT	993 vpd	864 vpd
Filters:	Mainline Only/Non-Intersection	Mainline Only/Non-Intersection
Total Crashes	**20**	**5**
Fatal Crashes (Fatalities)	1 (1)	0
Injury Crashes (Injuries)	11 (13)	3 (3)
Property Damage Only	8	2
Crash Types: # (%) [significance]		
Fixed Objects	15 (75.0%) [99.81%]	3 (60.0%) [100.00%]
Rear End	2 (10.0%)	0
Overturning	1 (5.0%)	2 (40.0%)
Wild Animal	1 (5.0%)	0
Other Non-Collision	1 (5.0%)	0
Fixed Object Crashes: # (%) [significance]		
Tree	11 (73.3%) [100.00%]	2 (66.7%)
Embankment	3 (20.0%)	0
Delineator	1 (6.7%)	0
Guard rail	0	1 (33.3%)

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. A SPF reflects the complex relationship between exposure (measured in ADT) and the crash count for a section of roadway measured in crashes per mile per year (CPMPY) or for an intersection,

measured in crashes per year. The SPF models provide an estimate for the expected crash frequency and severity for a range of ADT among similar facilities. This allows for an assessment of the magnitude of the safety problem from a frequency standpoint.

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

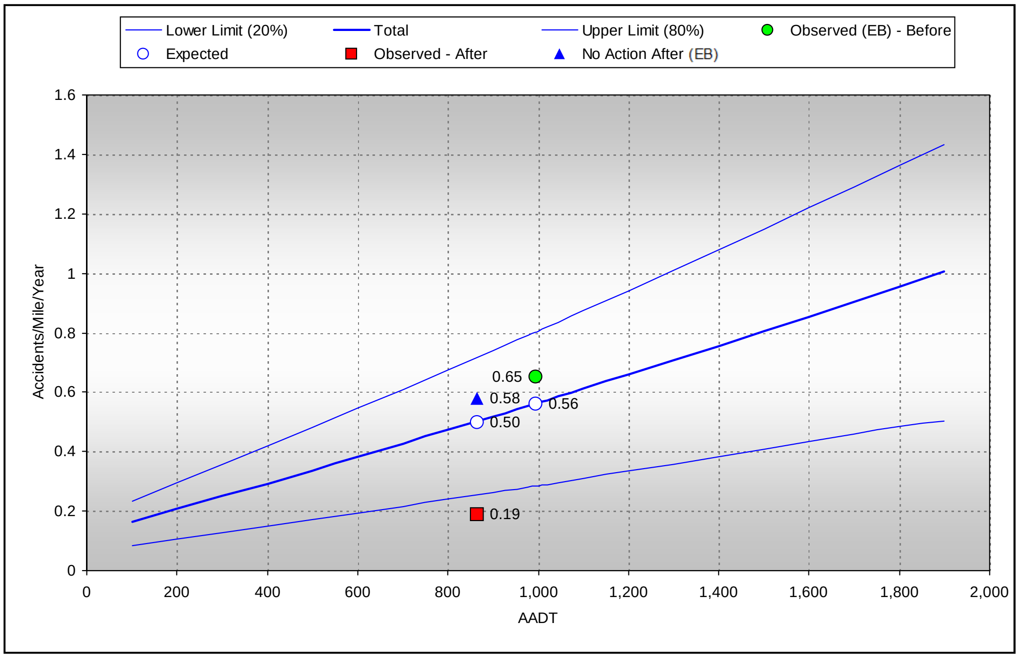
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

LOSS boundaries are calibrated by computing the 20^{th} and the 80^{th} percentiles using the Gamma Distribution Probability Density Function. Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT increases. LOSS reflects how a segment of roadway or intersection is performing in regard to its expected crash frequency at a specific level of ADT.

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect this improvement in the crash record. LOSS improved to LOSS I from LOSS III for total crashes in the after period, and Injury/Fatal crashes improved to LOSS II in the after period (see **Table 2**), due to the decrease in both types of severe crashes. However, it is difficult to conclude that the overall decrease in some types of crashes can be attributed solely to the installation of the guard rail on the curves. However, as will be discussed in the following section, the guard rail has significantly reduced certain types of crashes.

Figure 1 – SPF for Total Crashes

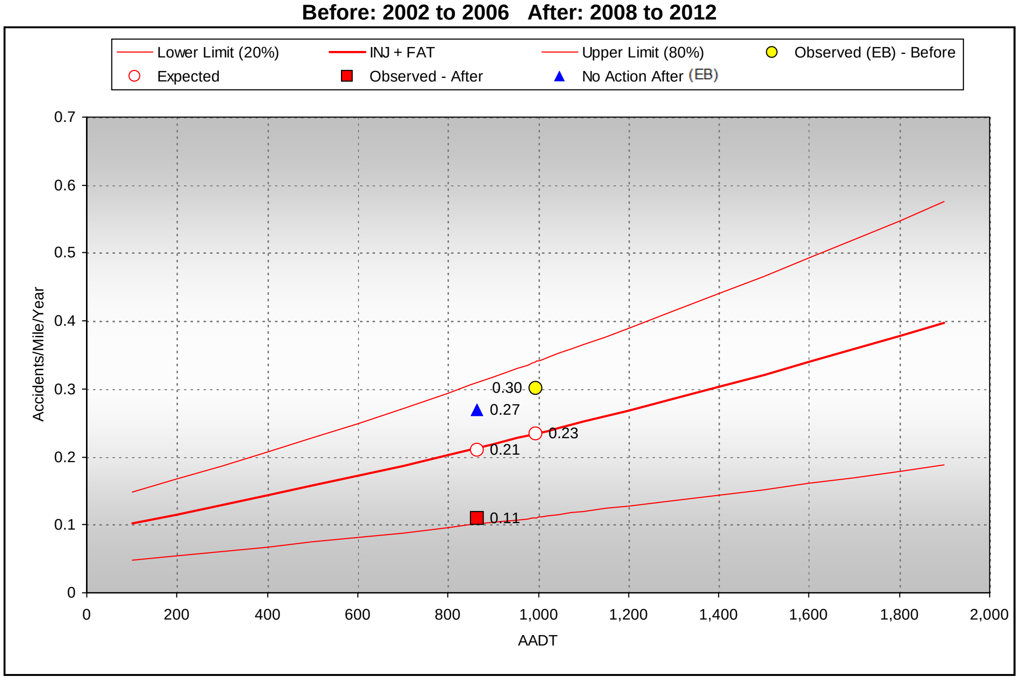
SH 165 (MP 18.65 – MP 23.90)
Before: 2002 to 2006 After: 2008 to 2012



Note: Safety Performance Function (SPF) Model – Rural Mountainous 2-Lane Undivided Highway

Figure 2 – SPF for Injury and Fatal Crashes

SH 165 (MP 18.65 – MP 23.90)
Before: 2002 to 2006 After: 2008 to 2012



Note: Safety Performance Function (SPF) Model – Rural Mountainous 2-Lane Undivided Highway

Table 2 – Safety Performance Function (SPF)

SH 165 MP 18.65-23.90	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Rural, Mountainous, 2-Lane, Undivided Highway	Rural, Mountainous, 2-Lane, Undivided Highway	Rural, Mountainous, 2-Lane, Undivided Highway
Total Crashes:			
LOSS	LOSS III	LOSS I	LOSS III
CPMPY	0.65	0.19	0.58
Mean CPMPY	0.56	0.50	0.50
Proportion of Mean	1.16	0.90	1.16
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS II	LOSS III
CPMPY	0.30	0.11	0.27
Mean CPMPY	0.23	0.21	0.21
Proportion of Mean	1.30	0.52	1.30

A more detailed review of the before and after crash record reveals that a significant improvement in safety can be attributed to the installation of the guard rail. **Table 3** shows a comparison of type of crashes that are most directly affected by the guard rail: off-road right. The No Build After crashes were estimated using the decrease in the mean predicted by the SPF reflecting AADT for the after period, of the SPF for total and injury crashes found in **Table 2** (decrease is 0.89 = 0.50/0.56). **Figures 1** and **2** also show that the number of crashes after construction was much better than it could have been without the project.

Table 3 – Results of Off-Road Left and Off-Median Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)
Crash Types:			
Off-Road RIght – Total	**10**	**2**	**9**
Fatal (fatalities)	1 (1)	0	1 (1)
Injury (injuries)	7 (9)	1 (1)	6 (8)
PDO	2	1	2
% Reduction in Total		78%	
Guard Rail – Total	**n/a**	**1**	**n/a**
Injury (injuries)	n/a	0	n/a
PDO	n/a	1	n/a

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Exhibit 3** for off-road right crashes. The increase in guard rail crashes was factored into the analysis by increasing the cost of construction for the off-road right crashes. During the 5-year after period, there was 1 PDO guard rail crashes. Over the design life of 20 years for the cable rail system, the increased cost of crashes would be

$37,200. Guard rail causes new crashes since it creates a barrier near the roadway, but the result is a trade-off of less serious crashes (PDOs primarily) instead of more serious fatal and injury crashes.

Exhibit 3 provides the Benefit/Cost calculations. The B/C ratio for the project is 12.67, showing that the improvement was certainly justified.

Exhibit 3 – Benefit Cost Analysis – Off-Road Right Crashes Only

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

06/24/2015

Job #: 20150624122143

Location: 165A **Begin:** 18.65 **End:** 23.90 **From:** 01/01/2002 **To:** 12/31/2006

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	2		Weighted PDO:	0.49	50% :ARF for PDO	Cost of PDO:	$ 9,300
INJ:	6	8 :Injured	Weighted INJ:	1.97	88% :ARF for INJ	Cost of INJ:	$ 80,700
FAT:	1	1 :Killed	Weighted FAT:	0.25	100% :ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	80% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
	Cost:	$ 489,629				Service Life:	20
	From:	01/01/2002				Capital Recovery Factor:	0.080
	To:	12/31/2006	Days:	1826		Annual Maintenance Cost:	$ 1,000

Benefit Cost Ratio: 12.67 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: GUARDRAIL - INSTALLATION - Off Road Right Crashes Only
Special Notes: Cost of 4 PDO ($9,300*4) added to the $452,429 construction cost

Location: 165A **Begin:** 18.65 **End:** 23.90 **From:**01/01/2002 **To:**12/31/2006

Severity

PDO:	8	
INJ:	11	13 :Injured
FAT:	1	1 :Killed
Total:	**20**	

Number of Vehicles

One Vehicle:	18
Two Vehicles:	1
Three or More:	1
Unknown:	0
Total:	**20**

Location

On Road:	5
Off Road Left:	5
Off Road Right:	10
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**20**

Lighting Conditions

Daylight:	14
Dawn or Dusk:	2
Dark - Lighted:	0
Dark - Unlighted:	4
Unknown:	0
Total:	**20**

Weather Conditions

None:	14
Rain:	2
Snow/Sleet/Hail:	3
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**20**

Crash Rates

PDO:	0.83 *	* MVMT
INJ:	1.13 *	** 100 MVMT
FAT:	10.31 **	**Total: 2.06** *

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	3
Head On:	0	Curb:	0
Rear End:	2	Delineator Post:	1
Sideswipe (Same):	0	Fence:	0
Sideswipe (Opposite):	0	Tree:	11
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	15
Wild Animal:	1	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**20**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	20
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**20**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	20
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**20**

Road Conditions

Dry:	14
Wet:	2
Muddy:	0
Snowy:	0
Icy:	3
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**20**

ADT: 993 **Length:** 5.34

Location: 165A **Begin:** 18.65 **End:** 23.90 **From:** 01/01/2002 **To:** 12/31/2006

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	14	1	1
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	2	1	0
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	0	0	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	3	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**20**	**2**	**1**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	11	1	1
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	4	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	3	1	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	1	0	0
Total:	**20**	**2**	**1**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	16	2	1
Alcohol Involved:	2	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	2	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**20**	**2**	**1**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	15	0	0
Slowing:	1	0	0
Stopped in Traffic:	1	1	1
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	2	0	0
Weaving:	0	0	0
Other:	1	1	0
Unknown:	0	0	0
Total:	**20**	**2**	**1**

Direction	Veh 1	Veh 2	Veh 3
North:	9	2	1
Northeast:	0	0	0
East:	2	0	0
Southeast:	0	0	0
South:	6	0	0
Southwest:	0	0	0
West:	3	0	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**20**	**2**	**1**

ADT: 993 **Length:** 5.34

Location: 165A **Begin:** 18.65 **End:** 23.90 **From:** 01/01/2008 **To:** 12/31/2012

Severity

PDO:	2	
INJ:	3	3 :Injured
FAT:	0	0 :Killed
Total:	**5**	

Number of Vehicles

One Vehicle:	5
Two Vehicles:	0
Three or More:	0
Unknown:	0
Total:	**5**

Location

On Road:	1
Off Road Left:	0
Off Road Right:	4
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**5**

Lighting Conditions

Daylight:	4
Dawn or Dusk:	1
Dark - Lighted:	0
Dark - Unlighted:	0
Unknown:	0
Total:	**5**

Weather Conditions

None:	3
Rain:	0
Snow/Sleet/Hail:	2
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**5**

Crash Rates

PDO:	0.24 *	* MVMT
INJ:	0.36 *	** 100 MVMT
FAT:	0.00 **	
Total:	**0.60** *	

Crash Type

Overturning:	2	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	0
Head On:	0	Curb:	0
Rear End:	0	Delineator Post:	0
Sideswipe (Same):	0	Fence:	0
Sideswipe (Opposite):	0	Tree:	2
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	3
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	1	Unknown:	0
Cable Rail:	0	**Total:**	**5**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	5
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**5**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	5
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**5**

Road Conditions

Dry:	2
Wet:	0
Muddy:	0
Snowy:	2
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**5**

ADT: 864 **Length:** 5.28

Location: 165A	Begin: 18.65	End: 23.90	From: 01/01/2008	To: 12/31/2012

Vehicle Type

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	1	0	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	1	0	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	1	0	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	2	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**5**	**0**	**0**

Contributing Factor

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	2	0	0
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	0	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	1	0	0
Total:	**5**	**0**	**0**

Condition of Driver

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	5	0	0
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**5**	**0**	**0**

Vehicle Movement

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	2	0	0
Slowing:	0	0	0
Stopped in Traffic:	0	0	0
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	3	0	0
Unknown:	0	0	0
Total:	**5**	**0**	**0**

Direction

Direction	Veh 1	Veh 2	Veh 3
North:	2	0	0
Northeast:	0	0	0
East:	1	0	0
Southeast:	0	0	0
South:	2	0	0
Southwest:	0	0	0
West:	0	0	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**5**	**0**	**0**

ADT: 864	Length: 5.28

Project Information

Project Name: SH 93 – SH 72 (MP 7.57) to SH 128 (MP 11.78)

Project Description: Upgrade Signal at SH 72 / SH 93 and Install Weather-Related Road Closure System

CDOT Region: 1 Project Def: 15828 County: Jefferson

Location: SH 93 Mile Points: from: 7.47 to 11.83 Length: 4.21 miles

Schedule: Work Start Date: 3/5/2007 Completion Date: 12/10/2007

Problem Description: Two problems were identified at the intersection of SH 72/SH 93 and along SH 93 to the north for approximately four miles to the intersection with SH 128. As described in the Highway Safety Improvement Program (HSIP) application, the five-year (1999 – 2003) crash history at the intersection of SH 72/SH 93 (which had span wire signalization) showed 40 crashes occurred including 15 approach turn, 9 rear-end, and 7 broadside crashes. These involved 1 fatal and 15 injury crashes. The section of SH 93 across Rocky Flats is subject to periodic sustained high winds and wind gusts in excess of 80 mph. High winds and gusts contribute to high-profile vehicles overturning and reduced visibility due to “white-out” and “ground blizzard” conditions which may contribute to the loss of vehicle control. In a three-year period (2001 – 2003), there were 29 PDO and 8 injury crashes.

Improvement Description: In 2007, new mast arms, signal heads with LED lenses, backplates, and a new detection system was constructed at the intersection. New pavement markings were placed to delineate lanes, cross walks and stop lines. The channelizing islands and curb ramps were also improved. To address the adverse wind and weather conditions across Rocky Flats, a variable message sign (VMS) was installed on northbound SH 93 just south of 64th Avenue (MP 3.794) to provide notice of closures and/or restrictions. Road closure gates were installed on the north leg of the SH 72/SH 93 intersection to facilitate temporary weather-related road closures. The cost of construction for the signal installation and related intersection improvements was approximately $400,000 and $199,548 for the weather information/closure installations. The total cost for the combined project was $599,548.

The HSIP application anticipated that three crash types could potentially be reduced by 15% by the signal improvement: approach turn, broadside, and rear-end crashes. The VMS and closure gate project was estimate to reduce weather-related crashes by 25%. The initial benefit/cost ratios were estimated to be 1.72 for the signal and intersection improvements and 1.17 for the weather-related infrastructure.

Summary and Findings

The analysis of safety before and after construction showed significant safety improvements resulted from the weather-related infrastructure that was installed along SH 93 (between SH 72 and SH 128) and the signal and related improvements at the SH 72 / SH 93 intersection. For this segment of SH 93, there were 260 total crashes during the five-year period before construction (2002 – 2006). In the five years after construction (2008 – 2012), the number of crashes decreased to 189. Although daily volumes decrease throughout the study period, the non-intersection crash rate on SH 93 also experienced a reduction. In addition, the number of injury and fatal crashes also diminished significantly.

The weather-related infrastructure (variable message sign and road closure gates) resulted in decreases in the number and severity of wind caused crashes. This portion of the project resulted in a Benefit/Cost ratio of 1.42. The signal and related improvements at the SH 72/SH 93 intersection resulted in a large increase in safety. During the before period, there was one fatal approach turn collision and a number of injury crashes (broadside, rear-end, sideswipe-same, and approach turn crashes). The after period experienced no fatal crashes and a reduction in the number of injury crashes. This portion of the project resulted in a significant Benefit/Cost ratio of 14.93. In summary, the ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 16.35 to one. The result is improvements that were certainly justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 260 during the five-year period (2002 to 2006) before the project was constructed (see **Table 1** and **Exhibit 1**) to 189 during the five-year after period (2008 to 2012) (see **Table 1** and **Exhibit 2**). The number of serious crashes showed a more significant decrease:

- Before (2002 – 2006) – 5 fatal crashes with 5 fatalities (2 head-on and 1 each involving overturning, approach turn, and a fixed object) and 75 injury crashes with 110 injuries
- After (2008 – 2012) – 2 fatal crashes (both were sideswipe opposite) and 45 injury crashes with 73 injuries

This decrease in severe crashes occurred along with a decrease in traffic volumes on SH 93: 18,300 vehicles per day (vpd) estimated for the before period and 15,900 vpd in the after period. The Rocky Flats Plant was a large traffic generator along SH 93. It produced weapons-grade plutonium through the mid-1990's. Clean-up of the site was completed in 2005, and it became a National Wildlife Refuge in 2007.

Because this project involved two separate improvements, the crash record in **Table 1** has separate listings for the non-intersection crashes along SH 93 and the intersection-related crashes at the intersection of SH 72 and SH 93. The crash rate along SH 93 showed a decrease in the accident rates as the proportional decrease in the number of crashes was greater than the decrease in traffic:

- Before (2002 – 2006): 1.13 crashes per million vehicle miles of travel (cpmvmt)
- After (2008 – 2012): 1.03 (cpmvmt)

Table 1 also shows that both the number and severity of crashes at the SH 72/SH 93 intersection also improved in the after period.

Table 1 - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)
AADT	18,300 vpd	15,900 vpd
Filters:	None – All Crashes Included	None – All Crashes Included
Total Crashes	**260**	**189**
Fatal Crashes (Fatalities)	5 (5)	2 (3)
Injury Crashes (Injuries)	75 (110)	45 (73)
Property Damage Only	180	142
SH 93 (MP 7.47 to MP 11.83) – Non-intersection / Mainline only		
Total Crashes	**173**	**135**
Fatal Crashes (Fatalities)	4 (4)	2 (3)
Injury Crashes (Injuries)	46 (64)	33 (57)
Property Damage Only	123	100
Crash Types: # (%) [significance]		
Fixed Objects	45 (26.0%) [99.42%]	43 (31.9%) [99.94%]
Rear End	37 (21.4%)	25 (18.5%)
Overturning	24 (13.9%)	13 (9.6%)
Wild Animal	19 (11.0%)	24 (17.8%)
Head-On	13 (7.5%)	11 (8.1%)
Sideswipe Opposite	11 (6.4%)	8 (5.9%) [99.57%]
Sideswipe Same	9 (5.2%)	2 (1.4%)
Fixed Object Crashes: # (% of FO) [significance]		
Fence	22 (48.9%) [100.0%]	15 (37.4%) [99.80%]
Guard Rail	1 (1.9%)	6 (14.0%) [100.00%]
Adverse Weather Conditions: # (% of non-intersection) [significance]		
Snow/Sleet/Hail	39 (22.5%) [100.0%]	35 (25.9%) [100%]
Wind	22 (12.7%) [100.0%]	10 (7.4%) [100%]
Adverse Road Conditions: # (% of non-intersection) [significance]		
Snowy	20 (11.6%) [100.0%]	13(9.6%) [100%]
Icy	25 (14.5%)	29 (21.5%) [100%]
Slushy	10 (5.8%) [100.0%]	3 (2.2%)
SH 72 (MP 10.6 to 10.70) / SH 93 (MP 7.47 – 7.67) – Intersection Crashes only		
Total Crashes	**43**	**32**
Fatal Crashes (Fatalities)	1 (1)	0
Injury Crashes (Injuries)	11 (19)	7 (10)
Property Damage Only	31	25
Crash Types: # (%) [significance]		
Rear End	19 (44.2%)	24 (75.0%)
Broadside	11 (25.6%)	4 (12.5%)
Approach Turn	6 (14.0%)	2 (6.2%)
Sideswipe Same	3 (7.0%)	0

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. A SPF reflects the complex relationship between exposure (measured in ADT) and the crash count for a section of roadway measured in crashes per mile per year (CPMPY) or for an intersection, measured in crashes per year. The SPF models provide an estimate for the expected crash frequency and severity for a range of ADT among similar facilities. This allows for an assessment of the magnitude of the safety problem from a frequency standpoint.

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

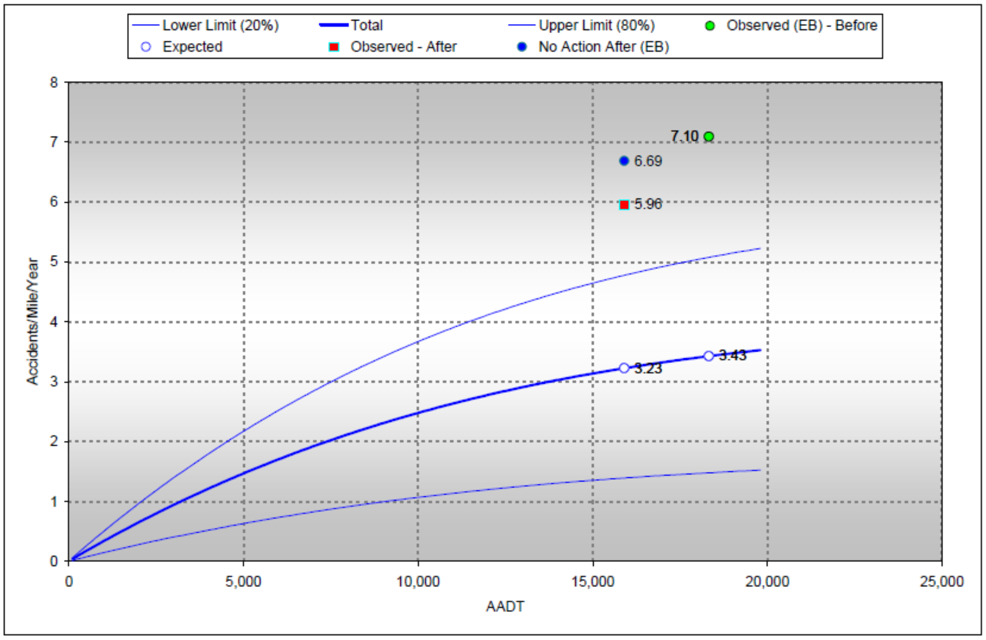
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

LOSS boundaries are calibrated by computing the 20^{th} and the 80^{th} percentiles using the Gamma Distribution Probability Density Function. Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT increases. LOSS reflects how a segment of roadway or intersection is performing in regard to its expected crash frequency at a specific level of ADT.

SPF analyses have not been preformed for urban (or rural) 2-lane, divided, signalized, 4-leg intersections so comparisons are not available for the intersection of SH 72/SH 93. SPF plots are available for rural, flat and rolling, 2-lane, undivided highways for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**). LOSS improved within the LOSS IV range for total crashes in the after period, and Injury/Fatal crashes improved within the LOSS III range in the after period (see **Table 2**), due to the decrease in both types of severe crashes.

Figure 1 - SPF for Total Crashes

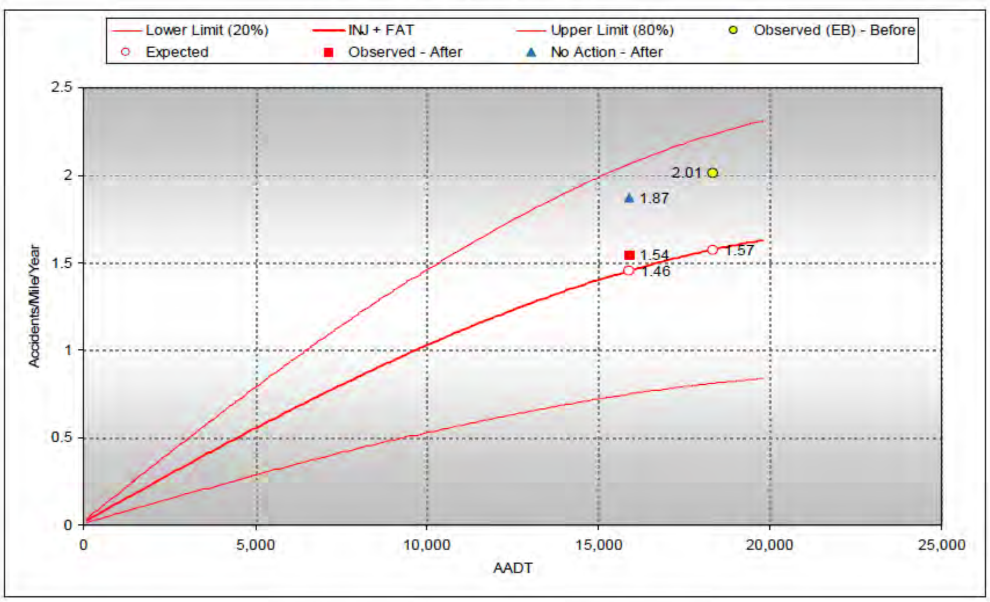
SH 93 (MP 7.47 to MP 11.83)
Before: 2002 to 2006 After: 2008 to 2012



Note: Safety Performance Function (SPF) Model: Colorado - Rural Flat and Rolling 2-Lane Undivided Highway

Figure 2 - SPF for Injury and Fatal Crashes

SH 93 (MP 7.47 to MP 11.83)
Before: 2002 to 2006 After: 2008 to 2012



Note: Safety Performance Function (SPF) Model: Colorado - Rural Flat and Rolling 2-Lane Undivided Highway

Table 2 – SH 93 (MP 7.47 to MP 11.83) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Rural Flat & Rolling, 2-lane Undivided Highway	Rural Flat & Rolling, 2-lane Undivided Highway	Rural Flat & Rolling, 2-lane Undivided Highway
Total Crashes:			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPMPY	7.10	5.96	6.69
Mean CPMPY	3.43	3.23	3.23
Proportion of Mean	2.070	1.845	2.070
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS III	LOSS III
CPMPY	2.01	1.54	1.87
Mean CPMPY	1.57	1.46	1.46
Proportion of Mean	1.280	1.055	1.280

A more detailed review of the before and after crash records reveals that a significant improvements in safety can be attributed to the installation of the weather information/closure system and the signal system upgrade. **Table 3** shows that wind-related crashes were reduced in the after period. The No Build After crashes were estimated using the decrease in the median of the SPF for total crashes found in **Table 2** (decrease is 0.942 = 6.69/7.10). **Table 4** shows the decrease in broadside, rear-end, sideswipe (same), and approach turn crashes was significant. The No Build After crashes were estimated using the decrease in the total approach volumes to the intersection between the before and after periods (decrease is 0.916 = 41,540 / 45,355). Particularly notable is the improvement in both the number and severity of approach turn crashes due to allowing protected-only left turns in the after period.

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Exhibit 3** for wind-related crashes on SH 93 between SH 72 and SH 128 and **Exhibit 4** for broadside, rear-end, sideswipe (same), and approach turn crashes at the SH 72/SH 93 intersection. The B/C ratio for wind-related crashes on SH 93 is 1.42 and the B/C ratio for crashes at the SH 72/SH 93 intersection is 14.93. The resulting B/C ratio for the combined project is 16.35 (1.42 + 14.93), showing that these improvements was certainly justified, by themselves and together.

Table 3 – Results of SH 93 (MP 7.47 to MP 11.83) Wind-related Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)
Crash Types:			
Wind-related – Total	**22**	**10**	**21**
Injury (injuries)	3 (3)	2 (2)	3 (3)
PDO	19	8	18
% Reduction in Total – (INJ / PDO)		33% / 56%	

Table 4 – Results of Improved Signalization Crash Analyses at SH 72 / SH 93 Intersection

	Before	After	No Build After
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)
Crash Types:			
Broadside – Total	**11**	**4**	**10**
Injury (injuries)	3 (5)	2 (3)	3 (5)
PDO	8	2	7
Read End – Total	**19**	**24**	**17**
Injury (injuries)	5 (5)	4 (6)	4 (4)
PDO	14	20	13
Sideswipe (Same) - Total	**3**	**0**	**3**
Injury (injuries)	0	0	0
PDO	3	0	3
Approach Turn Total	**6**	**2**	**6**
Fatal (fatalities)	1 (1)	0	1 (1)
Injury (injuries)	1 (6)	0 (0)	1 (6)
PDO	4	2	4
Total	**39**	**30**	**36**
Fatal (fatalities)	1 (1)	0	1 (1)
Injury (injuries)	9 (16)	6 (9)	8(15)
PDO	29	24	27
% Reduction in Total – (FAT / INJ / PDO)		100% / 40% / 11%	

Exhibit 3 – Benefit Cost Analysis – SH 93 (MP 7.47 to MP 11.83Non-intersection Wind-related Crashes Only

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

06/22/2015

Job #: 20150622132547

Location: 93A 72A/128A **Begin:** 7.47 **End:** 11.83 **From:** 01/01/2002 **To:** 12/31/2006

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	18		Weighted PDO:	3.95	56% :ARF for PDO	Cost of PDO:	$ 9,300
INJ:	3	3 :Injured	Weighted INJ:	0.66	33% :ARF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	100% :ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	52% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
						Service Life:	10
						Capital Recovery Factor:	0.129
						Annual Maintenance Cost:	$ 1,000

Cost: $ 199,548
From: 01/01/2008
To: 12/31/2012 Days: 1827

Benefit Cost Ratio: 1.42 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Non-intersection, wind-related crashes only
Special Notes: 2015 NSC crash costs

Exhibit 4 – Benefit Cost Analysis – Broadside, Rear-end, Sideswipe (same) and Approach Turn Crashes at Intersection of SH 72 (MP 10.6 to 10.70) and SH 93 (MP 7.47 – 7.67)

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

06/30/2015

Job #: 20150630083641

Location: 93A 72A **Begin:** 7.47 **End:** 7.67 **From:** 01/01/2002 **To:** 12/31/2006

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	27		Weighted PDO:	6.63	11% :ARF for PDO	Cost of PDO:	$ 9,300
INJ:	8	15 :Injured	Weighted INJ:	3.69	40% :ARF for INJ	Cost of INJ:	$ 80,700
FAT:	1	1 :Killed	Weighted FAT:	0.25	100% :ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	19% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance Cost:	$ 1,000

Cost: $ 400,000
From: 01/01/2008
To: 12/31/2012 Days: 1827

Benefit Cost Ratio: 14.93 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Broadside, Rear-end, Sideswipe (same), and Approach Turn Crashes Only
Special Notes: 2015 NSC crash costs

Location: 93A 72A/128A **Begin:** 7.47 **End:** 11.83 **From:** 01/01/2002 **To:** 12/31/2006

No filters, SH 72 & SH 128 intersections included

Severity

PDO:	180		
INJ:	75	110	:Injured
FAT:	5	5	:Killed
Total:	**260**		

Number of Vehicles

One Vehicle:	101
Two Vehicles:	143
Three or More:	16
Unknown:	0
Total:	**260**

Location

On Road:	182
Off Road Left:	19
Off Road Right:	55
Off Road at Tee:	4
Off in Median:	0
Unknown:	0
Total:	**260**

Lighting Conditions

Daylight:	158
Dawn or Dusk:	10
Dark - Lighted:	9
Dark - Unlighted:	71
Unknown:	12
Total:	**260**

Weather Conditions

None:	176
Rain:	5
Snow/Sleet/Hail:	43
Fog:	2
Dust:	0
Wind:	23
Unknown:	11
Total:	**260**

Crash Rates

PDO:	1.18	*
INJ:	0.49	*
FAT:	3.26	**
Total:	**1.70**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	26	Bridge Abutment:	0
Other Non Collision:	7	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	25	Embankment:	11
Head On:	13	Curb:	1
Rear End:	74	Delineator Post:	2
Sideswipe (Same):	12	Fence:	23
Sideswipe (Opposite):	11	Tree:	0
Approach Turn:	6	Large Boulders or Rocks:	2
Overtaking Turn:	4	Barricade:	0
Parked Motor Vehicle:	2	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	1
Domestic Animal:	1	Total Fixed Objects:	53
Wild Animal:	19	Rocks in Roadway:	0
Light/Utility Pole:	4	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	1
Sign:	8	Involving Other Object:	6
Bridge Rail:	0	Total Other Objects:	7
Guard Rail:	1	Unknown:	0
Cable Rail:	0	**Total:**	**260**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	260
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**260**

Road Description

At Intersection:	54
At Driveway Access:	17
Intersection Related:	16
Non Intersection:	173
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**260**

Road Conditions

Dry:	170
Wet:	18
Muddy:	0
Snowy:	21
Icy:	23
Slushy:	10
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	2
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	2
Slushy w/Icy Road Treatment:	1
Unknown:	13
Total:	**260**

ADT: 18,326 **Length:** 4.57

Location: 93A 72A/128A **Begin:** 7.47 **End:** 11.83 **From:**01/01/2002 **To:**12/31/2006

No filters, SH 72 & SH 128 intersections included

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	194	115	10
Passenger Car/Van w/Trl:	1	2	1
Pickup Truck/Utility Van:	37	24	4
Pickup Truck/Utility Van w/Trl:	4	2	0
SUV:	1	0	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	7	7	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	1	0	0
Motorcycle:	5	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	10	9	0
Total:	**260**	**159**	**16**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	193	140	14
Asleep at the Wheel:	3	0	0
Illness:	3	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	11	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	23	0	0
Driver Unfamilar with Area:	5	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	20	19	2
Total:	**260**	**159**	**16**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	245	159	16
Alcohol Involved:	12	0	0
RX, Medication, or Drugs Involved:	2	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**260**	**159**	**16**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	189	78	4
Slowing:	13	24	0
Stopped in Traffic:	2	47	12
Making Right Turn:	4	0	0
Making Left Turn:	23	1	0
Making U-Turn:	3	0	0
Passing:	4	1	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	0
Changing Lanes:	6	0	0
Avoiding Object/Veh in Road:	4	3	0
Weaving:	1	0	0
Other:	4	1	0
Unknown:	6	3	0
Total:	**260**	**159**	**16**

Direction	Veh 1	Veh 2	Veh 3
North:	118	71	6
Northeast:	0	0	0
East:	12	8	0
Southeast:	0	0	0
South:	95	69	7
Southwest:	1	0	0
West:	28	8	1
Northwest:	0	0	0
Unknown:	6	3	2
Total:	**260**	**159**	**16**

ADT: 18,326 **Length:** 4.57

Colorado Department of Transportation
DiExSys™ Roadway Safety Systems
Detailed Summary of Crashes Report

Exhibit 2 — 06/17/2015 — Job #: 20150617090701

Location: 93A 72A/128A **Begin:** 7.47 **End:** 11.83 **From:** 01/01/2008 **To:** 12/31/2012

No filters, SH 72 & SH 128 intersections included

Severity

PDO:	142		
INJ:	45	73	:Injured
FAT:	2	3	:Killed
Total:	**189**		

Number of Vehicles

One Vehicle:	87
Two Vehicles:	74
Three or More:	28
Unknown:	0
Total:	**189**

Location

On Road:	115
Off Road Left:	18
Off Road Right:	33
Off Road at Tee:	0
Off in Median:	1
Unknown:	22
Total:	**189**

Lighting Conditions

Daylight:	113
Dawn or Dusk:	7
Dark - Lighted:	8
Dark - Unlighted:	61
Unknown:	0
Total:	**189**

Weather Conditions

None:	123
Rain:	6
Snow/Sleet/Hail:	36
Fog:	2
Dust:	0
Wind:	11
Unknown:	11
Total:	**189**

Crash Rates

PDO:	1.08 *
INJ:	0.34 *
FAT:	1.52 **
Total:	**1.44** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	16	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	1	Culvert/Headwall:	0
Broadside:	5	Embankment:	11
Head On:	11	Curb:	1
Rear End:	66	Delineator Post:	4
Sideswipe (Same):	2	Fence:	15
Sideswipe (Opposite):	8	Tree:	0
Approach Turn:	2	Large Boulders or Rocks:	0
Overtaking Turn:	3	Barricade:	1
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	1	Total Fixed Objects:	46
Wild Animal:	24	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	4
Traffic Signal Pole:	1	Road Maintenance Equipment:	0
Sign:	6	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	4
Guard Rail:	6	Unknown:	0
Cable Rail:	0	**Total:**	**189**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	188
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	1	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**189**

Road Description

At Intersection:	13
At Driveway Access:	8
Intersection Related:	32
Non Intersection:	135
In Alley:	0
Roundabout:	0
Ramp:	1
Parking Lot:	0
Unknown:	0
Total:	**189**

Road Conditions

Dry:	124
Wet:	13
Muddy:	0
Snowy:	13
Icy:	29
Slushy:	3
Foreign Material:	1
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	1
Slushy w/Icy Road Treatment:	0
Unknown:	4
Total:	**189**

ADT: 15,901 **Length:** 4.53

Location: 93A 72A/128A **Begin:** 7.47 **End:** 11.83 **From:** 01/01/2008 **To:** 12/31/2012

No filters, SH 72 & SH 128 intersections included

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	103	57	13
Passenger Car/Van w/Trl:	1	0	0
Pickup Truck/Utility Van:	22	14	4
Pickup Truck/Utility Van w/Trl:	1	1	0
SUV:	47	28	11
SUV w/Trl:	1	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	3	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	7	2	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	3	0	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**189**	**102**	**28**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	95	98	28
Asleep at the Wheel:	6	0	0
Illness:	0	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	20	2	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	31	0	0
Driver Unfamilar with Area:	3	1	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	30	1	0
Total:	**189**	**102**	**28**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	182	101	28
Alcohol Involved:	4	1	0
RX, Medication, or Drugs Involved:	2	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**189**	**102**	**28**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	120	32	5
Slowing:	6	15	4
Stopped in Traffic:	1	47	15
Making Right Turn:	2	2	0
Making Left Turn:	7	2	0
Making U-Turn:	1	0	0
Passing:	2	1	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	3	3	4
Weaving:	2	0	0
Other:	45	0	0
Unknown:	0	0	0
Total:	**189**	**102**	**28**

Direction	Veh 1	Veh 2	Veh 3
North:	99	47	15
Northeast:	0	0	0
East:	6	1	0
Southeast:	0	0	0
South:	77	50	13
Southwest:	0	0	0
West:	6	4	0
Northwest:	0	0	0
Unknown:	1	0	0
Total:	**189**	**102**	**28**

ADT: 15,901 **Length:** 4.53

Project Information

Project Name: SH 52 / 95th Street

Project Description: Intersection Improvements

CDOT Region: 4 Project Def: 15861 County: Boulder

Location: SH 52 Mile Points: 3.16 Length: N/A

Schedule: Work Start Date: approx. 8/2007 Completion Date: approx. 2/2008

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history (1998 – 2002) showed a number of broadside and approach turn crashes.

Improvement Description: Between late 2007 and early 2008, the northbound and southbound pavement was widened. Additionally, northbound and southbound left-turn lanes were constructed and protected phasing was added. The cost of construction was $150,000.

The HSIP application anticipated that the following reductions in crashes might be realized by the improvement anticipated: northbound/southbound crashes – 35%. The initial benefit/cost ratio was estimated to be 2.52.

Summary and Findings

The analysis of safety before and after the intersection at SH 52 and 95th Street was reconstructed showed some reduction in the types of crashes that left-turn lane channelization and left-turn phasing is intended to mitigate. For this intersection, there were 19 total crashes (at intersection, intersection related) during the five-year period before the left turn lanes and signal phasing was installed (2002 – 2006). In the five years after construction (2009 – 2013), the number of crashes decreased slightly to 17. In addition, the number of injury crashes also diminished.

The northbound/southbound channelization and phasing improvements were directly responsible for decrease in the northbound and southbound crashes. During the before period, there was six northbound/southbound injury crashes and six property damage only crashes. The after period experienced two injury crashes of this type and two property damage only crashes.

The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 13.37 to one. The result is an improvement that was justified.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records shows a slight decrease in the number of crashes; the total number of crashes decreased from 19 during the five-year period (2002 to 2006) before the intersection was reconstructed (see **Table 1** and **Exhibit 1**) to 17 during the five-year after period (2009 to 2013) (see **Table 1** and **Exhibit 2**). The number of serious crashes showed a more significant decrease:

- Before (2002 – 2006) – 9 injury crashes with 16 injuries
- After (2009 – 2013) – 6 injury crashes with 7 injuries
- Reduction occurred predominantly in the N-S direction where improvements have been constructed.

Along with the decrease in severe crashes there was also a modest decrease in traffic volumes on SH 52A: 9,800 vehicles per day (vpd) estimated for the before period and 9,400 vpd in the after period. Even though there was a small reduction in traffic volume a small decrease was observed in crash rate in the after period.

- Before (2002 – 2006): 0.65 crashes per million entering vehicles (cpmev)
- After (2009 – 2013): 0.60 (cpmev)

Table 1 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
AADT	9,842 vpd / 6,200 vpd	9,351 vpd / 6,200 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**19**	**17**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	9 (16)	6 (7)
Property Damage Only	10	11
Crash Types: # (%) [significance]		
Rear End	8 (42.1%)	8 (47.1%)
Approach Turn	7 (36.8%) [99.44%]	5 (29.4%) [96.04%]
Broadside	2 (10.5%)	2 (11.8%)

Normally, the magnitude of safety problems on highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. However in the case the intersection of SH 52A with 95th Avenue, no SPF for this intersection configuration has been developed.

A more detailed review of the before and after crash record reveals that notable improvement in safety in the N/S direction can be attributed to the channelization and introduction of the left turn phase the northbound and southbound left-turns. **Table 2** shows a comparison of the crash type that is most directly affected by the intersection improvements: northbound/southbound vehicle crashes. The No Build After crashes were estimated using the change in the average daily traffic volumes found in **Table 1.**

Table 2 – Results of Northbound/Southbound Protected Left-Turns Crash Analyses

	Before	**After**	**No Build After**
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
Crash Types:			
NB/SB Crashes – Total	**12**	**4**	**12**
Fatal (fatalities)	0	0	0
Injury (injuries)	6 (10)	2 (2)	6 (10)
PDO	6	2	6
% Reduction in Total		66%	

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Exhibit 3** for the northbound/southbound crashes. The B/C ratio for decreasing the approach turn crashes is 13.37, showing that the improvement was justified.

Exhibit 3 – Benefit Cost Analysis – Northbound/Southbound Crashes

COLORADO Department of Transportation

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

06/26/2015

Job #: 20150626094633

Location: 52A **Begin:** 3.11 **End:** 3.21 **From:** 01/01/2002 **To:** 12/31/2006

Benefit Cost Ratio Calculations

Accidents			**Projected Accidents and Reduction Factors**			**Other Information**	
PDO:	6		Weighted PDO:	1.47	66% :ARF for PDO	Cost of PDO:	$ 9,300
INJ:	6	10 :Injured	Weighted INJ:	2.46	80% :ARF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	100% :ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	73% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance Cost:	$ 500

Cost: $ 150,000
From: 01/01/2002
To: 12/31/2006 Days: 1826

Benefit Cost Ratio: 13.37 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: LANES - ADD LEFT TURN, LANE WIDENING, PROTECTED PHASING
Special Notes: NORTHBOUND/SOUTHBOUND CRASHES

Colorado Department of Transportation
DiExSys™ Roadway Safety Systems
Detailed Summary of Crashes Report

Exhibit 1 *06/02/2015*

Job #: *20150602203255*

Location: 52A **Begin:** 3.11 **End:** 3.21 **From:** 01/01/2002 **To:** 12/31/2006

Severity

PDO:	10		
INJ:	9	16	:Injured
FAT:	0	0	:Killed
Total:	**19**		

Number of Vehicles

One Vehicle:	0
Two Vehicles:	17
Three or More:	2
Unknown:	0
Total:	**19**

Location

On Road:	19
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**19**

Lighting Conditions

Daylight:	11
Dawn or Dusk:	1
Dark - Lighted:	5
Dark - Unlighted:	1
Unknown:	1
Total:	**19**

Weather Conditions

None:	17
Rain:	1
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	1
Total:	**19**

Crash Rates

PDO:	5.56	*
INJ:	5.01	*
FAT:	0.00	**
Total:	**10.57**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	2	Embankment:	0
Head On:	0	Curb:	0
Rear End:	8	Delineator Post:	0
Sideswipe (Same):	0	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	7	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	1
Bridge Rail:	0	Total Other Objects:	1
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**19**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	19
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**19**

Road Description

At Intersection:	19
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**19**

Road Conditions

Dry:	17
Wet:	1
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	1
Total:	**19**

ADT: 9,842 **Length:** 0.10

Location: 52A **Begin:** 3.11 **End:** 3.21 **From:** 01/01/2002 **To:** 12/31/2006

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	12	15	2
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	4	2	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	0	0	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	2	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	1	2	0
Total:	**19**	**19**	**2**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	11	11	0
Slowing:	0	1	0
Stopped in Traffic:	0	7	2
Making Right Turn:	1	0	0
Making Left Turn:	7	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**19**	**19**	**2**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	13	17	2
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	2	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	2	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	1	0	0
Unknown:	1	2	0
Total:	**19**	**19**	**2**

Direction	Veh 1	Veh 2	Veh 3
North:	4	7	1
Northeast:	0	0	0
East:	4	3	1
Southeast:	0	0	0
South:	5	4	0
Southwest:	0	0	0
West:	6	5	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**19**	**19**	**2**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	17	19	2
Alcohol Involved:	2	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**19**	**19**	**2**

ADT: 9,842 **Length:** 0.10

Location: 52A **Begin:** 3.11 **End:** 3.21 **From:** 01/01/2009 **To:** 12/31/2013

Severity

PDO:	11		
INJ:	6	7	:Injured
FAT:	0	0	:Killed
Total:	**17**		

Number of Vehicles

One Vehicle:	1
Two Vehicles:	16
Three or More:	0
Unknown:	0
Total:	**17**

Location

On Road:	16
Off Road Left:	1
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**17**

Lighting Conditions

Daylight:	14
Dawn or Dusk:	0
Dark - Lighted:	3
Dark - Unlighted:	0
Unknown:	0
Total:	**17**

Weather Conditions

None:	13
Rain:	0
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	4
Total:	**17**

Crash Rates

PDO:	7.08	*
INJ:	3.86	*
FAT:	0.00	**
Total:	**10.94**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	2	Embankment:	1
Head On:	0	Curb:	0
Rear End:	8	Delineator Post:	0
Sideswipe (Same):	1	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	5	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**17**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	17
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**17**

Road Description

At Intersection:	9
At Driveway Access:	0
Intersection Related:	8
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**17**

Road Conditions

Dry:	17
Wet:	0
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**17**

ADT: 9,351 **Length:** 0.09

Location: 52A **Begin:** 3.11 **End:** 3.21 **From:** 01/01/2009 **To:** 12/31/2013

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	7	11	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	0	1	0
Pickup Truck/Utility Van w/Trl:	0	1	0
SUV:	9	2	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	0	0
School Bus < 15 People:	0	1	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**17**	**16**	**0**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	7	7	0
Slowing:	3	0	0
Stopped in Traffic:	0	8	0
Making Right Turn:	0	1	0
Making Left Turn:	5	0	0
Making U-Turn:	0	0	0
Passing:	2	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**17**	**16**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	0	3	0
Northeast:	0	0	0
East:	10	5	0
Southeast:	0	0	0
South:	2	1	0
Southwest:	0	0	0
West:	5	7	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**17**	**16**	**0**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	11	16	0
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	4	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	1	0	0
Total:	**17**	**16**	**0**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	16	16	0
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**17**	**16**	**0**

ADT: 9,351 **Length:** 0.09

Project Information

Project Name: US 34 / 11th Avenue

Project Description: Intersection Improvements

CDOT Region: 4 Project Def: 15862 County: Weld

Location: SH 34 Mile Points: 112.23 Length: N/A

Schedule: Work Start Date: approx. 9/2007 Completion Date: approx. 4/2008

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history showed a higher than expected number of rear-end type crashes. The traffic signal is over 20 years old with 8" yellow and green signal heads and no back plates, which does not meet CDOT standards.

Improvement Description: In late 2007 and early 2008, the traffic signal was upgraded to 12" LED signal heads with back-plates. Additionally, signal heads were installed on new poles and mast arms. Video detection was installed and the street lighting was upgraded. The cost of construction was $462,403.

The HSIP application anticipated that four crash types would be impacted by this improvement: rear-end, approach turn, broadside, and pedestrian type crashes. It was anticipated that there would be a 15% crash reduction for these crash types. The initial benefit/cost ratio was estimated to be 2.03.

Summary and Findings

The analysis of safety before and after the signal was upgraded at US 34 and 11th Avenue showed significant safety improvements. For this intersection, there were 106 total crashes during the five-year period before the upgrades (2001 – 2005). In the five years after construction (2009 – 2013), the number of crashes was decreased to 100. Since daily volumes continued to increase throughout the study period, the crash rate was reduced. In addition, the number of injury and fatal crashes also diminished.

The signal upgrade was responsible for decreases in the number and severity of rear end, approach turn, broadside, and pedestrian crashes. During the before period, there was one fatal pedestrian crash and a number of injury crashes. The after period experienced no fatal crashes and a reduction in the number of injury crashes.

The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 9.69 to one. The result is an improvement that was justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 104 during the five-year period (2001 to 2005) before the signal was upgraded (see **Table 1** and **Exhibit 1**) to 100 during the five-year after period (2009 to 2013) (see **Table 1** and **Exhibit 2**). The number of serious crashes showed a more significant decrease:

- Before (2001 – 2005) – 1 fatal crash with 1 fatality (pedestrian) and 28 injury crashes with 41 injuries
- After (2009 – 2013) – no fatal crashes and 18 injury crashes with 26 injuries

This decrease in severe crashes occurred in spite of a modest increase in traffic volumes at the intersection. This combination of increased traffic and decreased number of crashes also resulted in a decrease in the accident rates.

Table 1 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2001 to 12/31/2005 (5 yr.)	1/1/2009to 12/31/2013 (5 yr.)
AADT (US 34/11th Ave)	36,000/13,000 vpd	38,000/16,500 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**104**	**100**
Fatal Crashes (Fatalities)	1 (1)	0
Injury Crashes (Injuries)	28 (41)	18 (26)
Property Damage Only	75	82
Crash Types: # (%) [significance]		
Rear End	42 (40.4%)	54 (54.0%) [96.84%]
Approach Turn	21 (20.2%)	15 (15.0%)
Sideswipe Same	15 (14.4%) [99.37%]	12 (12.0%)
Broadside	14 (13.5%)	12 (12.0%)
Fixed Object	3 (2.9%)	6 (6.0%)
Pedestrian	1 (1.0%)	1 (1.0%)

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. A SPF reflects the complex relationship between exposure (measured in ADT) and the crash count for a section of roadway measured in crashes per mile per year (CPMPY) or for an intersection, measured in crashes per year. The SPF models provide an estimate for the expected crash frequency and severity for a range of ADT among similar facilities. This allows for an assessment of the magnitude of the safety problem from a frequency standpoint.

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be 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

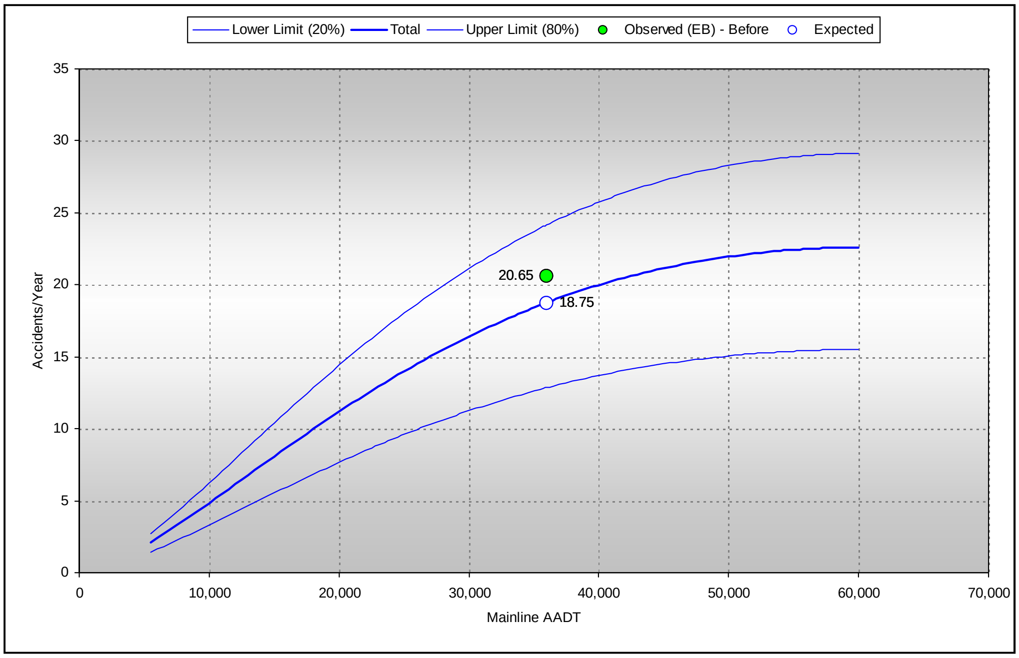
LOSS boundaries are calibrated by computing the 20^{th} and the 80^{th} percentiles using the Gamma Distribution Probability Density Function. Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT increases. LOSS reflects how a segment of roadway or intersection is performing in regard to its expected crash frequency at a specific level of ADT.

SPF plots for both total crashes (see **Figures 1** and **3**) and for fatal and injury crashes (see **Figure 2** and **4**) also reflect this improvement in the crash record. LOSS improved to the LOSS II range for total crashes in the after period from LOSS III, and Injury/Fatal crashes improved to LOSS I in the after period (see **Table 2**), due to the decrease in both types of severe crashes.

A more detailed review of the before and after crash record reveals that a significant improvement in safety can be attributed to the upgrade of the signal. **Table 3** shows a comparison of four types of crashes that are most directly affected by the improvement: rear end, approach turn, broadside, and pedestrian. The No Build After crashes were estimated using the increase in the median of the SPF for total crashes found in **Table 2** (increase is 1.17 = 21.85/18.75). **Figures 3** and **4** also show that the number of crashes after construction was much better than it could have been without the project.

Figure 1 – SPF for Total Crashes - Before

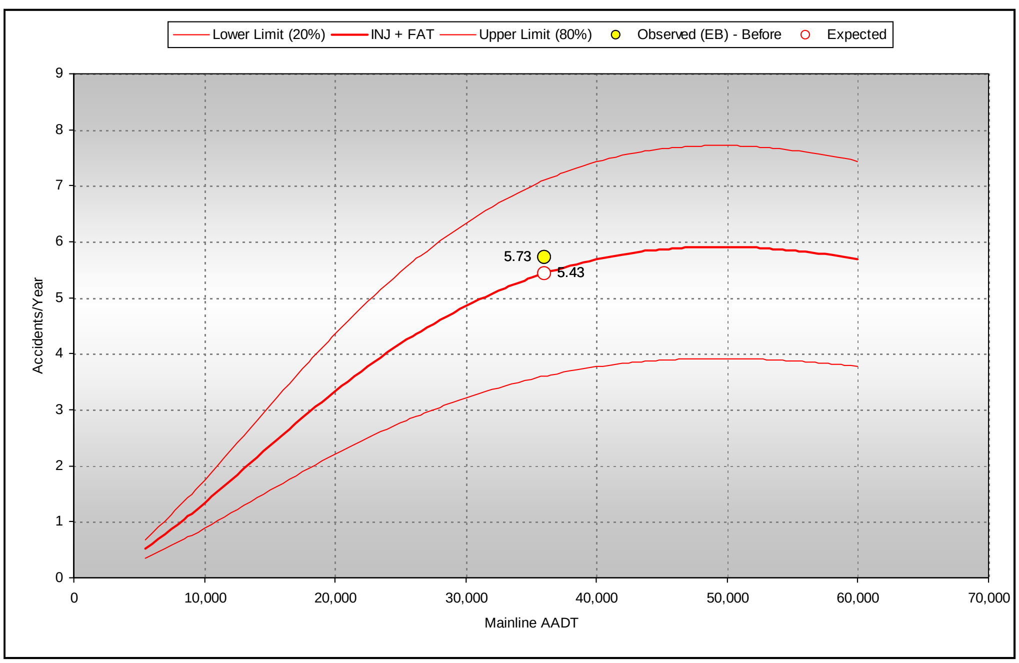
US 34 / 11th Avenue
2001 to 2005



Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Signalized 4-Leg Intersection

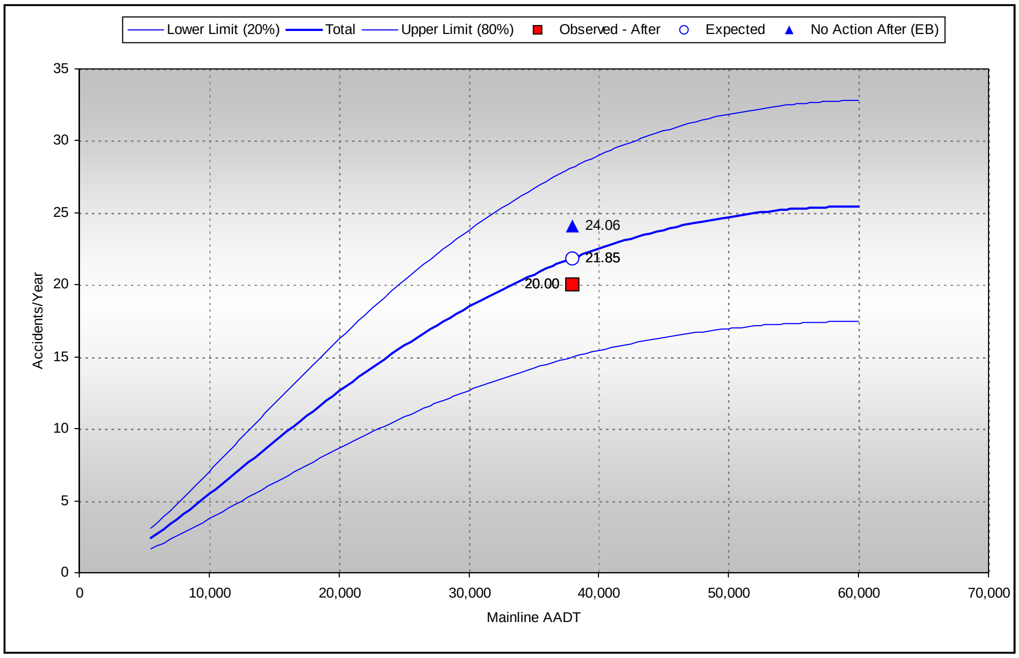
Figure 2 – SPF for Injury and Fatal Crashes - Before

US 34 / 11th Avenue
2001 to 2005



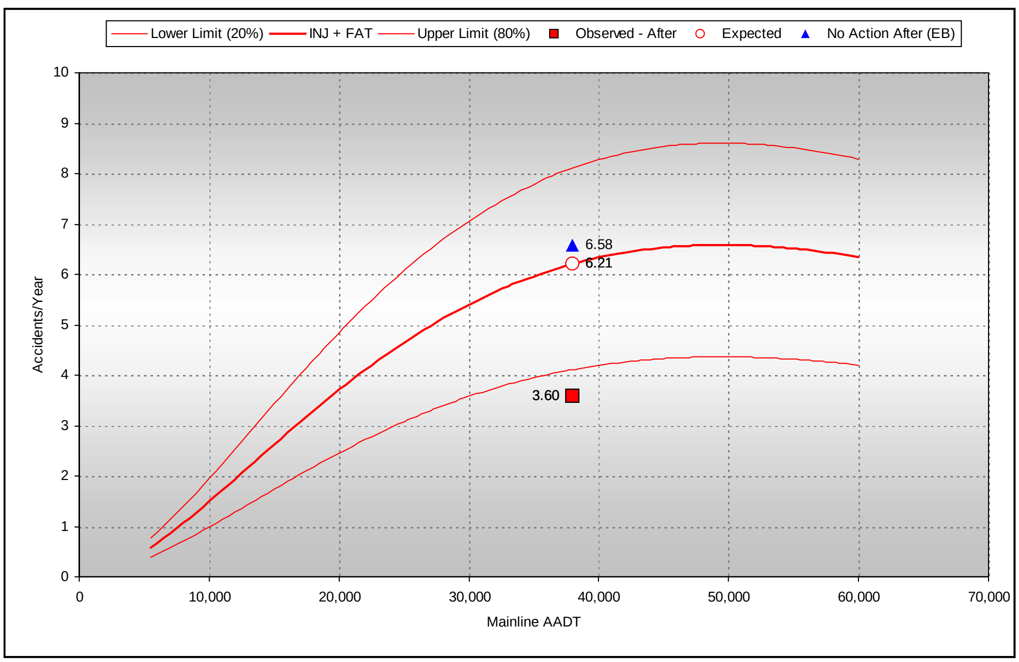
Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 3 – SPF for Total Crashes - After
US 34 / 11th Avenue
2009 to 2013



Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 3 – SPF for Injury and Fatal Crashes - After
US 34 / 11th Avenue
2009 to 2013



Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Signalized 4-Leg Intersection

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS III	LOSS II	LOSS III
CPY	20.65	20.00	24.06
Mean CPY	18.75	21.85	21.85
Proportion of Mean	1.10	0.92	1.10
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS I	LOSS III
CPY	5.73	3.60	6.58
Mean CPY	5.43	6.21	6.21
Proportion of Mean	1.06	0.58	10.6

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. Because there was an increase in the number of PDO crashes, the cost of these crashes was added to the cost of construction in the analysis. The results of the B/C analysis are shown in **Exhibit 3** for the impacted crash types. As shown, the B/C ratio for rear end, approach turn, broadside, and pedestrian crashes is 9.69, showing that the improvement was justified.

Table 3 – Results of Crash Analyses

	Before	**After**	**No Build After**
Time Period:	1/1/2001 to 12/31/2005 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
Crash Types:			
Rear Ends – Total	**42**	**54**	**49**
Injury (injuries)	16 (25)	6 (10)	19 (29)
PDO	26	48	30
% Reduction in Total		-10%	
Approach Turns– Total	**21**	**15**	**25**
Injury (injuries)	5 (5)	4 (8)	6 (6)
PDO	16	11	19
% Reduction in Total		40%	
Broadsides– Total	**14**	**12**	**17**
Injury (injuries)	4 (7)	5 (5)	5 (8)
PDO	10	7	12
% Reduction in Total		29%	
Pedestrian – Total	**1**	**1**	**3**
Fatal (fatalities)	1 (1)	0	1 (1)
Injury (injuries)	0	1 (1)	0
PDO	0	0	2
% Reduction in Total		66%	

Exhibit 3 – Benefit Cost Analysis – Rear End, Approach Turn, Broadside, Pedestrian Crashes Only

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

06/26/2015

Job #: 20150626105043

Location: 34A **Begin:** 111.95 **End:** 111.99 **From:** 01/01/2001 **To:** 12/31/2005

Benefit Cost Ratio Calculations

Accidents				Projected Accidents and Reduction Factors				Other Information	
PDO:	61			Weighted PDO:	13.39	0%	:ARF for PDO	Cost of PDO:	$ 9,300
INJ:	30	43	:Injured	Weighted INJ:	9.44	44%	:ARF for INJ	Cost of INJ:	$ 80,700
FAT:	1	1	:Killed	Weighted FAT:	0.22	100%	:ARF for FAT	Cost of FAT:	$ 1,500,000
				B/C Weighted Year Factor:	5.00	15%	:Weighted ARF	Interest Rate:	5%
								ADT Growth Factor:	2.0%
								Service Life:	10
								Capital Recovery Factor:	0.129
								Annual Maintenance Cost:	$ 500

Cost: $ 525,403
From: 01/01/2001
To: 12/31/2005 Days: 1826

Benefit Cost Ratio: 9.69 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SIGNALS - UPGRADE SIGNALS (GENERAL)
Special Notes: Add the cost of 10 PDO crashes (10*$9,300) to the cost of construction ($432,403)

Location: 34A **Begin:** 111.95 **End:** 111.99 **From:** 01/01/2001 **To:** 12/31/2005

Severity

PDO:	75		
INJ:	28	41	:Injured
FAT:	1	1	:Killed
Total:	**104**		

Number of Vehicles

One Vehicle:	4
Two Vehicles:	89
Three or More:	11
Unknown:	0
Total:	**104**

Location

On Road:	102
Off Road Left:	1
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**104**

Lighting Conditions

Daylight:	63
Dawn or Dusk:	3
Dark - Lighted:	34
Dark - Unlighted:	2
Unknown:	2
Total:	**104**

Weather Conditions

None:	97
Rain:	3
Snow/Sleet/Hail:	1
Fog:	1
Dust:	0
Wind:	0
Unknown:	2
Total:	**104**

Crash Rates

PDO:	34.89	*
INJ:	13.02	*
FAT:	46.51	**
Total:	**48.37**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	2	Culvert/Headwall:	0
Broadside:	14	Embankment:	0
Head On:	1	Curb:	0
Rear End:	42	Delineator Post:	1
Sideswipe (Same):	15	Fence:	0
Sideswipe (Opposite):	1	Tree:	0
Approach Turn:	21	Large Boulders or Rocks:	0
Overtaking Turn:	1	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	1	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	3
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	1
Bridge Rail:	0	Total Other Objects:	1
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**104**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	104
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**104**

Road Description

At Intersection:	78
At Driveway Access:	0
Intersection Related:	26
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**104**

Road Conditions

Dry:	94
Wet:	5
Muddy:	0
Snowy:	0
Icy:	1
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	3
Total:	**104**

ADT: 30,189 **Length:** 0.03

Location: 34A **Begin:** 111.95 **End:** 111.99 **From:** 01/01/2001 **To:** 12/31/2005

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	57	67	7
Passenger Car/Van w/Trl:	0	1	0
Pickup Truck/Utility Van:	34	23	2
Pickup Truck/Utility Van w/Trl:	1	2	1
SUV:	0	0	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	2	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	1	0
Motorhome:	0	0	0
Motorcycle:	0	2	0
Bicycle:	0	1	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	6	1	0
Other:	1	0	0
Unknown:	3	2	1
Total:	**104**	**100**	**11**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	57	44	2
Slowing:	7	5	0
Stopped in Traffic:	1	31	7
Making Right Turn:	5	1	0
Making Left Turn:	19	13	1
Making U-Turn:	0	0	0
Passing:	1	1	0
Backing:	0	0	0
Enter/Leave Parked Position:	1	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	9	1	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	2	2	0
Unknown:	2	2	1
Total:	**104**	**100**	**11**

Direction	Veh 1	Veh 2	Veh 3
North:	18	16	0
Northeast:	0	0	0
East:	41	35	5
Southeast:	0	0	0
South:	19	23	2
Southwest:	0	0	0
West:	24	26	1
Northwest:	1	0	0
Unknown:	1	0	3
Total:	**104**	**100**	**11**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	54	75	7
Asleep at the Wheel:	0	1	0
Illness:	1	0	0
Distracted by Passenger:	0	1	0
Driver Inexperience:	9	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	12	1	0
Driver Unfamilar with Area:	3	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	25	22	4
Total:	**104**	**100**	**11**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	97	100	11
Alcohol Involved:	7	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**104**	**100**	**11**

ADT: 30,189 **Length:** 0.03

Location: 34A **Begin:** 112.21 **End:** 112.25 **From:** 01/01/2009 **To:** 12/31/2013

Severity

PDO:	82	
INJ:	18	26 :Injured
FAT:	0	0 :Killed
Total:	**100**	

Number of Vehicles

One Vehicle:	6
Two Vehicles:	83
Three or More:	11
Unknown:	0
Total:	**100**

Location

On Road:	94
Off Road Left:	3
Off Road Right:	3
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**100**

Lighting Conditions

Daylight:	72
Dawn or Dusk:	8
Dark - Lighted:	19
Dark - Unlighted:	1
Unknown:	0
Total:	**100**

Weather Conditions

None:	90
Rain:	4
Snow/Sleet/Hail:	5
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**100**

Crash Rates

PDO:	34.98 *
INJ:	7.68 *
FAT:	0.00 **
Total:	**42.66** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	1	Culvert/Headwall:	0
Broadside:	12	Embankment:	0
Head On:	1	Curb:	1
Rear End:	54	Delineator Post:	0
Sideswipe (Same):	9	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	15	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	2	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	6
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	1	Road Maintenance Equipment:	0
Sign:	4	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**100**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	100
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**100**

Road Description

At Intersection:	67
At Driveway Access:	0
Intersection Related:	33
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**100**

Road Conditions

Dry:	86
Wet:	4
Muddy:	0
Snowy:	2
Icy:	7
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**100**

ADT: 32,092 **Length:** 0.04

Location: 34A **Begin:** 112.21 **End:** 112.25 **From:** 01/01/2009 **To:** 12/31/2013

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	55	56	7
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	20	11	0
Pickup Truck/Utility Van w/Trl:	2	1	0
SUV:	12	24	2
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	2	0	0
School Bus < 15 People:	1	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	1	0
Bicycle:	2	0	1
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	5	1	1
Other:	1	0	0
Unknown:	0	0	0
Total:	**100**	**94**	**11**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	52	86	11
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	12	4	0
Driver Fatigue:	3	1	0
Driver Preoccupied:	11	0	0
Driver Unfamilar with Area:	0	1	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	20	2	0
Total:	**100**	**94**	**11**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	96	94	11
Alcohol Involved:	4	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**100**	**94**	**11**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	56	41	3
Slowing:	6	10	0
Stopped in Traffic:	2	29	8
Making Right Turn:	6	5	0
Making Left Turn:	17	7	0
Making U-Turn:	1	0	0
Passing:	2	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	5	2	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	5	0	0
Unknown:	0	0	0
Total:	**100**	**94**	**11**

Direction	Veh 1	Veh 2	Veh 3
North:	19	14	4
Northeast:	0	0	0
East:	36	32	5
Southeast:	0	0	0
South:	17	20	0
Southwest:	0	0	0
West:	28	28	2
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**100**	**94**	**11**

ADT: 32,092 **Length:** 0.04

Project Information

Project Name: New Guardrail Installation between Marble and Redstone

Project Description: Install guardrail along SH 133 at select locations

CDOT Region: 3 | Project Def: 15900 | County: Gunnison/Pitkin

Location: SH 133 | Mile Points: 46.0 to 51.5 | Length: 5.50 miles

Schedule: Work Start Date: 7/30/2007 | Completion Date: 1/28/2008

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history showed a high percentage of severe run-of-the-road type crashes where the vehicle either overturned or struck a formidable object. Combining this with the fact that there have been no injury crashes involving guardrail, suggests that more guardrail along this stretch of highway might significantly reduce the probability of severe crashes. This segment of road has many curves as it follows the Crystal River northward. Crash statistics showed the following number and severity of total crashes (and off road) in the 4 year period between 1/1/2001 and 12/31/2003: PDO – 22 (10), INJ – 7 (5), and FAT 1 (1).

Improvement Description: In 2007 and early 2008, guardrail was installed on the outside of select curves for drop-off protection. The cost of construction was $703,852.

The HSIP application anticipated that off-road crash types would be impacted by this improvement. The following reductions in crashes were anticipated: fatal crashes – 60%, injury crashes – 40%, and property damage only – 0%. The initial benefit/cost ratio was estimated to be 4.89.

Summary and Findings

The analysis of safety before and after the guardrail was installed along SH 133 showed significant improvement in safety. For this segment of highway, there were 27 total crashes (non-intersection / mainline) during the five-year period before the rail was installed (2002 – 2006). In the five years after construction (2009 – 2013), the number of crashes was decreased to 13. In addition, the number of injury and fatal crashes also diminished. During the before period, there was three fatal crashes (overturning, embankment, and a large rock) and a number of injury crashes. The after period experienced one fatal crash (overturning) and a reduction in the number of injury crashes. All of the fatal crashes involved vehicles leaving the road on the right side.

An unusual circumstance has occurred during the after period in that none of the crashes involved hitting the guardrail as either the primary or secondary (or tertiary) occurrence. Since this project is the only significant change in this section of SH 133, the additional guardrail must improve safety in more ways than just creating a physical barrier to more significant hazards. New guardrail (and any related signing) likely increases curve visibility and psychological and cognitive awareness for drivers who may be more cautious in maneuvering through the curves.

The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 21.54 to one, showing that the improvement was certainly justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a large decrease in the number of crashes; the total number of crashes decreased from 27 during the five-year period (2002 to 2006) before the guardrail was installed (see **Table 1** and **Exhibit 1**) to 13 during the five-year after period (2009 to 2013) (see **Table 1** and **Exhibit 2**). The number of serious crashes also showed a significant decrease:

- Before (2002 – 2006) – 3 fatal crashes with 4 fatalities (overturning, embankment, and large boulder) and 7 injury crashes with 8 injuries
- After (2009 – 2013) – 1 fatal crashes with 1 fatalities (overturning – alcohol involved) and 1 injury crash with 1 injury

This decrease in severe crashes occurred along with an increase in traffic volumes on SH 133: 1,520 vehicles per day (vpd) during the before period and 1,810 vpd in the after period. This combination of increased traffic and decreased number of crashes resulted in a decrease in the accident rates:

- Before (2002 – 2006): 1.75 crashes per million vehicle miles of travel (cpmvmt)
- After (2009 – 2013): 0.71 (cpmvmt)

Table 1 – SH 133 (MP 46.0 to MP 51.5) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
AADT	1,520 vpd	1,810 vpd
Filters:	Mainline Only/Non-Intersection	Mainline Only/Non-Intersection
Total Crashes	**27**	**13**
Fatal Crashes (Fatalities)	3 (4)	1 (1)
Injury Crashes (Injuries)	7 (8)	1 (1)
Property Damage Only	17	11
Crash Types: # (%) [significance]		
Fixed Objects	17 (63.0%) [99.81%]	9 (69.2%) [100.00%]
Wild Animal	5 (18.5%)	2 (15.4%)
Overturning	3 (11.1%)	2 (15.4%)
Fixed Object Crashes: # (%) [significance]		
Large Boulders/Rocks	5 (29.4%)	7 (77.8%)
Embankment	4 (23.5%)	1 (11.1%)
Tree	4 (23.5%)	1 (11.1%)
Guardrail	2 (11.8%)	0

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. A SPF reflects the complex relationship between exposure (measured in ADT) and the crash count for a section of roadway measured in crashes per mile per year (CPMPY) or for an intersection,

measured in crashes per year. The SPF models provide an estimate for the expected crash frequency and severity for a range of ADT among similar facilities. This allows for an assessment of the magnitude of the safety problem from a frequency standpoint.

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be 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

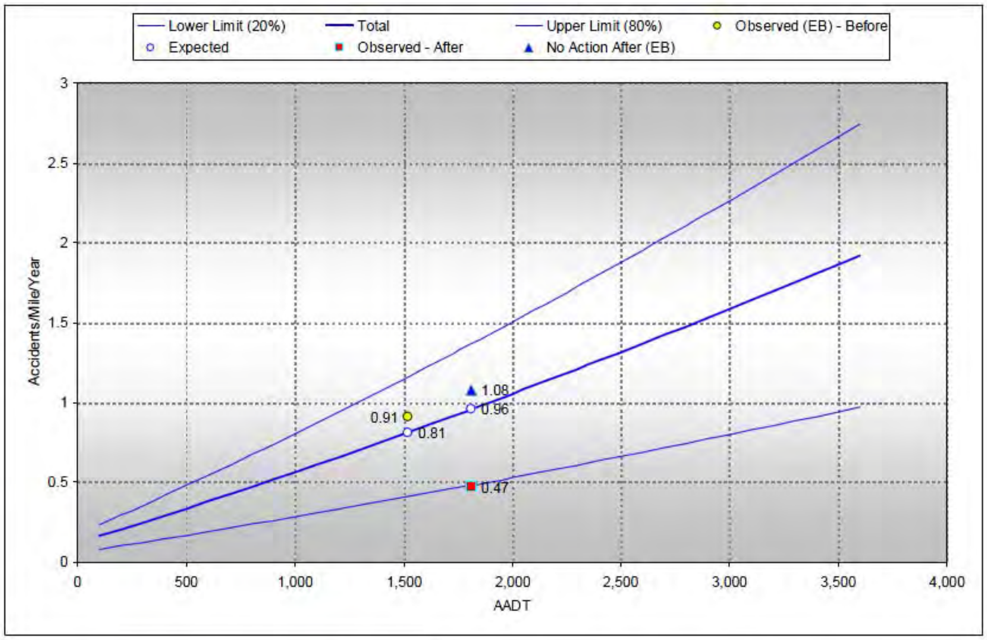
LOSS boundaries are calibrated by computing the 20^{th} and the 80^{th} percentiles using the Gamma Distribution Probability Density Function. Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT increases. LOSS reflects how a segment of roadway or intersection is performing in regard to its expected crash frequency at a specific level of ADT.

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect this improvement in the crash record. LOSS for both Total and Injury/Fatal crashes improved from LOSS III during the before period to the LOSS I range in the after period (see **Table 2**). The No Build After crashes were estimated using the increase in the median of the SPF for total crashes (1.12) and for injury/fatal crashes (1.03) found in **Table 2**.

A more detailed review of the before and after crash record (see **Table 3**) reveals that this pattern of significant improvement in safety also occurred for the types of crashes that are most directly affected by the guardrail: off-road right and off-road left. **Table 3** shows that poor roadway conditions (snowy/icy/slushy) are a contributing factor in more than half of these crashes in both the before and after periods. For the No Build After scenario, the same SPF increase factors were used – PDO (Total SPF change = 1.12) and Injury/Fatal (SPF change = 1.03). The unusual circumstance during the after period is that none of the crashes involved hitting the guardrail as either the primary or secondary (or tertiary) occurrence. Since this project is the only significant change in this section of SH 133, the additional guardrail must improve safety in more ways than just creating a physical barrier to more significant hazards. New guardrail (and any related signing and reflectors) likely increases curve visibility and delineation as well as psychological and cognitive awareness for drivers who may then be more cautious in maneuvering through the curves.

Figure 1 - SPF for Total Crashes

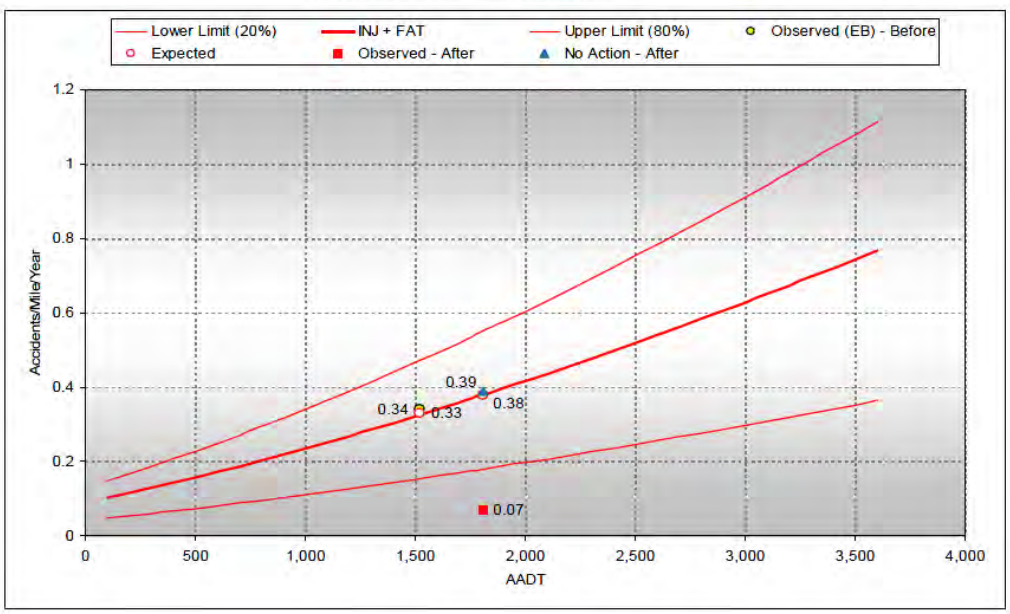
SH 133 (MP 46.0 to MP 51.5)
Before: 2002 to 2006 After: 2009 to 2013



Note: Safety Performance Function (SPF) Model: Colorado - Rural Mountainous 2-Lane Undivided Highway (2002)

Figure 2 - SPF for Injury and Fatal Crashes

SH 133 (MP 46.0 to MP 51.5)
Before: 2002 to 2006 After: 2009 to 2013



Note: Safety Performance Function (SPF) Model: Colorado - Rural Mountainous 2-Lane Undivided Highway (2002)

Table 2 – SH 133 (MP 46.0 to MP 51.5) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Rural, Mountainous, 2-Lane, Undivided Highway	Rural, Mountainous, 2-Lane, Undivided Highway	Rural, Mountainous, 2-Lane, Undivided Highway
AADT	1,520 vpd	1,810 vpd	1,810 vpd
Total Crashes:			
LOSS	LOSS III	LOSS I	LOSS III
CPMPY	0.91	0.47	1.08
Mean CPMPY	0.81	0.96	0.96
Proportion of Mean	1.12	0.49	1.12
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS I	LOSS III
CPMPY	0.34	0.07	0.39
Mean CPMPY	0.33	0.38	0.38
Proportion of Mean	1.03	0.18	1.03

Table 3 – SH 133 (MP 46.0 to MP 51.5) - Results of Off-Road Right and Left Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
AADT	1,520 vpd	1,810 vpd	1,810 vpd
Crash Types:			
Off-Road Right & Left –	**19**	**7**	**21**
Fatal (fatalities)	3 (4)	1 (1)	3 (4)
Injury (injuries)	6 (6)	0	6(6)
PDO	10	6	12
% Reduction in Total – FAT / INJ / PDO		75% / 100% / 50%	
Road Conditions	**19**	**7**	**n/a**
Dry	6	2	n/a
Wet	2	0	n/a
Snowy/Icy/Slushy	11	5	n/a

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Exhibit 3** for off-road right and left crashes. The B/C ratio for the project is 21.54, showing that the improvement was certainly justified.

Exhibit 3 – Benefit Cost Analysis – Off-Road Right Crashes Only

COLORADO Department of Transportation

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

06/25/2015

Job #: 20150625092132

Location: 133A **Begin:** 46.00 **End:** 51.50 **From:** 01/01/2002 **To:** 12/31/2006

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	12		Weighted PDO:	2.95	50% :ARF for PDO	Cost of PDO:	$ 9,300
INJ:	6	6 :Injured	Weighted INJ:	1.47	100% :ARF for INJ	Cost of INJ:	$ 80,700
FAT:	3	4 :Killed	Weighted FAT:	0.98	75% :ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	67% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
		Cost: $ 703,852				Service Life:	20
		From: 01/01/2009				Capital Recovery Factor:	0.080
		To: 12/31/2013	Days: 1826			Annual Maintenance Cost:	$ 1,000

Benefit Cost Ratio: 21.54 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Guardrail Installation - Off-Road Right & Left Crashes Only
Special Notes: Latest NSC Crash Costs

Colorado Department of Transportation
DiExSys™ Roadway Safety Systems
Detailed Summary of Crashes Report

Exhibit 1 *06/24/2015*

Job #: 20150624111126

Location: 133A **Begin:** 46.00 **End:** 51.50 **From:**01/01/2002 **To:**12/31/2006

Filters set for Mainline only, non-intersection

Severity

PDO:	17		
INJ:	7	8	:Injured
FAT:	3	4	:Killed
Total:	**27**		

Number of Vehicles

One Vehicle:	26
Two Vehicles:	0
Three or More:	1
Unknown:	0
Total:	**27**

Location

On Road:	8
Off Road Left:	7
Off Road Right:	12
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**27**

Lighting Conditions

Daylight:	17
Dawn or Dusk:	1
Dark - Lighted:	0
Dark - Unlighted:	9
Unknown:	0
Total:	**27**

Weather Conditions

None:	19
Rain:	1
Snow/Sleet/Hail:	7
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**27**

Crash Rates

PDO:	1.10 *	* MVMT
INJ:	0.45 *	** 100 MVMT
FAT:	19.49 **	**Total:** **1.75** *

Crash Type

Overturning:	3	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	4
Head On:	0	Curb:	0
Rear End:	0	Delineator Post:	1
Sideswipe (Same):	0	Fence:	1
Sideswipe (Opposite):	0	Tree:	4
Approach Turn:	0	Large Boulders or Rocks:	5
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	17
Wild Animal:	5	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	1
Bridge Rail:	0	Total Other Objects:	1
Guard Rail:	2	Unknown:	0
Cable Rail:	0	**Total:**	**27**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	27
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**27**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	27
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**27**

Road Conditions

Dry:	14
Wet:	2
Muddy:	0
Snowy:	3
Icy:	7
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**27**

ADT: 1,521 **Length:** 5.54

Location: 133A **Begin:** 46.00 **End:** 51.50 **From:** 01/01/2002 **To:** 12/31/2006

Filters set for Mainline only, non-intersection

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	17	0	1
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	6	0	0
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	0	0	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	2	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	0	0
Unknown:	0	1	0
Total:	**27**	**1**	**1**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	19	0	1
Asleep at the Wheel:	2	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	3	0	0
Driver Unfamilar with Area:	2	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	0	1	0
Total:	**27**	**1**	**1**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	27	1	1
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**27**	**1**	**1**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	21	1	1
Slowing:	0	0	0
Stopped in Traffic:	0	0	0
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	1	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	3	0	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	1	0	0
Total:	**27**	**1**	**1**

Direction	Veh 1	Veh 2	Veh 3
North:	13	1	1
Northeast:	0	0	0
East:	0	0	0
Southeast:	0	0	0
South:	12	0	0
Southwest:	0	0	0
West:	1	0	0
Northwest:	0	0	0
Unknown:	1	0	0
Total:	**27**	**1**	**1**

ADT: 1,521 **Length:** 5.54

Location: 133A **Begin:** 46.00 **End:** 51.50 **From:** 01/01/2009 **To:** 12/31/2013

Filters set for Mainline only, non-intersection

Severity

PDO:	11	
INJ:	1	1 :Injured
FAT:	1	1 :Killed
Total:	**13**	

Number of Vehicles

One Vehicle:	11
Two Vehicles:	2
Three or More:	0
Unknown:	0
Total:	**13**

Location

On Road:	6
Off Road Left:	4
Off Road Right:	3
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**13**

Lighting Conditions

Daylight:	7
Dawn or Dusk:	1
Dark - Lighted:	0
Dark - Unlighted:	5
Unknown:	0
Total:	**13**

Weather Conditions

None:	9
Rain:	0
Snow/Sleet/Hail:	4
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**13**

Crash Rates

PDO:	0.60 *	* MVMT
INJ:	0.05 *	** 100 MVMT
FAT:	5.45 **	**Total: 0.71** *

Crash Type

Overturning:	2	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	1
Head On:	0	Curb:	0
Rear End:	0	Delineator Post:	0
Sideswipe (Same):	0	Fence:	0
Sideswipe (Opposite):	0	Tree:	1
Approach Turn:	0	Large Boulders or Rocks:	7
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	9
Wild Animal:	2	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**13**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	13
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**13**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	13
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**13**

Road Conditions

Dry:	7
Wet:	0
Muddy:	0
Snowy:	1
Icy:	4
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**13**

ADT: 1,810 **Length:** 5.54

Location: 133A **Begin:** 46.00 **End:** 51.50 **From:** 01/01/2009 **To:** 12/31/2013

Filters set for Mainline only, non-intersection

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	3	0	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	6	0	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	1	2	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	2	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**13**	**2**	**0**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	7	2	0
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	2	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	1	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	3	0	0
Total:	**13**	**2**	**0**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	12	2	0
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**13**	**2**	**0**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	10	1	0
Slowing:	0	0	0
Stopped in Traffic:	0	0	0
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	1	0
Weaving:	1	0	0
Other:	2	0	0
Unknown:	0	0	0
Total:	**13**	**2**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	8	2	0
Northeast:	0	0	0
East:	0	0	0
Southeast:	0	0	0
South:	5	0	0
Southwest:	0	0	0
West:	0	0	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**13**	**2**	**0**

ADT: 1,810 **Length:** 5.54

Project Information

Project Name: US 50 / Purcell Boulevard

Project Description: Turn lanes, upgrade signal, signal timing

CDOT Region: 2 Project Def: 16005 County: Pueblo

Location: US 50 Mile Points: 309.78 Length: N/A

Schedule: Work Start Date: 7/11/2007 Completion Date: 11/13/2007

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history showed a higher than expected number of rear-end type crashes. This is due to a capacity problem which is caused because the intersection has to run split phase timing due to geometry problems.

Improvement Description: In 2007, the intersection was widened to construct dual left-turn lanes, two through lanes, and a right turn lane on Purcell. This corrected the geometry problem so the intersection no longer needed to run split phase timing. The cost of construction was $1,302,499.

The HSIP application anticipated that four crash types would be impacted by this improvement: rear-end, approach turn, broadside, and pedestrian type crashes. It was anticipated that there would be a 35% crash reduction for these crash types. The initial benefit/cost ratio was estimated to be 1.77.

Summary and Findings

The analysis of safety before and after the geometry and signal was upgraded at US 50 and Purcell Boulevard showed safety improvements. For this intersection, there were 109 total crashes during the five-year period before the upgrades (2002 – 2006). In the five years after construction (2008 – 2012), the number of crashes was decreased to 87. Since daily volumes continued to increase throughout the study period, the crash rate was reduced. In addition, the number of injuries also diminished although there was an additional fatality in the after period.

The signal and geometry upgrade was responsible for decreases in the number and severity of rear end, approach turn, and broadside. The ratio of benefits and cost for this project shows that benefits were less than costs by a ratio of 0.74 to one. However, this B/C analysis includes a tragic but random event that was totally unrelated to the signal or modified intersection geometry. Removing the fatality gives a B/C ratio is 4.00, showing that the improvement was likely justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 109 during the five-year period (2002 to 2006) before the signal was upgraded (see **Table 1** and **Exhibit 1**) to 87 during the five-year after period (2008 to 2012) (see **Table 1** and **Exhibit 2**). The number of serious crashes showed only a slight decrease, although the number of injuries decreased significantly:

- Before (2002 – 2006) – no fatal crashes and 35 injury crashes with 58 injuries
- After (2008 – 2012) – 1 fatal crash with 1 fatality (rear-end) and 30 injury crashes with 43 injuries

The fatal crash in the after period occurred in unusual circumstances. An eastbound vehicle was stopped at a green light for a southbound fire truck traveling with lights and sirens. A second eastbound vehicle did not stop and hit the stopped vehicle at a high speed in a rear-end type crash. This decrease in injuries occurred in spite of a modest increase in traffic volumes at the intersection.

Table 1 - Results of Overall Crash Analyses

SH50A, MP 309.76-309.80	Before	After
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)
AADT (SH 50/Purcell Blvd)	29,131/16,500 vpd	30,488/16,500 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**109**	**87**
Fatal Crashes (Fatalities)	0	1 (1)
Injury Crashes (Injuries)	32 (58)	30 (43)
Property Damage Only	77	56
Crash Types: # (%) [significance]		
Rear End	84 (77.1%) [100.00%]	63 (72.4%) [100.00%]
Broadside	11 (10.1%)	6 (6.9%)
Sideswipe Same	8 (7.3%)	4 (4.6%)
Approach Turn	1 (0.9%)	9 (10.3%)

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. A SPF reflects the complex relationship between exposure (measured in ADT) and the crash count for a section of roadway measured in crashes per mile per year (CPMPY) or for an intersection, measured in crashes per year. The SPF models provide an estimate for the expected crash frequency and severity for a range of ADT among similar facilities. This allows for an assessment of the magnitude of the safety problem from a frequency standpoint.

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be 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

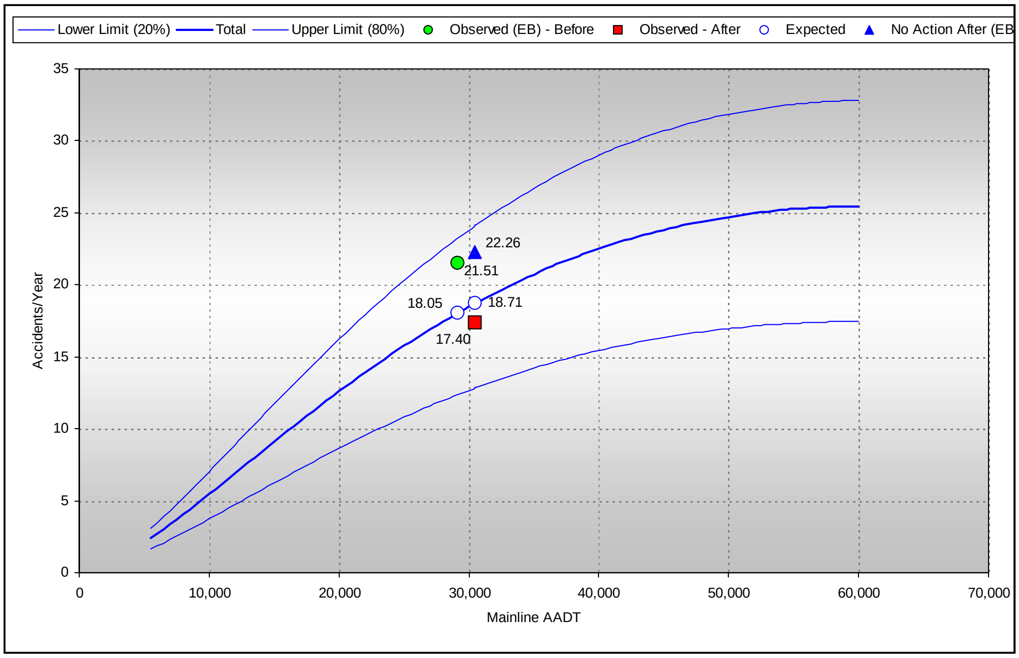
LOSS boundaries are calibrated by computing the 20^{th} and the 80^{th} percentiles using the Gamma Distribution Probability Density Function. Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT increases. LOSS reflects how a segment of roadway or intersection is performing in regard to its expected crash frequency at a specific level of ADT.

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect this improvement in the crash record. LOSS improved to the LOSS II range from LOSS III for total crashes and remained within the LOSS III range for Injury/Fatal crashes in the after period (see **Table 2**).

Figure 1 – SPF for Total Crashes

US 50 / Purcell Blvd

Before: 2002 to 2006 After: 2008 to 2012

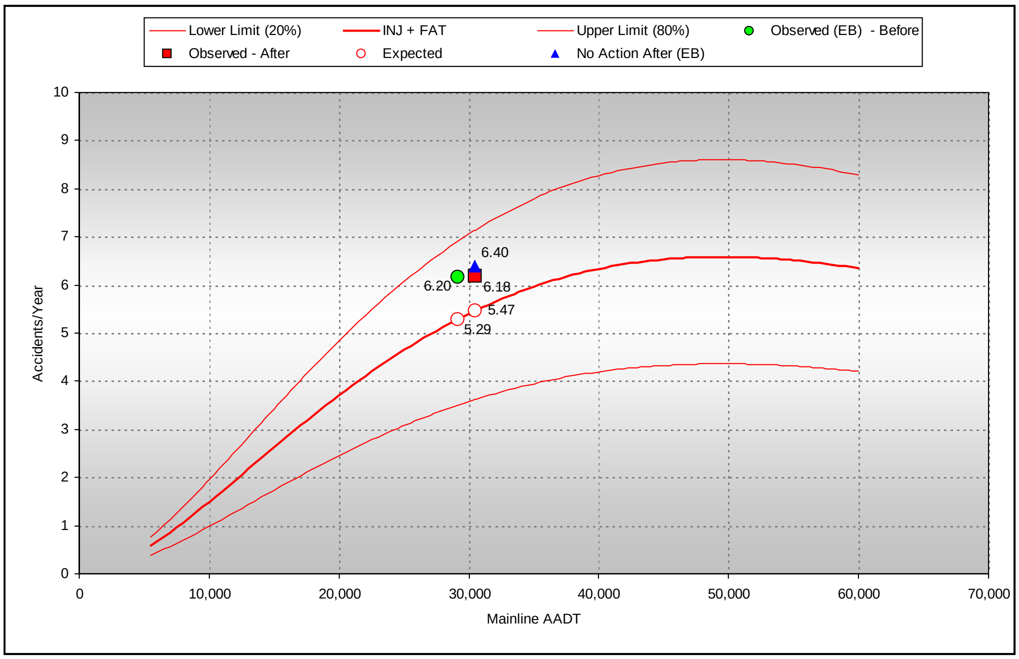


Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 2 – SPF for Injury and Fatal Crashes

US 50 / Purcell Blvd

Before: 2002 to 2006 After: 2008 to 2012



Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Signalized 4-Leg Intersection

Table 2 – Safety Performance Function (SPF)

SH50A, MP 309.76-309.80	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS III	LOSS II	LOSS III
CPY	21.51	17.40	22.26
Mean CPY	18.05	18.71	18.71
Proportion of Mean	1.19	0.93	1.19
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS III	LOSS III
CPY	6.18	6.20	6.40
Mean CPY	5.29	5.47	5.47
Proportion of Mean	1.17	1.13	1.17

A more detailed review of the before and after crash record reveals that a significant improvement in safety can be attributed to the upgrade of the signal, with the exception of the previously mentioned fatality. **Table 3** shows a comparison of three types of crashes that are most directly affected by the improvement: rear end, approach turn, and broadside. The No Build After crashes were estimated using the increase in the median of the SPF for total crashes found in **Table 2** (increase is 1.04 = 18.71/18.02).

Table 3 – Results of Crash Analyses

SH50A, MP 309.76-309.80	Before	After	No Build After
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)	1/1/2008 to 12/31/2012 (5 yr.)
Crash Types:			
Rear Ends – Total	**84**	**63**	**87**
Fatal (fatalities)	0	1 (1)	0
Injury (injuries)	28 (47)	22 (31)	29 (49)
PDO	56	40	58
% Reduction in Total		18%	
Approach Turns– Total	**1**	**9**	**1**
Injury (injuries)	1 (7)	1 (2)	1 (7)
PDO	0	8	0
% Reduction in Total		-800%	
Broadsides– Total	**11**	**6**	**11**
Injury (injuries)	3 (4)	5 (8)	3 (4)
PDO	8	1	8
% Reduction in Total		45%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Exhibit 3** for the impacted crash types. The after period had a rear-end fatality when there was no fatality in the no action after. To account for the cost of the fatality in the B/C analysis, the cost of a fatality was added in to the overall cost of the project. As shown, the B/C ratio for rear end, approach turn, and broadside crashes is 0.74, showing that the improvement may not have been justified. However, it may be worth discounting the fatality due to its unique nature. Since the crash occurred on a green light with traffic stopped for a fire truck, it likely unrelated to the signal or modified intersection geometry. **Exhibit 4** provides the results of the B/C analysis without considering the fatality. As shown, the B/C ratio is 4.00, showing that the improvement may have been justified.

Exhibit 3 – Benefit Cost Analysis – Rear End, Approach Turn, Broadside Crashes Only

CDOT
COLORADO Department of Transportation

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

06/30/2015

Job #: 20150630133126

Location: 50A **Begin:** 309.76 **End:** 309.80 **From:** 01/01/2002 **To:** 12/31/2006

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	66		Weighted PDO:	16.21	26% :ARF for PDO	Cost of PDO:	$ 9,300
INJ:	33	60 :Injured	Weighted INJ:	14.74	32% :ARF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	28% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance Cost:	$ 500

Cost: $ 7,302,499
From: 01/01/2002
To: 12/31/2006 Days: 1826

Benefit Cost Ratio: 0.72 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SIGNALS - UPGRADE SIGNALS AND MODIFY GEOMETRY (GENERAL)
Special Notes: Add the cost of 4 fatalities (4*$1,500,000) to the cost of construction ($1,302,499)

Exhibit 4 – Benefit Cost Analysis – Rear End, Approach Turn, Broadside Crashes Only, Excluding Fatality

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

06/30/2015

Job #: 20150630133126

Location: 50A **Begin:** 309.76 **End:** 309.80 **From:** 01/01/2002 **To:** 12/31/2006

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	66		Weighted PDO:	16.21	26% :ARF for PDO	Cost of PDO:	$ 9,300
INJ:	33	60 :Injured	Weighted INJ:	14.74	32% :ARF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	28% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance Cost:	$ 500

Cost: $ 1,302,499
From: 01/01/2002
To: 12/31/2006 Days: 1826

Benefit Cost Ratio: 4.00 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SIGNALS - UPGRADE SIGNALS AND MODIFY GEOMETRY (GENERAL)
Special Notes:

Location: 50A **Begin:** 309.76 **End:** 309.80 **From:** 01/01/2002 **To:** 12/31/2006

Severity

PDO:	77	
INJ:	32	58 :Injured
FAT:	0	0 :Killed
Total:	**109**	

Number of Vehicles

One Vehicle:	3
Two Vehicles:	90
Three or More:	16
Unknown:	0
Total:	**109**

Location

On Road:	107
Off Road Left:	0
Off Road Right:	2
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**109**

Lighting Conditions

Daylight:	81
Dawn or Dusk:	6
Dark - Lighted:	15
Dark - Unlighted:	4
Unknown:	3
Total:	**109**

Weather Conditions

None:	95
Rain:	6
Snow/Sleet/Hail:	2
Fog:	1
Dust:	0
Wind:	2
Unknown:	3
Total:	**109**

Crash Rates

PDO:	37.12 *
INJ:	15.43 *
FAT:	0.00 **
Total:	**52.54** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	1
Broadside:	11	Embankment:	0
Head On:	0	Curb:	0
Rear End:	84	Delineator Post:	0
Sideswipe (Same):	8	Fence:	0
Sideswipe (Opposite):	1	Tree:	0
Approach Turn:	1	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	2
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	1
Bridge Rail:	0	Total Other Objects:	1
Guard Rail:	1	Unknown:	0
Cable Rail:	0	**Total:**	**109**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	109
Crossroad (A):	0

Frontage/Ramp Intersections

M: 0	N: 0	O: 0	P: 0

Ramps

B: 0	F: 0	J: 0
C: 0	G: 0	K: 0
D: 0	H: 0	L: 0
E: 0	I: 0	

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**109**

Road Description

At Intersection:	83
At Driveway Access:	0
Intersection Related:	26
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**109**

Road Conditions

Dry:	96
Wet:	8
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	4
Total:	**109**

ADT: 29,131 **Length:** 0.03

Location: 50A **Begin:** 309.76 **End:** 309.80 **From:** 01/01/2002 **To:** 12/31/2006

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	77	76	12
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	14	22	4
Pickup Truck/Utility Van w/Trl:	5	1	0
SUV:	0	1	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	6	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	7	5	0
Total:	**109**	**106**	**16**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	70	17	7
Slowing:	21	12	1
Stopped in Traffic:	3	68	7
Making Right Turn:	7	0	0
Making Left Turn:	4	8	1
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	1	1	0
Total:	**109**	**106**	**16**

Direction	Veh 1	Veh 2	Veh 3
North:	9	11	2
Northeast:	0	0	0
East:	39	37	7
Southeast:	0	0	0
South:	7	7	2
Southwest:	0	0	0
West:	53	50	3
Northwest:	0	0	0
Unknown:	1	1	2
Total:	**109**	**106**	**16**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	43	95	16
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	10	2	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	39	3	0
Driver Unfamilar with Area:	3	1	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	2	0	0
Unknown:	7	5	0
Total:	**109**	**106**	**16**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	103	106	16
Alcohol Involved:	4	0	0
RX, Medication, or Drugs Involved:	2	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**109**	**106**	**16**

ADT: 29,131 **Length:** 0.03

Location: 50A **Begin:** 309.76 **End:** 309.80 **From:** 01/01/2008 **To:** 12/31/2012

Severity

PDO:	56		
INJ:	30	43	:Injured
FAT:	1	1	:Killed
Total:	**87**		

Number of Vehicles

One Vehicle:	3
Two Vehicles:	81
Three or More:	3
Unknown:	0
Total:	**87**

Location

On Road:	85
Off Road Left:	1
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**87**

Lighting Conditions

Daylight:	51
Dawn or Dusk:	6
Dark - Lighted:	26
Dark - Unlighted:	4
Unknown:	0
Total:	**87**

Weather Conditions

None:	80
Rain:	2
Snow/Sleet/Hail:	4
Fog:	0
Dust:	0
Wind:	0
Unknown:	1
Total:	**87**

Crash Rates

PDO:	24.55	*
INJ:	13.15	*
FAT:	43.84	**
Total:	**38.15**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	6	Embankment:	0
Head On:	0	Curb:	1
Rear End:	63	Delineator Post:	0
Sideswipe (Same):	4	Fence:	0
Sideswipe (Opposite):	2	Tree:	0
Approach Turn:	9	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	2
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	1	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**87**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	87
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**87**

Road Description

At Intersection:	49
At Driveway Access:	0
Intersection Related:	38
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**87**

Road Conditions

Dry:	78
Wet:	4
Muddy:	0
Snowy:	0
Icy:	1
Slushy:	0
Foreign Material:	2
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	1
Total:	**87**

ADT: 30,448 **Length:** 0.04

Location: 50A **Begin:** 309.76 **End:** 309.80 **From:** 01/01/2008 **To:** 12/31/2012

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	46	49	2
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	18	13	0
Pickup Truck/Utility Van w/Trl:	2	0	0
SUV:	18	21	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	2	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**87**	**84**	**3**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	28	81	3
Asleep at the Wheel:	1	1	0
Illness:	0	0	0
Distracted by Passenger:	3	0	0
Driver Inexperience:	13	1	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	16	1	0
Driver Unfamilar with Area:	5	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	1	0	0
Physical Disability:	0	0	0
Unknown:	19	0	0
Total:	**87**	**84**	**3**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	79	84	3
Alcohol Involved:	4	0	0
RX, Medication, or Drugs Involved:	2	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	2	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**87**	**84**	**3**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	53	12	1
Slowing:	15	6	0
Stopped in Traffic:	1	54	2
Making Right Turn:	5	2	0
Making Left Turn:	5	10	0
Making U-Turn:	1	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	2	0	0
Avoiding Object/Veh in Road:	1	0	0
Weaving:	1	0	0
Other:	3	0	0
Unknown:	0	0	0
Total:	**87**	**84**	**3**

Direction	Veh 1	Veh 2	Veh 3
North:	5	4	0
Northeast:	0	0	0
East:	35	30	0
Southeast:	0	0	0
South:	10	12	0
Southwest:	0	0	0
West:	37	38	3
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**87**	**84**	**3**

ADT: 30,448 **Length:** 0.04

Project Information

Project Name: SH 45 / Red Creek Springs Rd

Project Description: Add right turn lanes, replace existing signal

CDOT Region: 2 Project Def: 16006 County: Pueblo

Location: SH 45 Mile Points: 3.95 Length: N/A

Schedule: Work Start Date: 1/12/2009 Completion Date: 11/10/2009

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the three-year crash history showed a higher than expected number of rear-end type crashes. This is due to a capacity problem which is caused by the side streets being too narrow to accommodate turn lanes. As a result, side street green time has to be extended, which causes progression problems on SH 45. In addition, the corner radii are small.

Improvement Description: In 2009, the Red Creek Springs Road was widened to add an eastbound right-turn lane. SH 45 was widened for a southbound right-turn lane. The cost of construction was $779,500.

The HSIP application anticipated that there would be a 15% crash reduction for all intersection crashes. The initial benefit/cost ratio was estimated to be 1.18.

Summary and Findings

The analysis of safety before and after the geometry and signal was upgraded at US 45 and Red Creek Springs Road showed no safety improvements. For this intersection, there were 47 total crashes during the four-year period before the upgrades (2005 – 2008). In the four years after construction (20010 – 2013), the number of crashes decreased to 46. Since daily volumes continued to increase throughout the study period, the crash rate was reduced. However, the number of injuries increase from 20 in the before period to 34 in the after period.

The signal and geometry upgrade was responsible for decreases in the number and severity of broadside, and pedestrian crashes. However, there was a significant increase in the severity of rear-end crashes. The overall ratio of benefits and cost when including approach turns, broadsides, rear-ends, and pedestrian crashes show the resulting B/C ratio of the project was 0.08. The result is an improvement whose safety benefits did not outweigh the cost.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 47 during the four-year period (2005 to 2008) before the signal was upgraded and the geometry was improved (see **Table 1** and **Exhibit 1**) to 46 during the four-year after period (2010 to 2013) (see **Table 1** and **Exhibit 2**). The number of serious crashes increased while the PDO crashes decreased.

Table 1 - Results of Overall Crash Analyses

SH45, MP 3.93-3.97	Before	After
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2010 to 12/31/2013 (4 yr.)
AADT (SH 45/RCS Rd)	25,500/5,500 vpd	27,000/5,500 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**47**	**46**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	13 (20)	20 (34)
Property Damage Only	34	26
Crash Types: # (%) [significance]		
Rear End	17 (36.2%)	21 (45.7%)
Approach Turn	12 (25.5%)	14 (30.4%) [97.64%]
Broadside	11 (23.4%) [95.04%]	4 (8.7%)
Pedestrian	3 (6.4%) [99.06%]	0

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. A SPF reflects the complex relationship between exposure (measured in ADT) and the crash count for a section of roadway measured in crashes per mile per year (CPMPY) or for an intersection, measured in crashes per year. The SPF models provide an estimate for the expected crash frequency and severity for a range of ADT among similar facilities. This allows for an assessment of the magnitude of the safety problem from a frequency standpoint.

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be 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

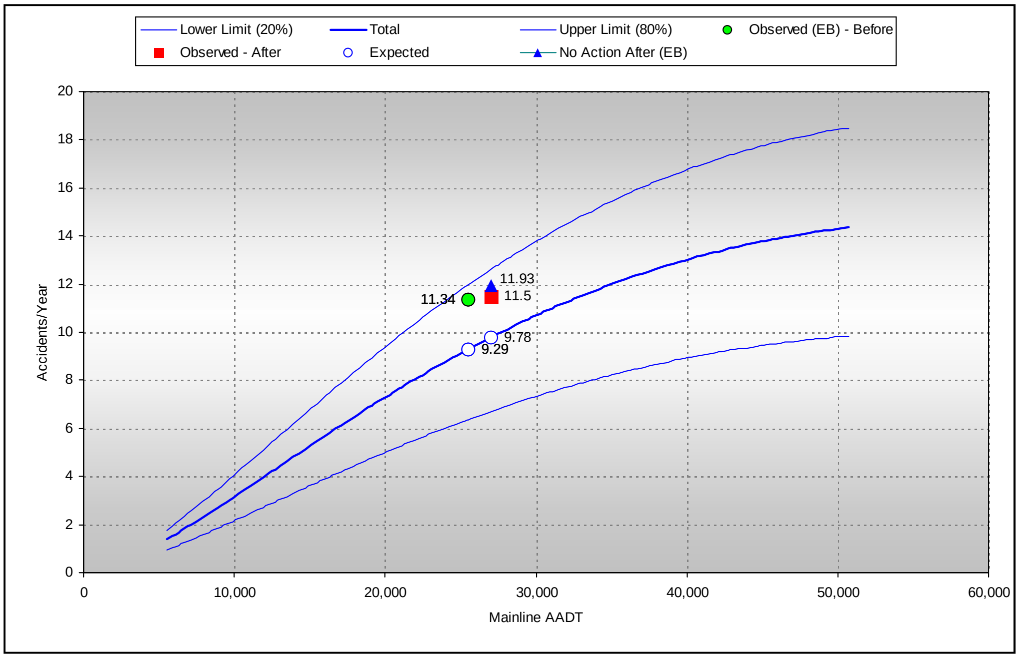
LOSS boundaries are calibrated by computing the 20th and the 80th percentiles using the Gamma Distribution Probability Density Function. Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT increases. LOSS reflects how a segment of roadway or intersection is performing in regard to its expected crash frequency at a specific level of ADT.

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the improvement in the total crash record while showing the increase in severe crashes. LOSS improved within the LOSS III range for total crashes and increased to LOSS IV for Injury/Fatal crashes in the after period (see **Table 2**).

Figure 1 – SPF for Total Crashes

US 45 / Red Creek Springs Road

Before: 2005 to 2008 After: 2010 to 2013

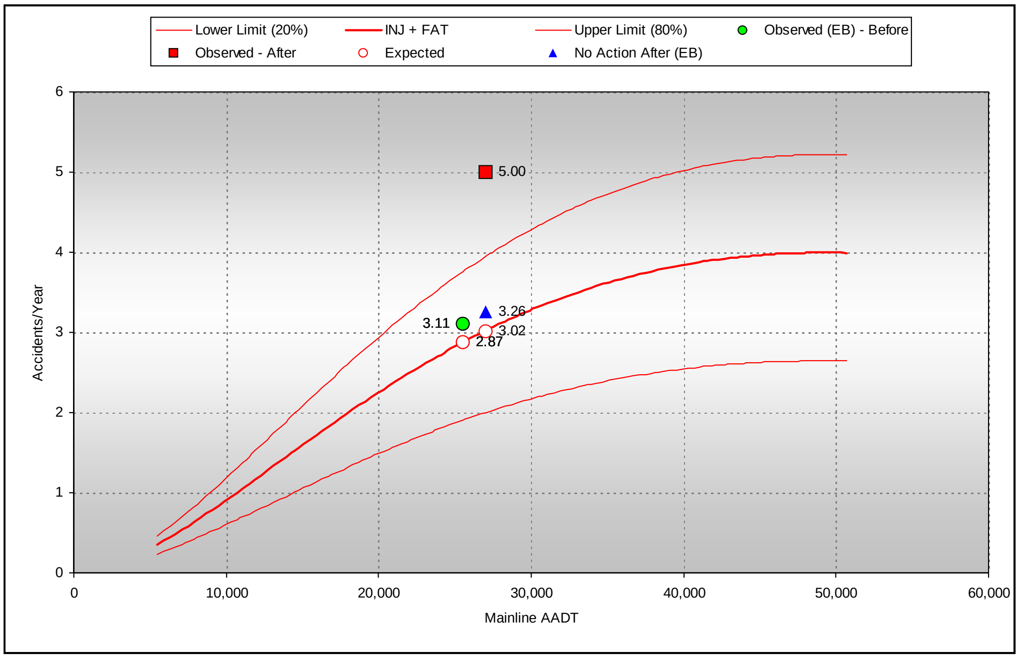


Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 2 – SPF for Injury and Fatal Crashes

US 45 / Red Creek Springs Road

Before: 2005 to 2008 After: 2010 to 2013



Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Signalized 4-Leg Intersection

Table 2 – Safety Performance Function (SPF)

SH45, MP 3.93-3.97	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS III	LOSS III	LOSS III
CPY	11.34	11.50	11.93
Mean CPY	9.29	9.78	9.78
Proportion of Mean	1.22	1.18	1.22
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS IV	LOSS III
CPY	3.11	5.00	3.26
Mean CPY	2.87	3.02	3.02
Proportion of Mean	1.08	1.66	1.08

A more detailed review of the before and after crash record reveals that some improvement in the number of crashes can be attributed to the upgrade of the signal and modified geometry, although the severity of crashes increased. **Table 3** shows a comparison of four types of crashes that are most directly affected by the improvement: rear end, approach turn, broadside, and pedestrian. The No Build After crashes were estimated using the increase in the mean predicted by the SPF reflecting AADT for the after period, the SPF for total crashes found in **Table 2** (increase is 1.05 = 9.78/9.29). As shown, the pedestrian and broadside crashes had a significant decrease in number of crashes. However, the number of rear-end crashes resulting in injuries increased.

Table 3 – Results of Crash Analyses

SH45, MP 3.93-3.97	Before	After	No Build After
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2010 to 12/31/2013 (4 yr.)	1/1/2010 to 12/31/2013 (4 yr.)
Crash Types:			
Rear Ends – Total	**17**	**21**	**18**
Injury (injuries)	0	7 (12)	0
PDO	17	14	18
% Reduction in Total		-16%	
Approach Turns– Total	**12**	**14**	**13**
Injury (injuries)	4 (7)	6 (12)	4 (7)
PDO	8	8	9
% Reduction in Total		-8%	
Broadsides– Total	**11**	**4**	**11**
Injury (injuries)	4 (8)	4 (6)	4 (8)
PDO	7	0	7
% Reduction in Total		64%	
Pedestrians– Total	**3**	**0**	**3**
Injury (injuries)	3 (3)	0	3 (3)
PDO	0	0	0
% Reduction in Total		100%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Exhibit 3** for the impacted crash types. The after period had a significantly larger number of Injury crashes than predicted. To account for the increase in Injury crashes in the B/C analysis, the cost of the injuries was added in to the overall cost of the project. As shown, the B/C ratio for rear end, approach turn, broadside, and pedestrian crashes is 0.08, showing that the safety benefits of the improvement did not outweigh the cost.

Exhibit 3 – Benefit Cost Analysis – Rear End, Approach Turn, Broadside, Pedestrian Crashes Only

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

06/30/2015

Job #: 20150630141815

Location: 45A **Begin:** 3.93 **End:** 3.97 **From:** 01/01/2005 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors				Other Information	
PDO:	34		Weighted PDO:	10.44	35%	:ARF for PDO	Cost of PDO:	$ 9,300
INJ:	11	18 :Injured	Weighted INJ:	5.53	0%	:ARF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	100%	:ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	26%	:Weighted ARF	Interest Rate:	5%
							ADT Growth Factor:	2.0%
							Service Life:	20
							Capital Recovery Factor:	0.080
							Annual Maintenance Cost:	$ 500

Cost: $ 5,621,500
From: 01/01/2005
To: 12/31/2008 Days: 1461

Benefit Cost Ratio: 0.08 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SIGNALS - UPGRADE SIGNALS AND MODIFY GEOMETRY (GENERAL)
Special Notes: Add the cost of 60 injuries (60*$80,700) to the cost of construction ($779,500)

Colorado Department of Transportation
DiExSys™ Roadway Safety Systems
Detailed Summary of Crashes Report

Exhibit 1 *06/30/2015*

Job #: 20150630141050

Location: 45A **Begin:** 3.93 **End:** 3.97 **From:** 01/01/2005 **To:** 12/31/2008

Severity

PDO:	34		
INJ:	13	20	:Injured
FAT:	0	0	:Killed
Total:	**47**		

Number of Vehicles

One Vehicle:	1
Two Vehicles:	43
Three or More:	3
Unknown:	0
Total:	**47**

Location

On Road:	46
Off Road Left:	0
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**47**

Lighting Conditions

Daylight:	31
Dawn or Dusk:	2
Dark - Lighted:	13
Dark - Unlighted:	0
Unknown:	1
Total:	**47**

Weather Conditions

None:	43
Rain:	1
Snow/Sleet/Hail:	0
Fog:	1
Dust:	0
Wind:	0
Unknown:	2
Total:	**47**

Crash Rates

PDO:	16.08	*
INJ:	6.15	*
FAT:	0.00	**
Total:	**22.23**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	3	Culvert/Headwall:	0
Broadside:	11	Embankment:	0
Head On:	0	Curb:	0
Rear End:	17	Delineator Post:	0
Sideswipe (Same):	1	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	12	Large Boulders or Rocks:	0
Overtaking Turn:	1	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	1	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**47**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	47
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**47**

Road Description

At Intersection:	40
At Driveway Access:	0
Intersection Related:	7
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**47**

Road Conditions

Dry:	42
Wet:	2
Muddy:	0
Snowy:	1
Icy:	0
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	1
Total:	**47**

ADT: 33,650 **Length:** 0.04

Location: 45A **Begin:** 3.93 **End:** 3.97 **From:** 01/01/2005 **To:** 12/31/2008

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	28	30	2
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	11	7	1
Pickup Truck/Utility Van w/Trl:	0	1	0
SUV:	5	4	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	1	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	2	0	0
Other:	0	3	0
Unknown:	0	0	0
Total:	**47**	**46**	**3**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	26	24	1
Slowing:	0	2	0
Stopped in Traffic:	0	15	2
Making Right Turn:	4	1	0
Making Left Turn:	16	2	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	2	0
Total:	**47**	**46**	**3**

Direction	Veh 1	Veh 2	Veh 3
North:	13	11	0
Northeast:	0	0	0
East:	9	11	1
Southeast:	0	0	0
South:	19	13	2
Southwest:	0	0	0
West:	6	9	0
Northwest:	0	0	0
Unknown:	0	2	0
Total:	**47**	**46**	**3**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	34	44	3
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	3	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	3	1	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	7	1	0
Total:	**47**	**46**	**3**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	43	46	3
Alcohol Involved:	4	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**47**	**46**	**3**

ADT: 33,650 **Length:** 0.04

Colorado Department of Transportation
DiExSys™ Roadway Safety Systems
Detailed Summary of Crashes Report

Exhibit 2 *06/30/2015*

Job #: 20150630140411

Location: 45A **Begin:** 3.93 **End:** 3.97 **From:** 01/01/2010 **To:** 12/31/2013

Severity

PDO:	26	
INJ:	20	34 :Injured
FAT:	0	0 :Killed
Total:	**46**	

Number of Vehicles

One Vehicle:	2
Two Vehicles:	40
Three or More:	4
Unknown:	0
Total:	**46**

Location

On Road:	43
Off Road Left:	0
Off Road Right:	2
Off Road at Tee:	0
Off in Median:	1
Unknown:	0
Total:	**46**

Lighting Conditions

Daylight:	33
Dawn or Dusk:	1
Dark - Lighted:	12
Dark - Unlighted:	0
Unknown:	0
Total:	**46**

Weather Conditions

None:	43
Rain:	2
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**46**

Crash Rates

PDO:	15.33 *
INJ:	11.79 *
FAT:	0.00 **
Total:	**27.12** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	4	Embankment:	0
Head On:	0	Curb:	0
Rear End:	21	Delineator Post:	0
Sideswipe (Same):	2	Fence:	1
Sideswipe (Opposite):	2	Tree:	0
Approach Turn:	14	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	1	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	1
Domestic Animal:	0	Total Fixed Objects:	2
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**46**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	46
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**46**

Road Description

At Intersection:	32
At Driveway Access:	0
Intersection Related:	14
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**46**

Road Conditions

Dry:	43
Wet:	2
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**46**

ADT: 27,000 **Length:** 0.04

User: Henderson on LAP14

Location: 45A **Begin:** 3.93 **End:** 3.97 **From:** 01/01/2010 **To:** 12/31/2013

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	21	24	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	14	10	2
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	7	7	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	1	0
Motorized Bicycle:	1	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	2	1	1
Other:	0	0	0
Unknown:	0	0	0
Total:	**46**	**44**	**4**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	21	21	1
Slowing:	2	5	0
Stopped in Traffic:	0	14	3
Making Right Turn:	4	2	0
Making Left Turn:	14	1	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	2	1	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	1	0	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**46**	**44**	**4**

Direction	Veh 1	Veh 2	Veh 3
North:	19	15	3
Northeast:	0	0	0
East:	8	10	1
Southeast:	0	0	0
South:	9	13	0
Southwest:	0	0	0
West:	9	5	0
Northwest:	0	0	0
Unknown:	1	1	0
Total:	**46**	**44**	**4**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	32	43	4
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	5	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	1	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	7	1	0
Total:	**46**	**44**	**4**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	43	44	4
Alcohol Involved:	3	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**46**	**44**	**4**

ADT: 27,000 **Length:** 0.04

Project Information

Project Name: Signal at Industrial / Purcell

Project Description: Install a new signal

CDOT Region: 2 Project Def: 16010 County: Pueblo

Location: Industrial Boulevard/Purcell Boulevard

Schedule: Work Start Date: approx. 5/2008 Completion Date: approx. 6/2009

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history showed a higher than expected number of broadside type crashes. The intersection was unsignalized but met signal warrants.

Improvement Description: In late 2008 and early 2009, a traffic signal was installed at this intersection. The cost of construction was $391,768.

The HSIP application anticipated that four crash types would be impacted by this improvement: rear-end, approach turn, broadside, and sideswipe same direction type crashes. It was anticipated that there would be a 25% crash reduction for these crash types. The initial benefit/cost ratio was estimated to be 1.12.

Summary and Findings

The analysis of safety before and after the signal was installed at Industrial Boulevard and Purcell Boulevard showed no safety improvements. For this intersection, there were 14 total crashes during the three-year period before the upgrades (2005 – 2007). In the three years after construction (2011 – 2013), the number of crashes increased to 22. Despite daily volumes increasing slightly throughout the study period, the crash rate increased. In addition, the number of injury and fatal crashes also increased.

The signal installation was responsible for a moderate decrease in the number broadside crashes, but the after period showed an increase in the number and severity of approach turn, rear-end, and sideswipe same direction crashes. The result is an improvement that was likely not justified from the standpoint of safety. This outcome suggests that considering relatively low traffic volumes at this location a modern roundabout would be a preferred countermeasure.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows an increase in the number of crashes; the total number of crashes increased from 14 during the three-year period (2005 to 2007) before the signal was installed (see **Table 1** and **Exhibit 1**) to 22 during the three-year after period (2011 to 2013) (see **Table 1** and **Exhibit 2**).

This increase in crashes occurred along with a modest increase in traffic volumes at the intersection. This combination of increased traffic and increased number of crashes also resulted in a increase in the accident rates:

- Before (2005 – 2007): 1.15 crashes per million entering vehicles (cpmev)
- After (2011 – 2013): 1.75 (cpmev)

Table 1 - Results of Overall Crash Analyses

Purcell/Industrial	**Before**	**After**
Time Period:	1/1/2005 to 12/31/2007 (3 yr.)	1/1/2011 to 12/31/2013 (3 yr.)
AADT (Purcell/Industrial)	6,000/5,100 vpd	6,000/5,500 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**14**	**22**
Fatal Crashes (Fatalities)	0	1 (1)
Injury Crashes (Injuries)	2 (2)	5 (9)
Property Damage Only	12	16
Crash Types: # (%) [significance]		
Broadside	6 (42.9%) [98.27%]	4 (18.2%)
Sideswipe Same	3 (21.4%)	4 (18.2%)
Rear End	2 (14.3%)	4 (18.2%)
Approach Turn	1 (7.1%)	9 (40.9%) [99.51%]

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. A SPF reflects the complex relationship between exposure (measured in ADT) and the crash count for a section of roadway measured in crashes per mile per year (CPMPY) or for an intersection, measured in crashes per year. The SPF models provide an estimate for the expected crash frequency and severity for a range of ADT among similar facilities. This allows for an assessment of the magnitude of the safety problem from a frequency standpoint.

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

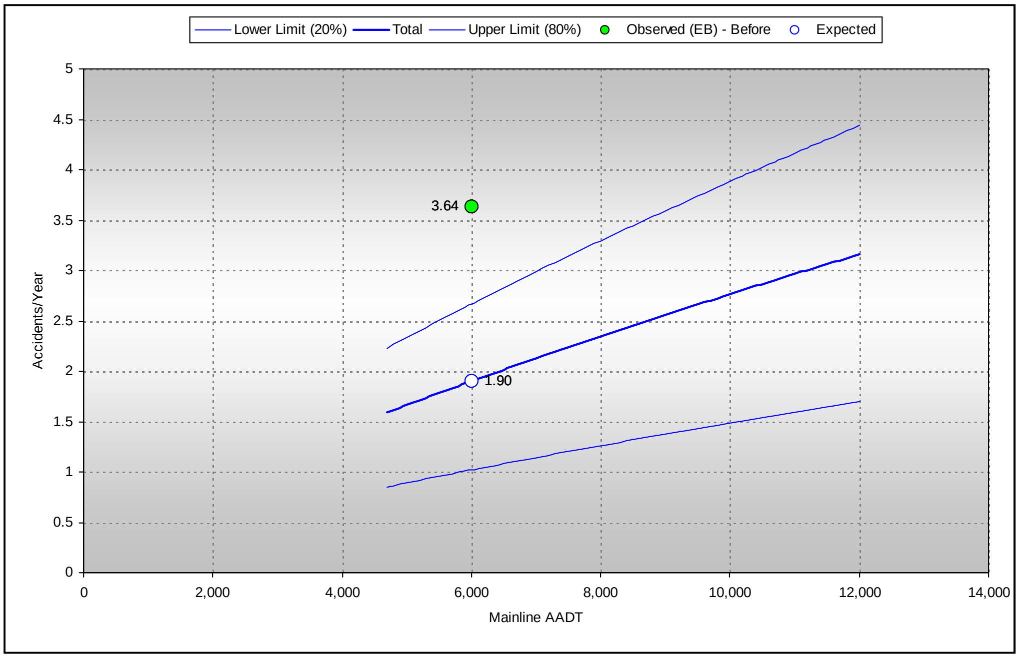
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT increases. LOSS reflects how a segment of roadway or intersection is performing in regard to its expected crash frequency at a specific level of ADT.

SPF plots for both total crashes (see **Figures 1** and **3**) and for fatal and injury crashes (see **Figure 2** and **4**) reflect no improvement in the crash record. LOSS worsened within the LOSS IV range for total crashes in the after period, and Injury/Fatal crashes worsened to LOSS IV from LOSS II in the after period (see **Table 2**). **Figure 5** and **6** show the SPF plots for the no action after period.

Figure 1 – SPF for Total Crashes - Before

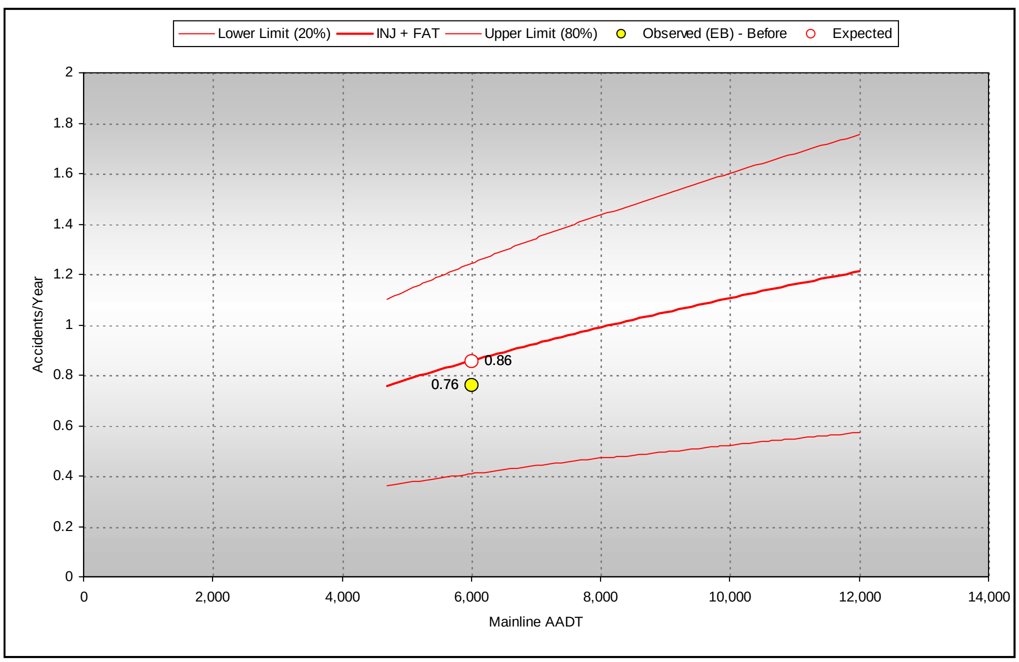
Industrial Blvd/Purcell Blvd
2005 to 2007



Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Unsignalized 4-Leg Intersection

Figure 2 – SPF for Injury and Fatal Crashes - Before

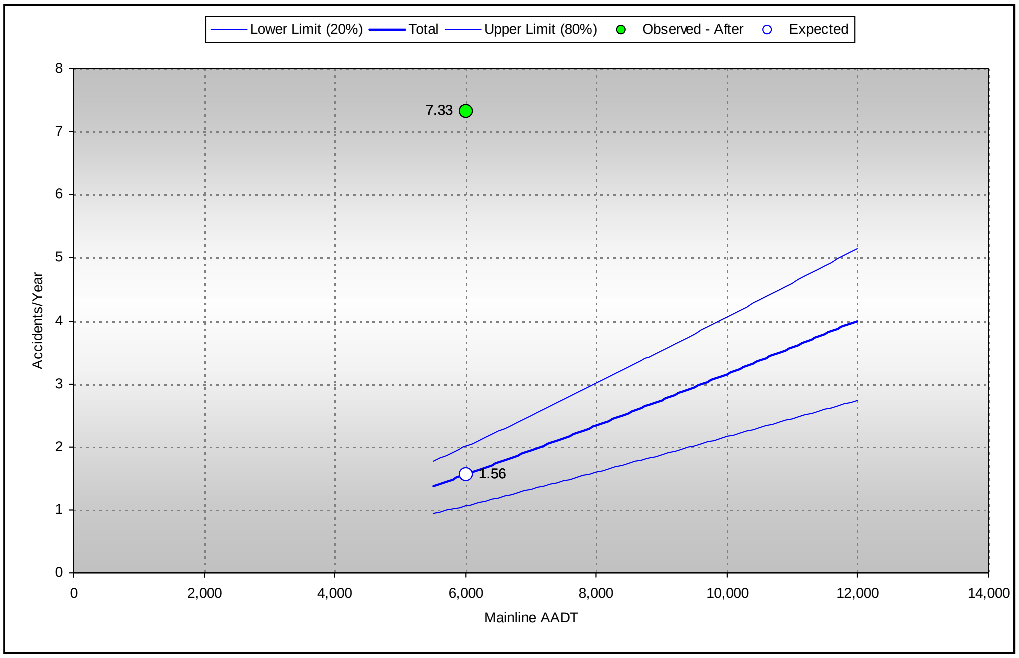
Industrial Blvd/Purcell Blvd
2005 to 2007



Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Unsignalized 4-Leg Intersection

Figure 3 – SPF for Total Crashes - After

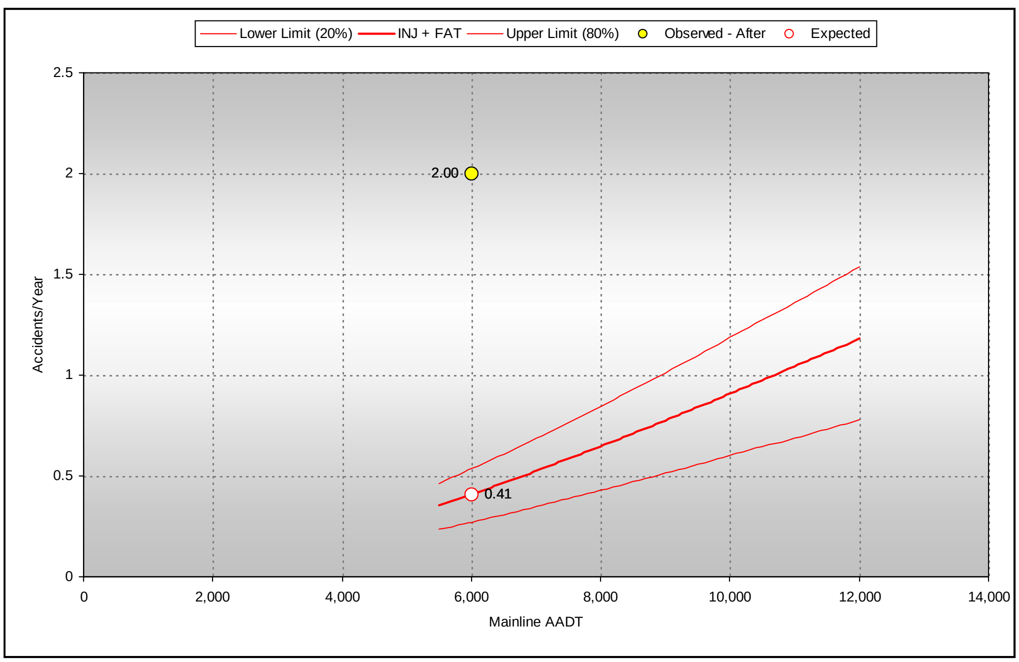
Industrial Blvd/Purcell Blvd
2011 to 2013



Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Signalized 4-Leg Intersection

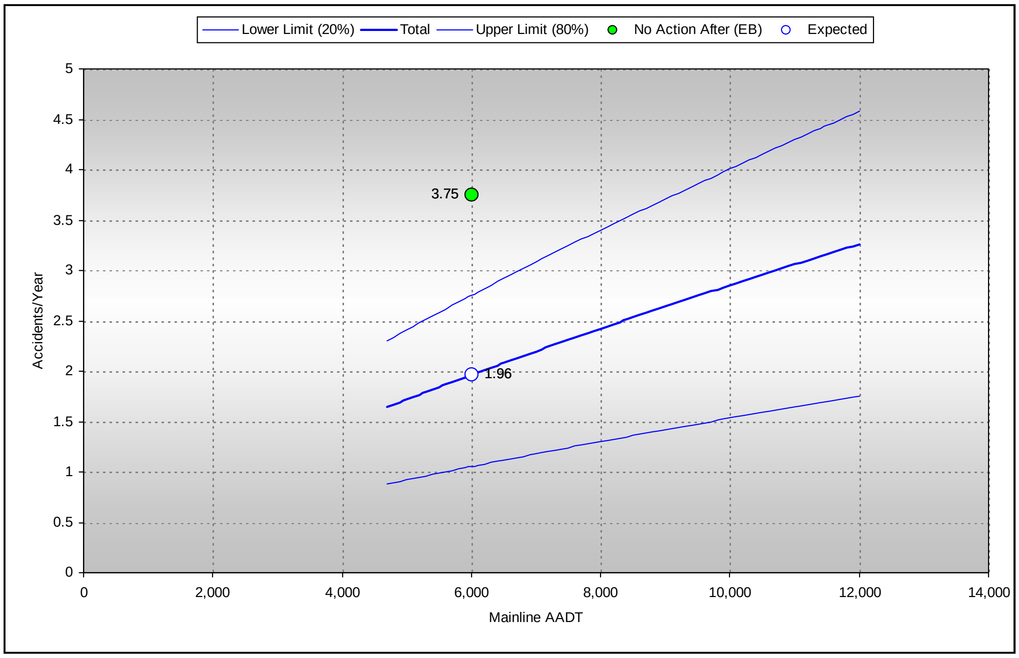
Figure 3 – SPF for Injury and Fatal Crashes - After

Industrial Blvd/Purcell Blvd
2011 to 2013



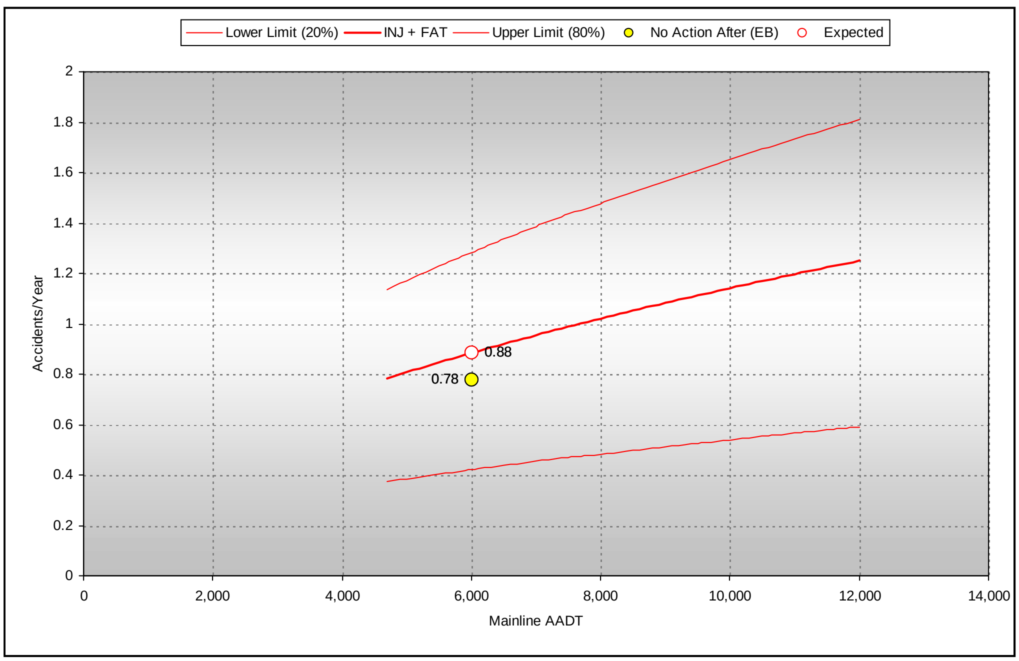
Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 5 – SPF for Total Crashes – No Action After
Industrial Blvd/Purcell Blvd
2011 to 2013



Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Unsignalized 4-Leg Intersection

Figure 6 – SPF for Injury and Fatal Crashes – No Action After
Industrial Blvd/Purcell Blvd
2011 to 2013



Note: Safety Performance Function (SPF) Model – Urban 4-Lane Divided Unsignalized 4-Leg Intersection

Table 2 – Safety Performance Function (SPF)

Purcell/Industrial	**Before**	**After**	**No Build After**
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Unsignalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Unsignalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPY	3.64	7.33	3.75
Mean CPY	1.90	1.56	1.96
Proportion of Mean	1.92	4.70	1.92
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS IV	LOSS II
CPY	0.76	2.00	0.78
Mean CPY	0.86	0.41	0.88
Proportion of Mean	0.88	4.88	0.88

A more detailed review of the before and after crash record reveals that very little improvement in safety can be attributed to the installation of the signal. **Table 3** shows a comparison of four types of crashes that are most directly affected by the improvement: rear end, approach turn, broadside, and sideswipe same direction. The No Build After crashes were estimated using the increase in the median of the SPF for total crashes found in **Table 2** (increase is 1.03 = 1.96/1.90). As shown, the number of broadsides crashes decreased (although the severity increased) and all other crash types had an increase in number of crashes.

Table 3 – Results of Crash Analyses

Purcell/Industrial	**Before**	**After**	**No Build After**
Time Period:	1/1/2005 to 12/31/2007 (3 yr.)	1/1/2011 to 12/31/2013 (3 yr.)	1/1/2011 to 12/31/2013 (3 yr.)
Crash Types:			
Broadsides– Total	**6**	**4**	**6**
Injury (injuries)	0	1 (3)	0
PDO	6	3	6
% Reduction in Total		33%	
Sideswipe Same Direction – Total	**3**	**4**	**3**
Injury (injuries)	0	0	0
PDO	3	4	3
% Reduction in Total		-33%	
Rear Ends – Total	**2**	**4**	**2**
Injury (injuries)	0	2 (4)	0
PDO	2	2	2
% Reduction in Total		-100%	
Approach Turns– Total	**1**	**9**	**1**
Fatal (fatalities)	0	1 (1)	0
Injury (injuries)	0	2 (2)	0
PDO	1	6	1
% Reduction in Total		-800%	

There was no improvement in safety amongst the combined impacted crash types in the number of PDO, Injury, or Fatality crashes, showing that the improvement was likely not justified from a safety standpoint.

Colorado Department of Transportation
DiExSys™ Roadway Safety Systems
Detailed Summary of Crashes Report

Exhibit 1 *06/24/2015*

Job #: 20150624084513

Location: Accident History for INDUSTRIAL and PURCELL **From:** 01/01/2005 **To:** 12/31/2007

Severity

PDO:	12	
INJ:	2	2 :Injured
FAT:	0	0 :Killed
Total:	**14**	

Number of Vehicles

One Vehicle:	0
Two Vehicles:	13
Three or More:	1
Unknown:	0
Total:	**14**

Location

On Road:	14
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**14**

Lighting Conditions

Daylight:	12
Dawn or Dusk:	1
Dark - Lighted:	0
Dark - Unlighted:	1
Unknown:	0
Total:	**14**

Weather Conditions

None:	14
Rain:	0
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**14**

Crash Rates

PDO:	N/A *	* MVMT
INJ:	N/A *	** 100 MVMT
FAT:	N/A **	**Total: N/A** *

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	6	Embankment:	0
Head On:	0	Curb:	0
Rear End:	2	Delineator Post:	0
Sideswipe (Same):	3	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	1	Large Boulders or Rocks:	0
Overtaking Turn:	1	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	0
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0		
Concrete Barrier:	0	**Total:**	**14**

Mainline/Ramps/Frontage Roads

Mainline:	0
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	14
Total:	**14**

Road Description

At Intersection:	14
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**14**

Road Conditions

Dry:	13
Wet:	1
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**14**

Location: Accident History for INDUSTRIAL and PURCELL **From:**01/01/2005 **To:**12/31/2007

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	7	6	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	2	5	1
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	2	2	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	2	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	1	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**14**	**14**	**1**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	3	9	1
Slowing:	1	0	0
Stopped in Traffic:	0	2	0
Making Right Turn:	4	2	0
Making Left Turn:	6	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	1	0
Unknown:	0	0	0
Total:	**14**	**14**	**1**

Direction	Veh 1	Veh 2	Veh 3
North:	2	3	0
Northeast:	0	0	0
East:	6	5	0
Southeast:	0	0	0
South:	2	4	0
Southwest:	1	0	0
West:	2	2	1
Northwest:	1	0	0
Unknown:	0	0	0
Total:	**14**	**14**	**1**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	11	14	1
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	1	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	0	0	0
Total:	**14**	**14**	**1**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	14	14	1
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**14**	**14**	**1**

Colorado Department of Transportation
DiExSys™ Roadway Safety Systems
Detailed Summary of Crashes Report

Exhibit 2 06/24/2015

Job #: 20150624084844

Location: Accident History for INDUSTRIAL and PURCELL **From:** 01/01/2011 **To:** 12/31/2013

Severity

PDO:	16	
INJ:	5	9 :Injured
FAT:	1	1 :Killed
Total:	**22**	

Number of Vehicles

One Vehicle:	0
Two Vehicles:	22
Three or More:	0
Unknown:	0
Total:	**22**

Location

On Road:	21
Off Road Left:	1
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**22**

Lighting Conditions

Daylight:	14
Dawn or Dusk:	5
Dark - Lighted:	3
Dark - Unlighted:	0
Unknown:	0
Total:	**22**

Weather Conditions

None:	15
Rain:	0
Snow/Sleet/Hail:	1
Fog:	0
Dust:	0
Wind:	0
Unknown:	6
Total:	**22**

Crash Rates

PDO:	N/A *	* MVMT
INJ:	N/A *	** 100 MVMT
FAT:	N/A **	**Total: N/A** *

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	4	Embankment:	0
Head On:	0	Curb:	1
Rear End:	4	Delineator Post:	0
Sideswipe (Same):	4	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	9	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**22**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	0
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	0

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	0
E:	0	I:	0		

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	22
Total:	**22**

Road Description

At Intersection:	21
At Driveway Access:	0
Intersection Related:	1
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**22**

Road Conditions

Dry:	19
Wet:	2
Muddy:	0
Snowy:	0
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**22**

Location: Accident History for INDUSTRIAL and PURCELL **From:**01/01/2011 **To:**12/31/2013

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	14	12	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	2	2	0
Pickup Truck/Utility Van w/Trl:	2	1	0
SUV:	4	5	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	1	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**22**	**22**	**0**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	9	16	0
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	3	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	2	1	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	6	5	0
Total:	**22**	**22**	**0**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	22	22	0
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**22**	**22**	**0**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	6	17	0
Slowing:	1	0	0
Stopped in Traffic:	0	0	0
Making Right Turn:	2	1	0
Making Left Turn:	12	4	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**22**	**22**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	5	6	0
Northeast:	0	0	0
East:	4	7	0
Southeast:	0	0	0
South:	8	6	0
Southwest:	0	0	0
West:	5	3	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**22**	**22**	**0**