HIGHWAY SAFETY IMPROVEMENT PROGRAM (HSIP) BEFORE/AFTER SAFETY ANALYSES

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INTRODUCTION

The purpose of this study was to continue evaluating the effectiveness of safety improvement projects on safety performance at locations chosen by the Colorado Department of Transportation (CDOT). This report examines the 38 locations that were analyzed and the methodology used in the process.

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

ANALYSIS AND RESULTS

The 38 projects chosen by CDOT for analysis are located on state highways and non-state highways and cover a variety of safety improvements to both roadways and intersections. Roadway improvements included median barriers, guard rail, ITS improvements, wildlife protection and rumble strips. Intersection improvements analyzed included new signals, signal upgrades (such as larger signal heads and replacing old span-wire signals), and geometric improvements.

Table 1 shows 38 individual projects that have been grouped by type of improvement that was completed. In addition, the table lists the locations, the type of crash(es) that created the safety concerns, the predicted benefit/cost (B/C) ratio, and the observed B/C ratio. Averages and weighted averages for both predicted and observed B/C ratios are also included for each improvement group.

Table 1. Summary of Safety Analyses Locations

Def.	Region	Highway/Intersection	MP	Crash Type	Improvement	Year Completed	Predicted B/C	Observed B/C
Signal Improvements								
17527	1	Alameda & Depew	N/A	Intersection Related	Wire Arm to Mast Arm	2011	5.21	-5.29
17527	1	Alameda & Harlan	N/A	Intersection Related	Wire Arm to Mast Arm	2011	1.32	18.07
17999	3	US 6 & I-70B	N/A	Intersection Related	Mast Arm Replaced & Signal Upgrades	2012	0.96	7.18
17627	3	US 6 & SH 139	N/A	Intersection Related	Install Signal	2015	1.02	
18460	5	Signalized Intersections along SH 160/172/550	N/A	Approach Turn	Flashing Yellow Arrow Upgrades	2011	3.81	-2.32
18783	2	SH 83 & Walker Rd	N/A	Intersection Related	Geometric Improvements/ Lighting	2014	1.00	–12.34
Guardrail								
17561	4	Boyd Lake Ave	N/A	Intersection Related	Concrete Barrier	2011	29.6	-1.02
17571	4	LCR 27	N/A	Intersection Related	Guardrail	2011	65.34	18.61
17571	4	LCR 74E	N/A	Intersection Related	Guardrail	2011	109.23	675.62
17647	4	US 85	235-250.5	Off Median/Left - Head On & Sideswipe Opposite Off Left - Overturning Off Left/Median - Cable Rail	Cable Rail	2012	7.13	6.00
Culvert Repair								
17568	4	LCR38E	N/A	Intersection Related	Culvert Repair	2010	4.43	105.93
Wildlife Protection								
17656	1	US 6	272.5-274.1	Wild Animal Crashes	Wildlife Fencing & Crossing	2011	1.36	1.44
18075	2	I-25	124.0-127.0	Wild Animal Crashes	Wildlife Fencing	2012	1	2.2
18264 (B)	3	SH 82	15.95 - 22.05	Wild Animal Crashes	Wildlife Fencing	2013	3.82	0.7
18841	3	I-70	87 - 110	Wild Animal Crashes	Wildlife Fencing	2014	1.05	0.59
Variable Message Signing (VMS)								
17664	1	C-470	19.5-24.5	Westbound Non-Intersection, Mainline Crashes	VMS	2012	2.24	6.85
18139	1	I-70	215.0-217.75	Eastbound Non-Intersection, Mainline Crashes	VMS	2015	1.93	0.87
17601 (A)	3	I-70	124 to 125	Non-Intersection	VMS	2012	1.28	10.54
17601 (B)	3	SH 40	136 to 142	Non-Intersection	VMS	2012	2.81	19.47

17601 (C)	3	SH 82	27.5 to 30.5	Non-Intersection	VMS	2012	0.62	3.19
Geometry Improvements								
17763	3	Railroad Ave & SH 13 Bypass	N/A	Intersection Related	Correct superelevation, increase deflection angle, implement median	2011	1.06	2.78
17779	4	SH 392 & WCR 35	N/A	Intersection Related	Add EB & WB Left Turn Lanes	2010	3.3	38.57
17821	2	SH 115A	0.85-1.6 Elm Ave Int.	Intersection Related	Center Turn Lane Extensions & Intersection Realignment	2014	1.75	2.29
18001	1	Garrison St & Ralston Rd	N/A	Intersection Related	Left Turn Alignment & Signal Improvements	2013	3.08	5.48
18080	2	SH 45 & WCR 96	N/A	Intersection Related	Add WBR Accel Lane & SBL Turn Lane	2013	1.12	0.47
18237	5	SH 172	23.59-24.48	Intersection Related	Install TWLTL	2014	0.94	3.21
17608	2	S Carefree Roundabout	N/A	Intersection Related	Lane reduction from 2 lanes to 1 lane to remove overlap	2014	4.42	20.11
17582	4	Weld Co Rd 34 at Weld Co Rd 17	N/A	Intersection Related	Grade of Co Rd 17 south of the intersection was flattened to improve sight distance	2012	1.02	N/A
18264 (A)	3	SH 82 at JW Dr / Valley Road	N/A	Intersection Related	Added Pork Chops, Median, Acceleration Lane	2013	0.9	-0.12
18544	1	120th & Colorado Blvd	N/A	Intersection Related	Added NBL and SBL Turn Lanes and Intersection Realignment	2014	1.41	-0.29
18561	2	US 50	318 - 359	Run Off Road, Head Ons, & Sideswipe Opposite	Median & Shoulder Rumble Strips	2012	3.33	41.02
18787	4	SH 66 & WCR 1	N/A	Intersection Related	Upgrade Signals & Add Turn Lanes	2014	2.21	-3.29
Median								
17936 (A)	6	SH 30	4.28 - 4.53	Non-Intersection / Intersection Related / Driveway Access Related	Install Raised Median	2012	9.31	48.83
17936 (B)	6	SH 30	5.47 - 6	Non-Intersection / Intersection Related / Driveway Access Related	Install Raised Median	2012	7.89	5.6
17936 (C)	6	SH 30	6.44 - 6.53	Non-Intersection / Intersection Related / Driveway Access Related	Install Raised Median	2012	3.55	19.44
17936 (D)	6	SH 30	10.0 - 10.16	Non-Intersection / Intersection Related / Driveway Access Related	Install Raised Median	2012	4.62	0.72
17936 (E)	6	SH 83	74.85 - 75.18	Non-Intersection / Intersection Related / Driveway Access Related	Install Raised Median	2012	11.08	13.33
Rumble Strips								
18415	5	US 24	213.54-226.5	Head On/Sideswipe Opposite (On Road), Off Left and Off Median	Install Centerline Rumble Strips	2011	7.69	111.08

SUMMARY AND RECOMMENDATIONS

It is important for CDOT to continue to conduct 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 to understand the impacts of different improvement types and why the initially predicted safety improvements are not always observed following construction. It is recommended that CDOT institutionalize this process and perform a before/after safety analysis evaluation of safety performance for all projects constructed when after period crash data becomes available. Analyzing safety performance of projects before and after completion will allow CDOT to make better and more informed decisions for future projects, thereby maximizing the positive impact of the limited safety improvement funding that is available.

SAFETY REPORTS

The following is a list of the projects that were analyzed for this Before/After Safety Analyses. The safety reports for each individual analysis are provided in ascending order in the pages following the list. These individual reports provide significantly more detail than that given in the preceding pages, including individual project specific observations and discussion.

- 17527- Alameda Ave & Harlan St / Depew St
- 17561 – 5th St & Boyd Lake Ave
- 17568 – Larimer CR 38E, MP 8.00-9.00
- 17571 – Larimer CR 27-Larimer CR 74E
- 17582 - Weld CR 34 & Weld CR 17
- 17601 – SH 40A & SH 82A /I-70A
- 17608 – S. Carefree Circle & N New Center Point
- 17627 - US 6 and SH 139
- 17647 - US 85 MP 235.0 - 250.5
- 17656 - US 6 MP 272.5 – 274.1
- 17664 - 470A MP 19.5 – 24.5
- 17763 - Railroad Ave & SH 13 Bypass
- 17779 - SH 392 & WCR 35 *Various Locations*
- 17821 - 115A & Elm Ave
- 17936 - SH30A and SH83A
- 17999 - US 6 & I-70B
- 18001 – Garrison Rd & Ralston Rd
- 18075 – I-25 MP 124.0 – 127.0
- 18080 - SH 45 & WCR 96
- 18139 - I-70A MP 215 – 217.75
- 18237 – SH 172 CR 513
- 18264 - SH 82 & Valley Road/ JW Drive
- 18264B - SH 82 MP 15.95 – 22.05
- 18415 - US 24 MP 213.54 – 226.5
- 18460 - SH 160, 172, & 550 *Various Locations*
- 18544 - 120th Ave & Colorado Blvd
- 18561 - US 50 MP 318.0 – 359.0
- 18783 - SH 83 & Walker Rd
- 18787 - SH 66 & WCR 1
- 18841 – I-70 MP 87.0 – 110.0

(All Reports in order listed above)

APPENDIX A. STATEWIDE METHODOLOGY

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

By

DiExSys-FHU

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.

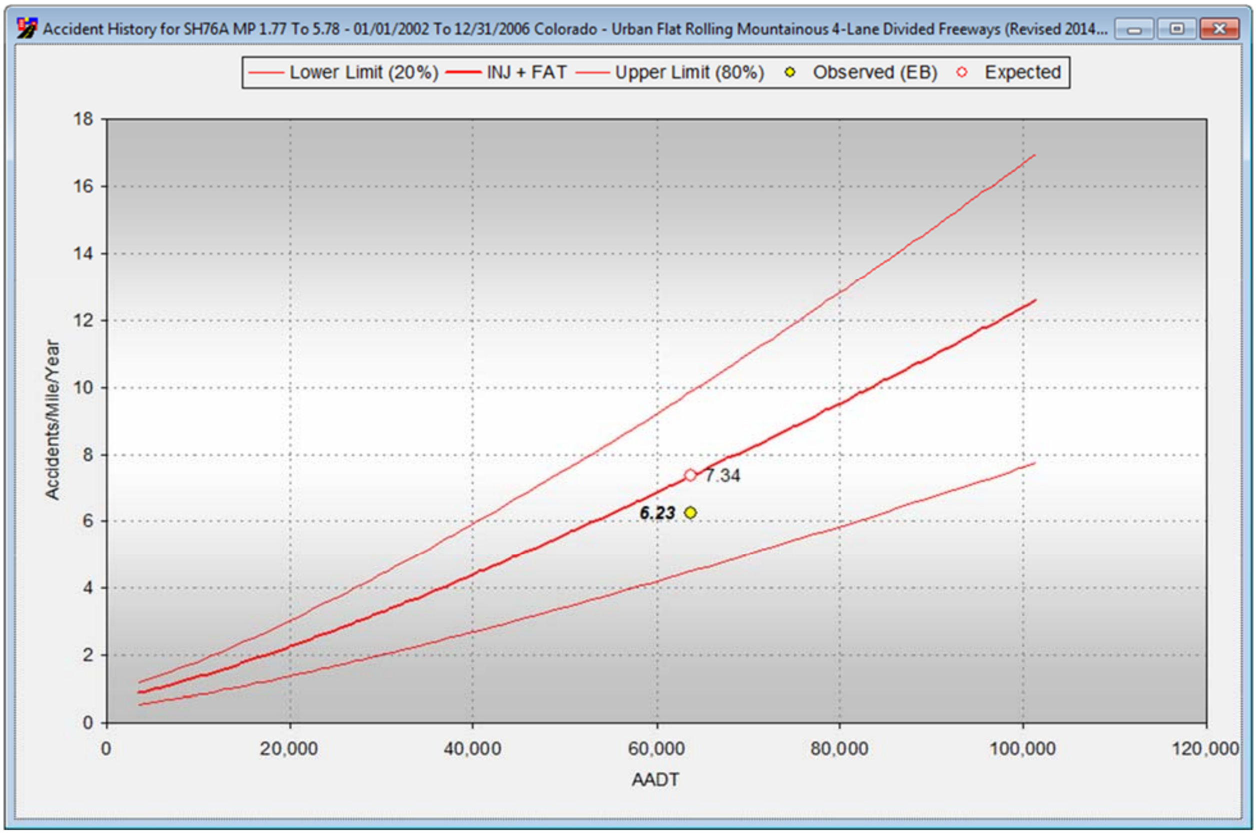


Figure 1 EB Corrected SPF Inj+Fat - I-76 (MP 1.77 to MP 5.78)
(Before Period - 1/1/2002-12/31/2006)

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.

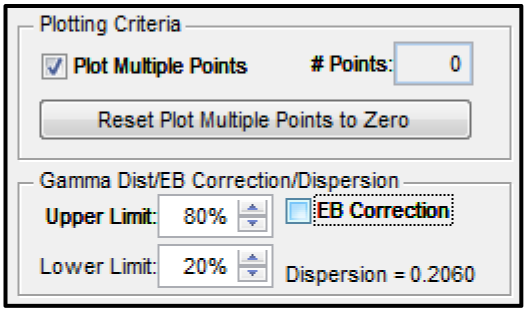


Figure 2 EB Correction Turned Off

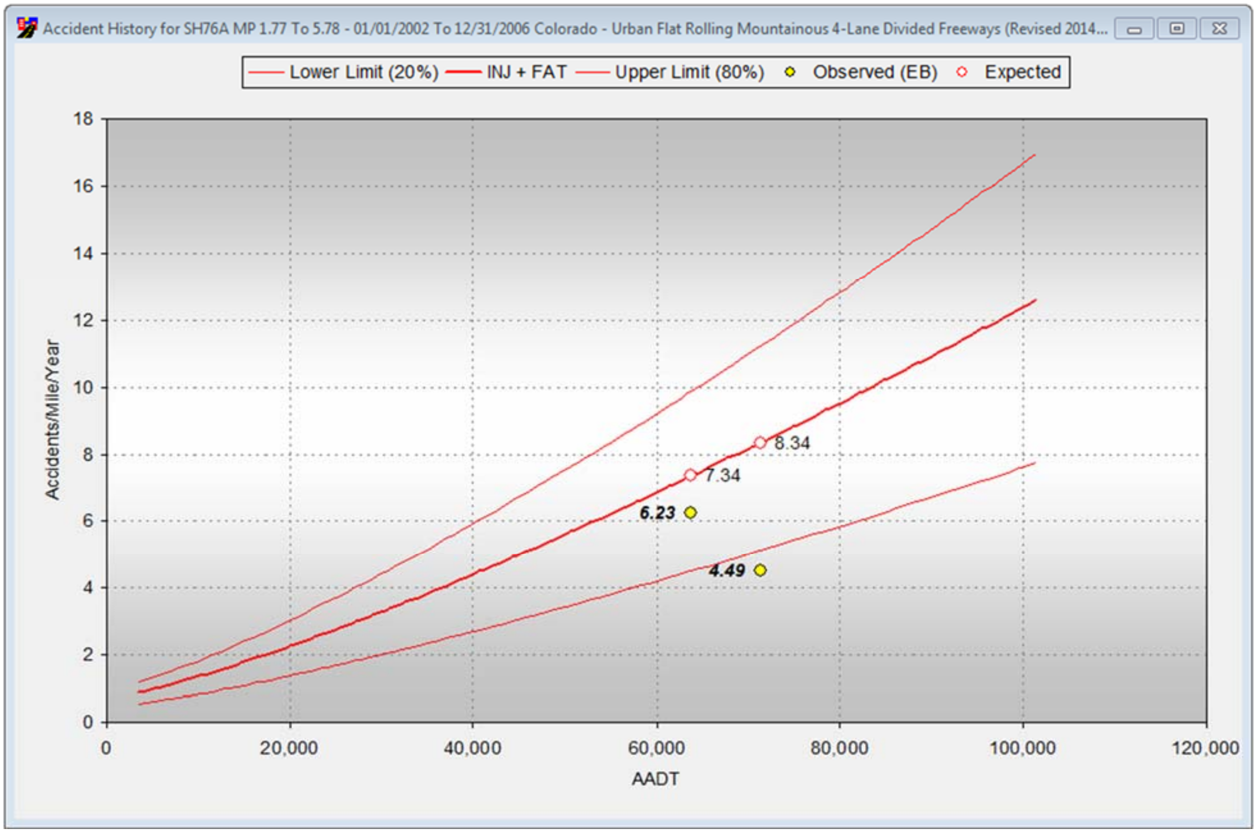


Figure 3 SPF Inj+Fat - I-76 (MP 1.77 to MP 5.78)
(EB Corrected Before Period- 1/1/2002-12/31/2006) and
(After Period - 1/1/2008-12/31/2012)

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)

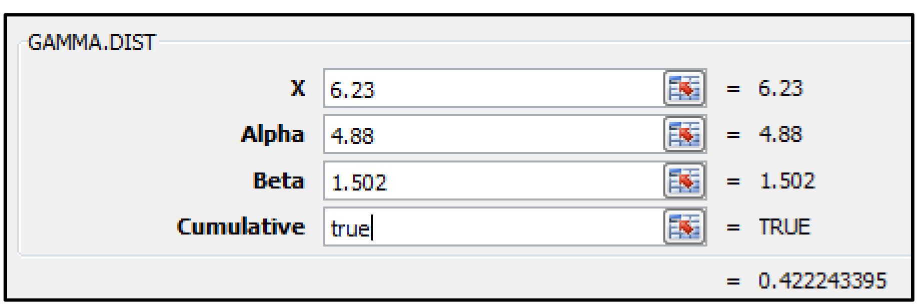


Figure 4 Cumulative Probability of Gamma Function in Excel

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)

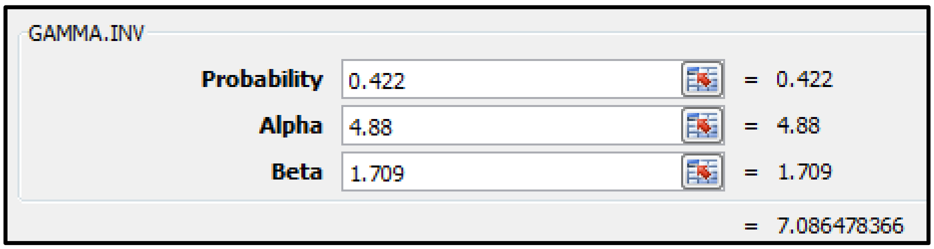


Figure 5 Inverse Gamma Function for a Specified Percentile in Excel

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.

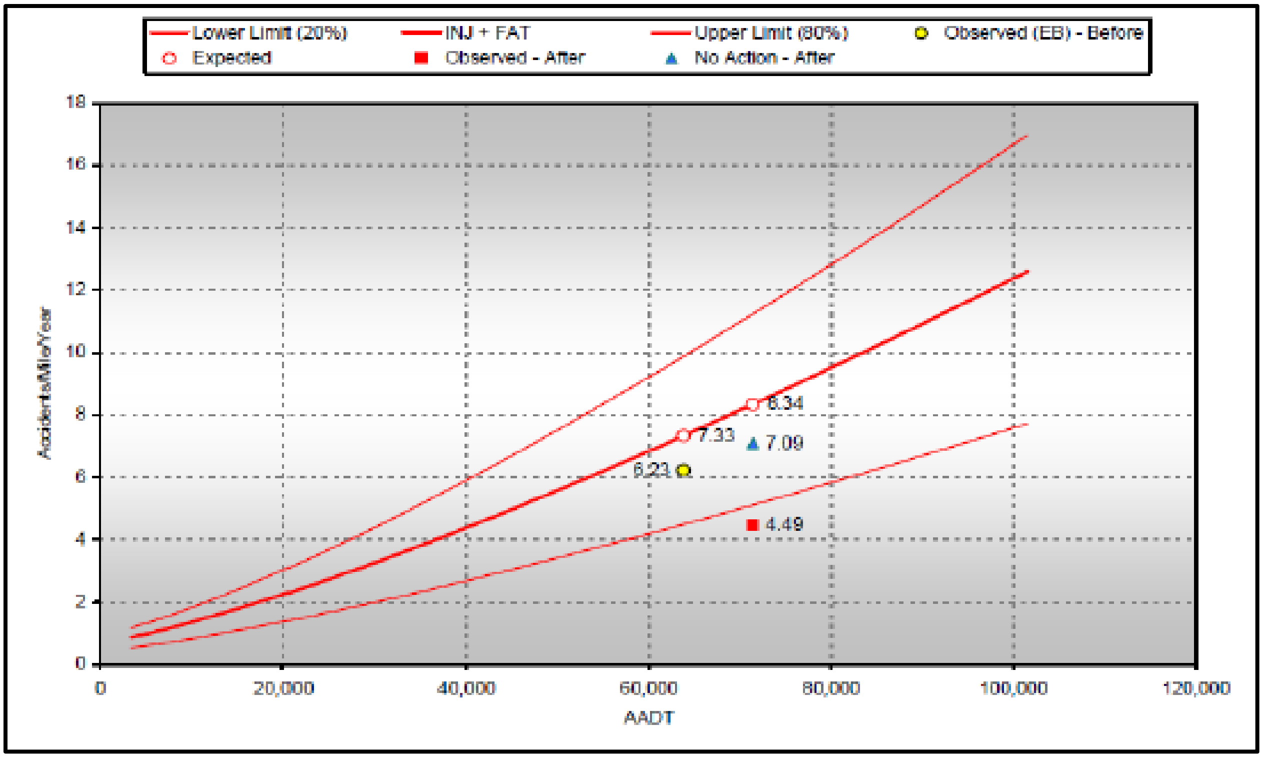


Figure 3 SPF Inj+Fat - I-76 (MP 1.77 to MP 5.78)
(EB Corrected Before Period, Before Without Construction, and After Period)

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

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

Project Information

Project Name: Alameda Ave & Harlan St/Depew St Signal Improvements

Project Description: Traffic Signals Upgrade

CDOT Region: 6 Project Def: 17527 County: Jefferson

Location: Alameda Ave Mile Points: N/A Length: N/A

Schedule: Work Start Date: mid 2011 Work End Date: mid 2011

Problem Description:

No problem description was provided for the original HSIP funding application for the intersection improvement project.

Improvement Description:

In 2011, the span wire traffic signal systems at both intersections were replaced with mast arm systems on each corner of both intersections. Additionally, sidewalk improvements were constructed at the Depew Street intersection, including new curb cuts were installed at the northwest, northeast, and southeast corners. The total cost of the project was $432,007.22


Alameda Ave & Depew St – Facing East – Before (left) and After (right) improvements


Alameda Ave & Harlan St – Facing East – Before (left) and After (right) improvements

Summary & Findings

Depew: The analysis of safety conditions before and after improvements at the Alameda Avenue & Depew Street intersection were constructed shows a marginal decrease in the total number of crashes. The rate of crashes decreased by 16%, but the number of injuries at this intersection increased. Rear End and Broadside crashes were greatly reduced in the after period, but Approach Turn crashes, which did not occur prior to the construction of intersection improvements, increased.

Harlan: The analysis of safety conditions before and after improvements at the Alameda Avenue & Harlan Street intersection were constructed shows an increase in the total number of crashes. The rate of crashes also increased by 21%, and the number of injury crashes and injuries at this intersection increased in the after period. One fatal crash occurred in the before period, but no fatal crashes occurred in the after period. Broadside crash frequency decreased by 29% in the after period, but Rear End and Approach Turn crash frequency increased.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – Alameda Ave & Depew St

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at the Alameda Avenue & Depew Street intersection shows a slight decrease in the number of crashes from the five-year before period (2006-2010) to the five-year after period (2012-2016). The number of severe (fatal and injury) crashes also decreased slightly, but the total number of people injured in crashes increased.

- Before Period: 9 severe crashes, 10 injured
- After Period: 8 severe crashes, 14 injured

The crash rate for all crashes at this intersection decreased by 17% between the before period and after period.

- Before Period: 0.459 crashes per million entering vehicles
- After Period: 0.383 crashes per million entering vehicles

Table 1. Results of Overall Crash Analyses – Depew St

		Before	After
Time Period:		01/01/2006 – 12/31/2010 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)
AADT	Alameda Ave:	26,020	27,330
	Depew St:	approx. 2,605	approx. 2,735
Crash Filters:		Intersection Related	
Total Crashes:		**24**	**21**
Fatal Crashes (Fatalities):		0 (0)	0 (0)
Injury Crashes (Injuries):		9 (10)	8 (14)
PDO Crashes:		15	13

Safety Performance Functions

SPF plots for both total crashes (**Figure 1** and **Figure 2**) and for severe (injury and fatal) crashes (**Figure 3** and **Figure 4**) at the Alameda Avenue & Depew Street intersection reflect a decrease in the crash record for this project. The intersection is LOSS II for total frequency of crashes in both the before and after periods and LOSS III for the severity of crashes in both the before and after periods.

Figure 1. SPF For Total Crashes – Before

Alameda Avenue & Depew Street
Before: 2006–2010 After: 2012–2016

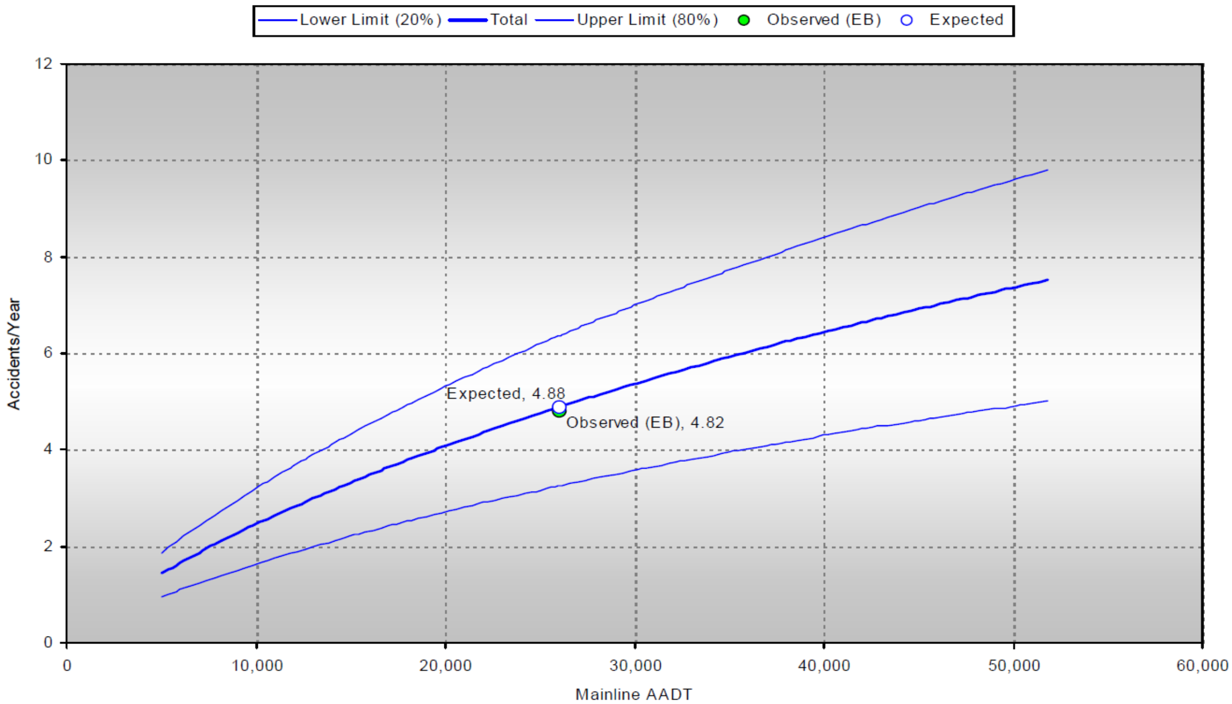


Figure 2. SPF For Total Crashes – After

Alameda Avenue & Depew Street
Before: 2006–2010 After: 2012–2016

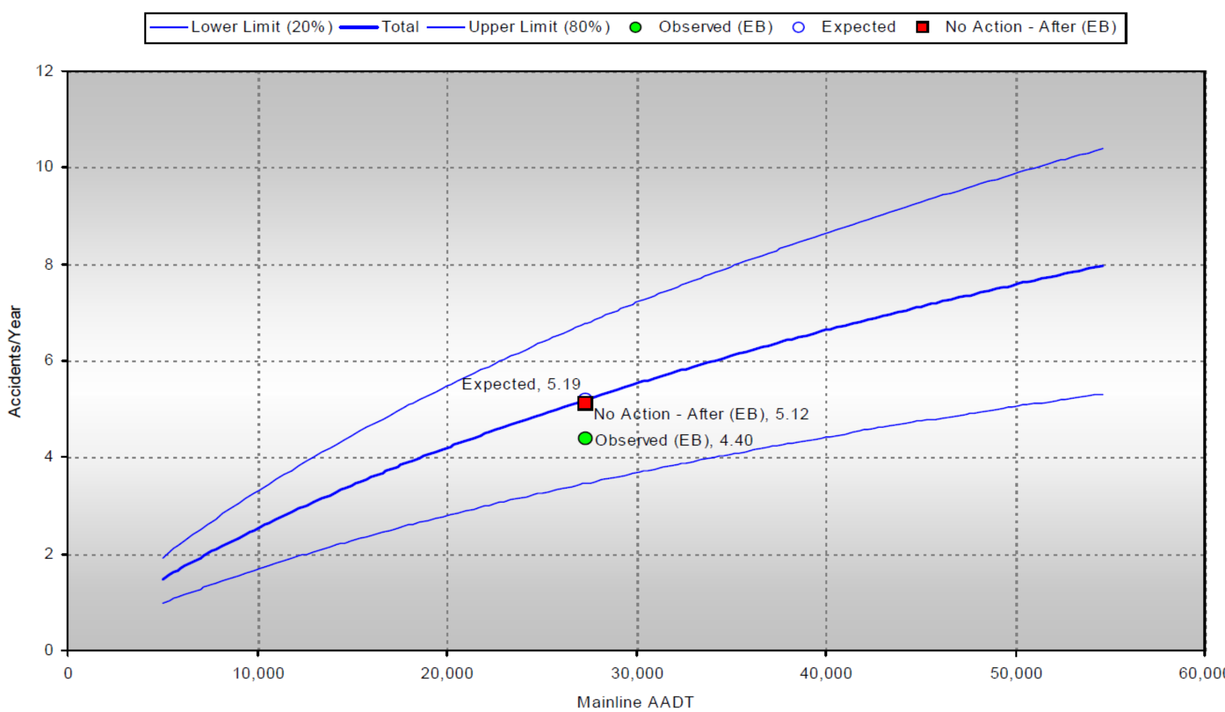


Figure 3. SPF For Severe Crashes – Before

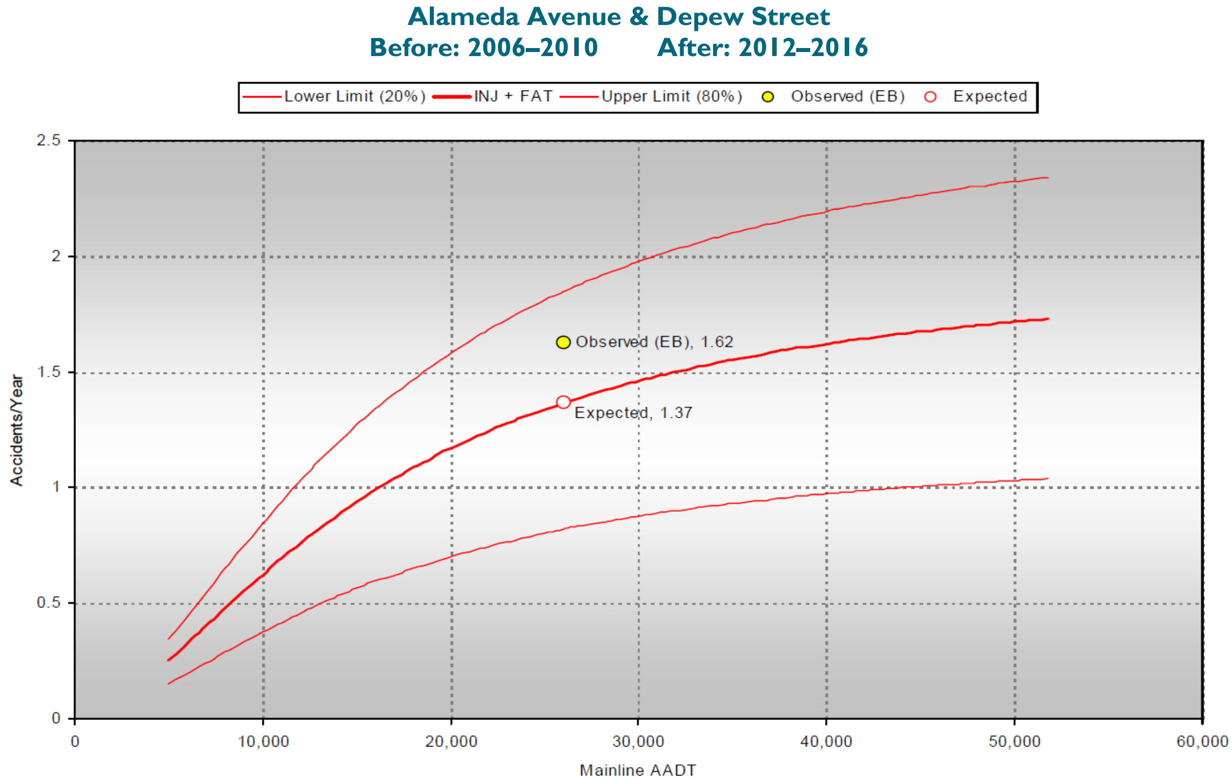


Figure 4. SPF For Severe Crashes – After

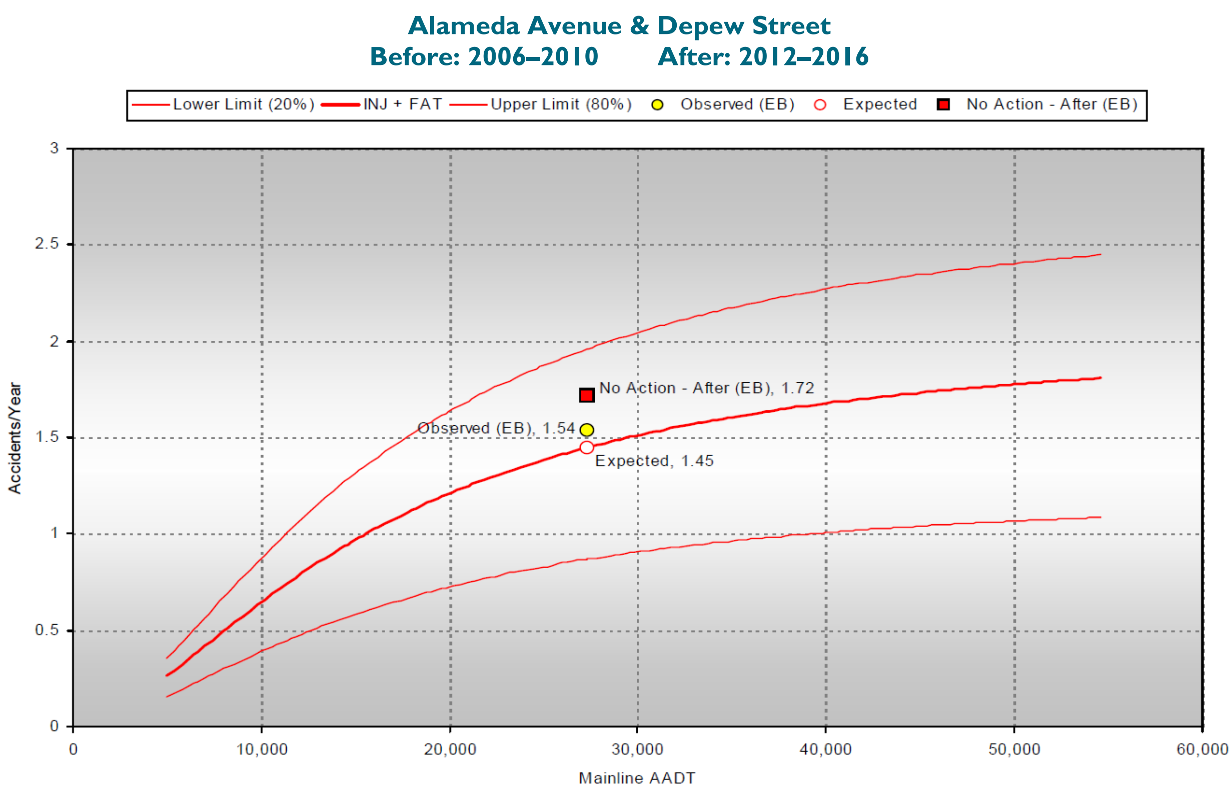


Table 2 provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods at the Alameda Avenue & Depew Street intersection.

Table 2. Safety Performance Function (SPF) Summary – Depew St

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Urban 4-Lane Signalized 4-Leg Intersection	Urban 4-Lane Signalized 4-Leg Intersection	Urban 4-Lane Signalized 4-Leg Intersection
Total Crashes			
LOSS	LOSS II	LOSS II	LOSS II
CPY	4.82	4.40	5.12
Mean CPY	4.88	5.19	5.19
Proportion of Mean	0.99	0.85	0.99
Severe (Injury & Fatal) Crashes			
LOSS	LOSS III	LOSS III	LOSS III
CPY	1.62	1.54	1.72
Mean CPY	1.37	1.45	1.45
Proportion of Mean	1.19	1.06	1.19

Crash Type Analyses

A more detailed review of the before and after crash record shows the crash types that were most affected by the traffic signal upgrade at the Alameda Avenue & Depew Street intersection. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: Rear End, Approach Turn, and Broadside. After the signal upgrade, there was a decrease in Rear End crashes (nearly 50%). There was also a decrease in Broadside crashes (over 50%). Approach Turn crashes, which did not occur prior to the construction of intersection improvements, increased.

The No-Build After crashes were estimated using the change in traffic volumes on Alameda Avenue between the before and after period, as found in **Table 1** (approximately 5%).

Table 3. Results of Crash Analyses – Depew St

	Before	After	No Action After
Time Period	01/01/2006 – 12/31/2010 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)
Total Crashes	**24**	**21**	**25**
Injury (Injuries)	9 (10)	8 (14)	9 (10)
PDO	15	13	16
% Reduction in Total (Injury/PDO)	--	-40% / 19%	--
Rear End	**13**	**7**	**14**
Injury (Injuries)	4 (4)	2 (3)	4 (4)
PDO	9	5	10
% Reduction in Total (Injury/PDO)	--	25% / 50%	--
Approach Turn	**0**	**8**	**0**
Injury (Injuries)	0 (0)	5 (10)	0 (0)
PDO	0	3	0
% Reduction in Total (Injury/PDO)	--	INF / INF	--
Broadside	**7**	**3**	**7**
Injury (Injuries)	3 (4)	0 (0)	3 (4)
PDO	4	3	4
% Reduction in Total (Injury/PDO)	--	100% / 25%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. The increased injuries experienced at the intersections between the After and No Action conditions are represented by negative CMF in the VZS module. **A calculated B/C ratio of -5.29 was ultimately**.

Figure 5. Benefit-Cost Analysis Summary

Location: Accident History for All Locations **From:**01/01/2012 **To:**12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	16		Weighted PDO:	3.93	19% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	9	10 :Injured	Weighted INJ:	2.46	-40% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	-2% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
Cost:	$ 216,003					Capital Recovery Factor:	0.080
From:	01/01/2006					Annual Maintenance/Delay Cost:	$ 0
To:	12/31/2010		Days: 1826				

Benefit Cost Ratio: -5.29 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Alameda & Depew

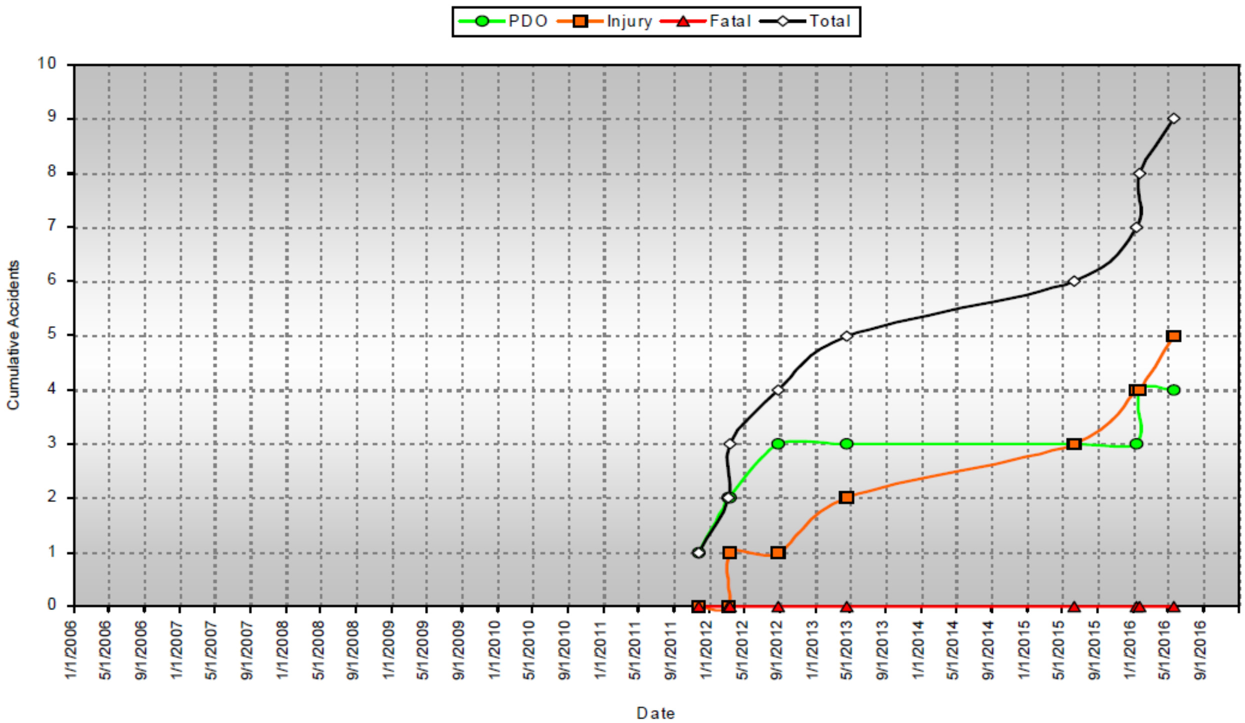
Special Notes: Intersection Related Crashes

Approach Turn Crash Analysis

It was noted that approach turn crashes increased in frequency in the after period. **Figure 6** provides an 11-year history of the approach turn crashes occurring at the Alameda Avenue & Depew Street intersection. The increase in frequency began in January 2012 and may be related to the implementation of flashing yellow arrow from the proposed project. Crash frequency was reduced between May 2013 and May 2015 but increased again in 2016. This increase appears unrelated to the safety project.

Figure 6. Approach Turn Crash Analysis

Alameda Avenue & Depew Street



Results of Safety Analyses – Alameda Ave & Harlan St

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at the Alameda Avenue & Harlan Street intersection shows an increase in the number of crashes from the five-year before period (2006-2010) to the five-year after period (2012-2016). The number of injury crashes and injuries also increased. One fatal crash occurred in the before period (one fatality), but no fatal crashes occurred in the after period.

- Before Period: 9 severe crashes, 12 injured, 1 killed
- After Period: 15 severe crashes, 17 injured, 0 killed

The crash rate for all crashes at this intersection increased by 21% between the before period and after period.

- Before Period: 0.678 crashes per million entering vehicles
- After Period: 0.823 crashes per million entering vehicles

Table 4. Results of Overall Crash Analyses – Harlan St

		Before	After
Time Period:		01/01/2006 – 12/31/2010 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)
AADT	Alameda Ave:	26,020	27,330
	Harlan St:	approx. 6,315	6,630
Crash Filters:		Intersection Related	
Total Crashes:		**40**	**51**
Fatal Crashes (Fatalities):		1 (1)	0 (0)
Injury Crashes (Injuries):		8 (12)	15 (17)
PDO Crashes:		31	36

Safety Performance Functions

SPF plots for both total crashes (**Figure 7** and **Figure 8**) and for severe (injury and fatal) crashes (**Figure 9** and **Figure 10**) at the Alameda Avenue & Harlan Street intersection reflect an increase in the crash record for this project. The intersection is LOSS II for both total and severe frequency of crashes in the before period and LOSS III for both total and severe frequency of crashes in the after period.

Figure 7. SPF For Total Crashes – Before

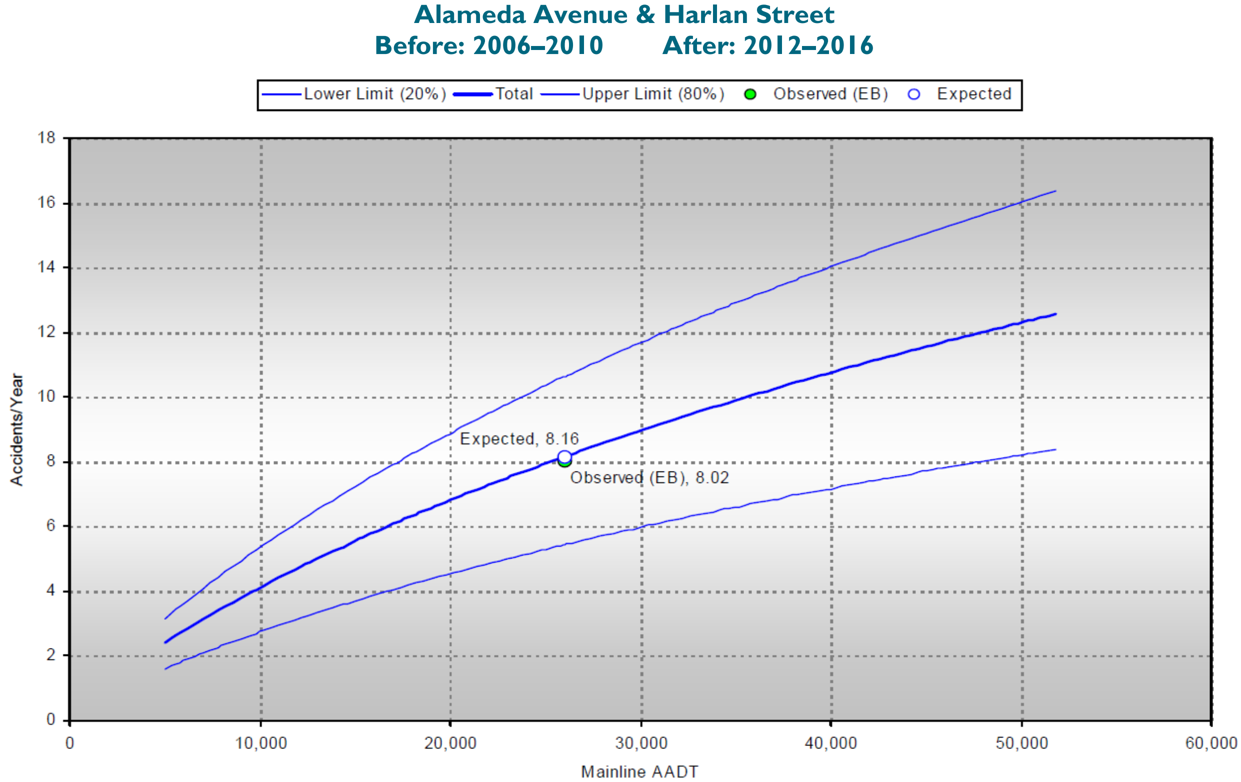


Figure 8. SPF For Total Crashes – After

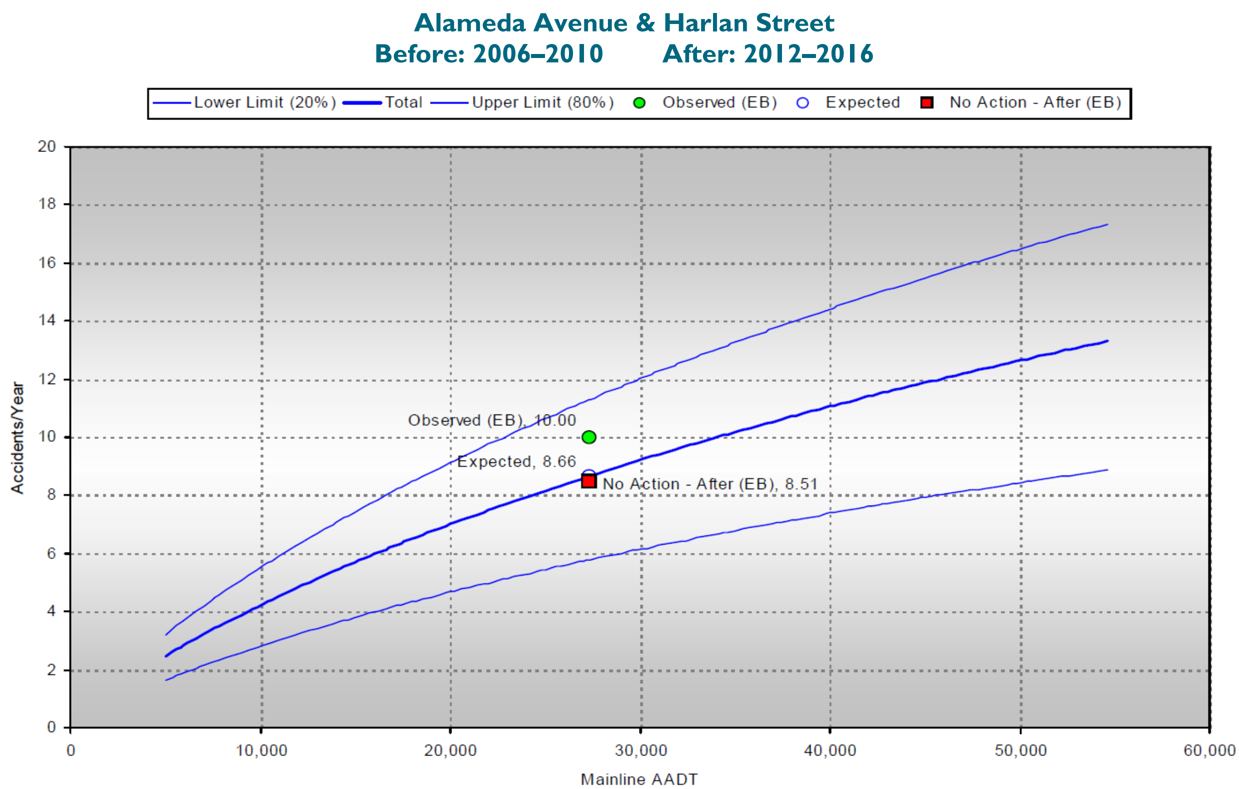


Figure 9. SPF For Severe Crashes – Before

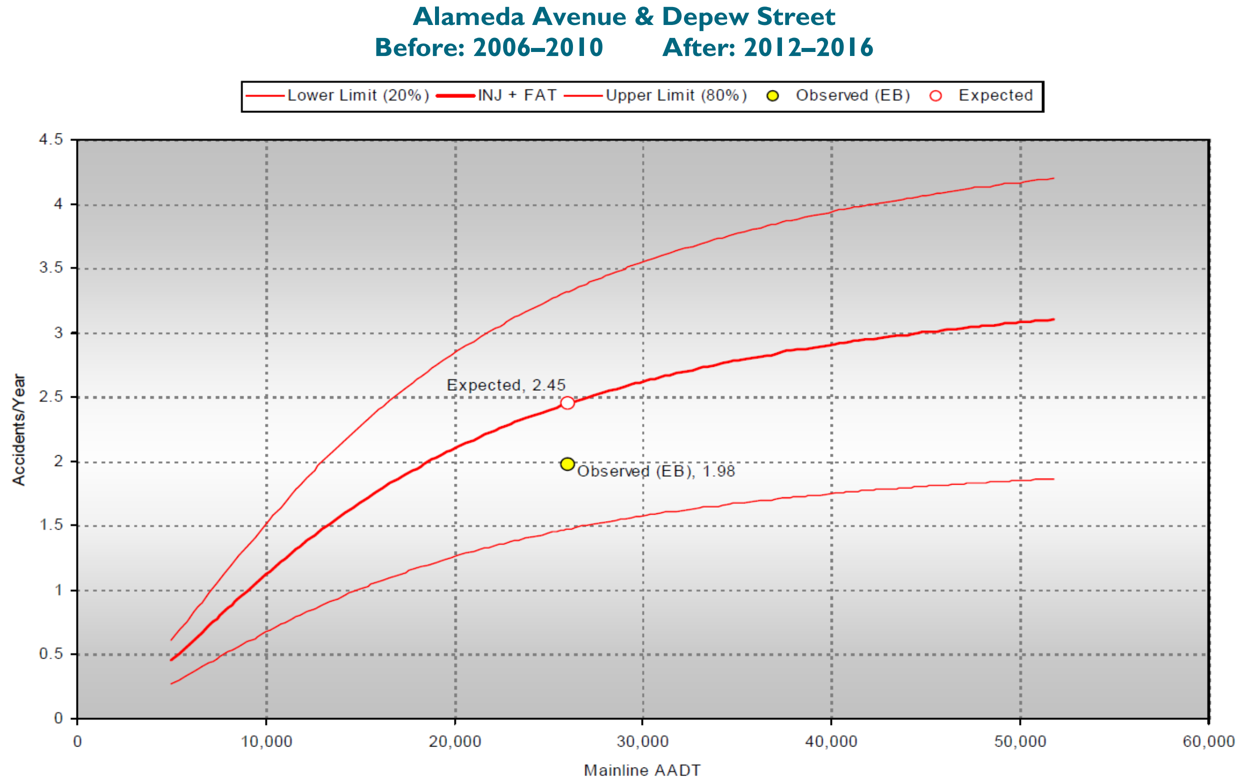


Figure 10. SPF For Severe Crashes – After

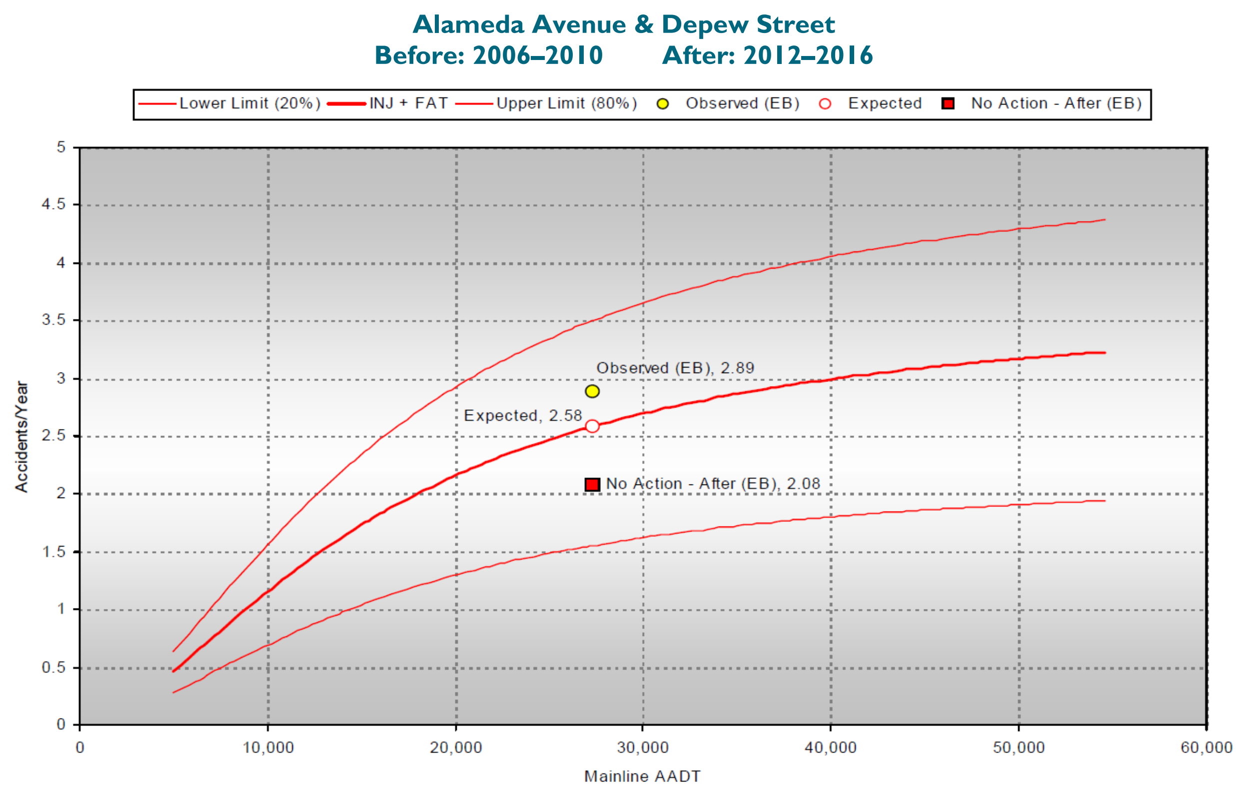


Table 5 provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods at the Alameda Avenue & Harlan Street intersection.

Table 5. Safety Performance Function (SPF) Summary – Harlan St

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Urban 4-Lane Signalized 4-Leg Intersection	Urban 4-Lane Signalized 4-Leg Intersection	Urban 4-Lane Signalized 4-Leg Intersection
Total Crashes			
LOSS	LOSS II	LOSS III	LOSS II
CPY	8.02	10.00	8.51
Mean CPY	8.16	8.66	8.66
Proportion of Mean	0.98	1.15	0.98
Severe (Injury & Fatal) Crashes			
LOSS	LOSS II	LOSS III	LOSS III
CPY	1.98	2.89	2.08
Mean CPY	2.45	2.58	2.58
Proportion of Mean	0.81	1.12	0.81

Crash Type Analyses

A more detailed review of the before and after crash record shows the crash types that were most affected by the traffic signal upgrade at the Alameda Avenue & Harlan Street intersection. **Table 6** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: Rear End, Approach Turn, and Broadside. After the signal upgrade, there was an increase in Rear End crashes (nearly 40%) and Approach Turn crashes (30%). Broadside crashes decreased after the signal upgrade (nearly 40%).

Table 6. Results of Crash Analyses – Harlan St

	Before	After	No Action After
Time Period	01/01/2006 – 12/31/2010 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)
Total Crashes	**40**	**51**	**42**
Fatal (Fatalities)	1 (1)	0 (0)	1 (1)
Injury (Injuries)	8 (12)	15 (17)	8 (12)
PDO	31	36	33
% Reduction in Total (Fatal/Injury/PDO)	--	100% / -42% / -9%	--
Rear End	**16**	**22**	**17**
Injury (Injuries)	3 (5)	5 (6)	3 (5)
PDO	13	17	14
% Reduction in Total (Injury/PDO)	--	-20% / -21%	--
Approach Turn	**10**	**13**	**11**
Injury (Injuries)	4 (6)	5 (6)	4 (6)
PDO	6	8	7
% Reduction in Total (Injury/PDO)	--	0% / -14%	--
Broadside	**8**	**5**	**8**
Injury (Injuries)	1 (1)	0 (0)	1 (1)
PDO	7	5	7
% Reduction in Total (Injury/PDO)	--	100% / 29%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 11** for all crashes at the intersection. The increased injuries experienced at the intersections between the After and No Action conditions are represented by negative CMF in the VZS module. **A calculated B/C ratio of 18.07 was ultimately realized** and is largely attributed to the one likely random fatal crash in the before period.

However, it should be noted that the primary driver in this large B/C ratio is the fatality that occurred in the before period at the Alameda Avenue & Harlan Street intersection, when there were no fatalities in the after period. There is some randomness in whether a severe crash becomes an injury or a fatality, especially when looking at a short time period. Therefore, it is difficult to say if the B/C is a good measure of the project effectiveness. Especially in this case the fatal involved a hit-and-run with a pedestrian in which the driver of the pickup truck was intoxicated, suggesting that reduction in fatalities was not related to signal upgrades.

Figure 11. Benefit-Cost Analysis Summary

Location: Accident History for All Locations **From:**01/01/2012 **To:**12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	33		Weighted PDO:	8.11	-9% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	8	12 :Injured	Weighted INJ:	2.95	-42% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	1	1 :Killed	Weighted FAT:	0.25	100% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	-12% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
	Cost:	$ 216,003				Service Life:	20
	From:	01/01/2006				Capital Recovery Factor:	0.080
	To:	12/31/2010	Days: 1826			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: **18.07** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Alameda & Harlan

Special Notes: Intersection Related Crashes

Project Information

Project Name:		Boyd Lake Ave at 5th St Guardrail			
Project Description:		Guardrail and Signage			
CDOT Region:	4	Project Def:	17561	County:	Larimer
Location:	Boyd Lake Avenue	Mile Points:	N/A	Length:	660 ft
Schedule:		Work Start Date:	Apr 2011	Work End Date:	Sep 2011

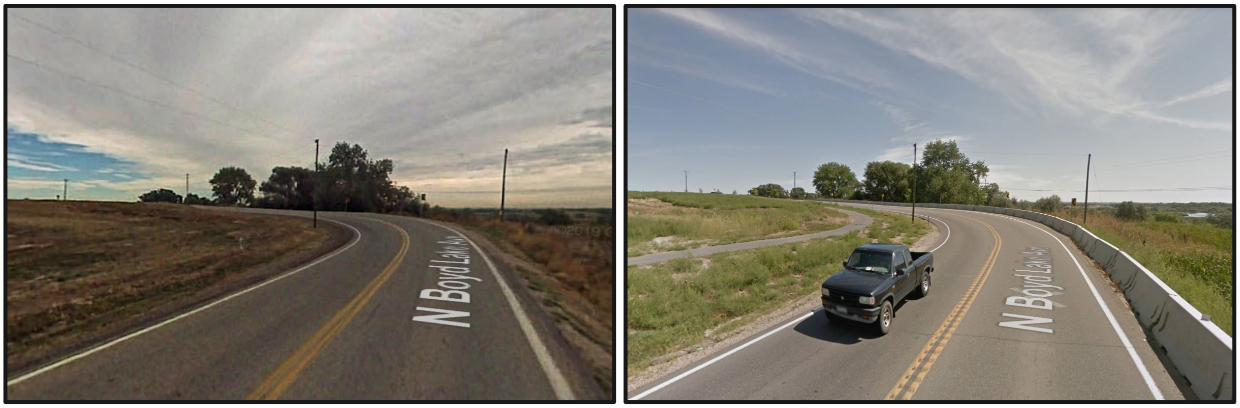
Problem Description:

The project area is a sharp 90-degree curve where 5th Street (also Larimer County Road 20C) meets Boyd Lake Avenue northeast of Loveland, Colorado. The five-year crash history (2006 – 2010) showed that there were four crashes, three of which were injury crashes (4 injured). Three of the four crashes were off-road (left and right) crashes.

5th Street & Boyd Lake Avenue in Loveland, Colorado

Improvement Description:

The project involved installation of approximately 660 feet of Type 7 guardrail along the eastbound 5th Street / northbound Boyd Lake Avenue to deter run off road crashes. Additionally, a centerline rumble strip was installed as well as curve warning signs with a flashing beacon and speed feedback radar signs. The cost of construction was $100,000.



5th Street & Boyd Lake Avenue – Facing Northeast – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements along 5th Street / Boyd Lake Avenue were constructed show an increase in the total number and severity of crashes, although the number of people injured remains the same (four). A comparison of all crash types before and after the improvements were made showed that there was an increase in fixed object crashes (barrier/barricade) and head on crashes.

The total number of crashes increased from 4 to 8, and Injury crashes increased from 3 to 4. The number injuries remained the same at 4 injuries. No fatal crashes were recorded in the before or after period. The ADT increased from 3,569 vpd in the before period to 4,205 vpd in the after period, an increase of approximately 18%.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 10 years for this project was –1.02:1. The result is an improvement that was not justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – LCR 38E

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at along Boyd Lake Ave/5th Street in the project area shows a 100% increase in the number of crashes from the five-year before period (2006-2010) to the five-year after period (2012-2016). The number of injury crashes increased by 33%.

- Before Period: 1 PDO, 3 Injury crashes, 4 injured
- After Period: 4 PDO, 4 Injury crashes, 4 injured

The crash rate for all crashes at this location decreased by 69% between the before period and after period. It should be noted the crash rates calculated are for a very short, 0.22-mile segment.

- Before Period: 4.9 crashes per million vehicle miles traveled
- After Period: 8.3 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses

		Before	After
Time Period:		01/01/2006 – 12/31/2010 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)
AADT	5th St / Boyd Lake Ave	3,569	4,205
Crash Filters:		None	
Total Crashes:		**4**	**8**
Fatal Crashes (Fatalities):		0	0
Injury Crashes (Injuries):		3 (4)	4 (4)
PDO Crashes:		1	4

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for Boyd Lake Avenue in the project area reflect a decrease in the crash record for this project. The intersection is LOSS IV for total frequency of crashes in both the before and after periods and LOSS IV for the severity of crashes in both the before and after periods.

It should be noted that SPF methodology is usually applied to segments that are a minimum of one mile in length and the crashes per mile per year for the study segment is likely inaccurate for Boyd Lake Avenue.

Figure 1. SPF For Total Crashes

Before: 2006–2010 After: 2012–2016

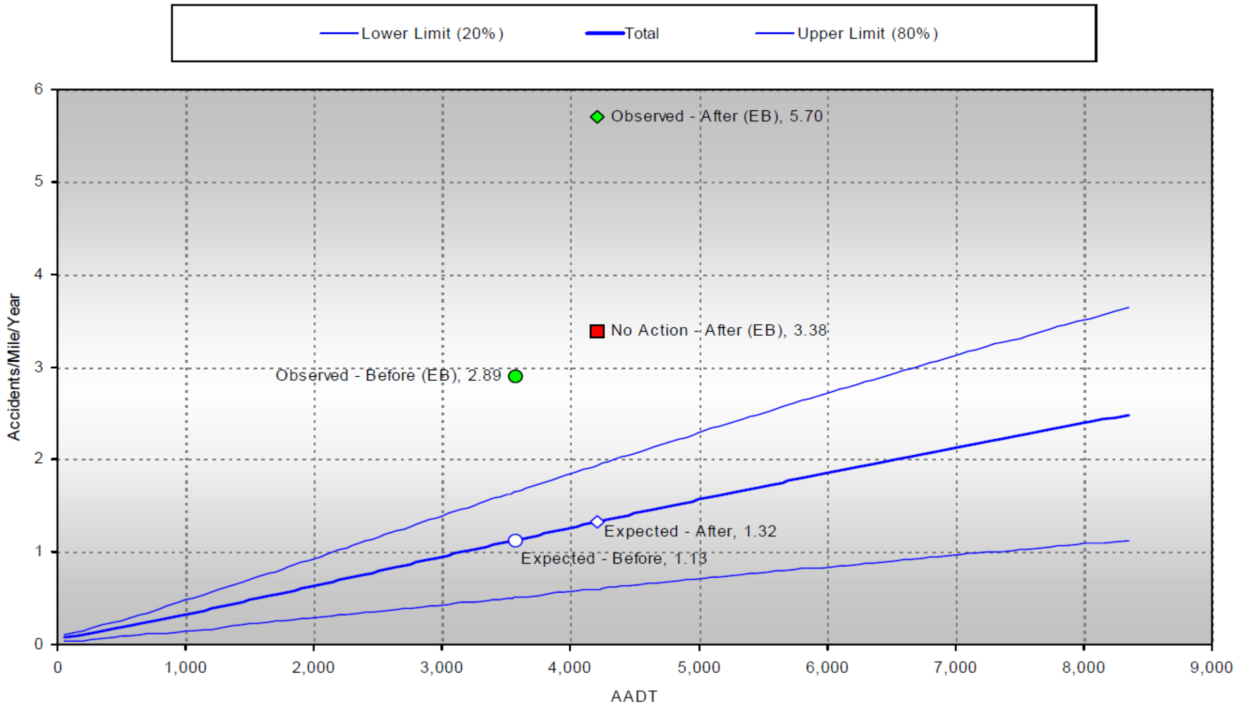


Figure 2. SPF For Severe Crashes

Before: 2006–2010 After: 2012–2016

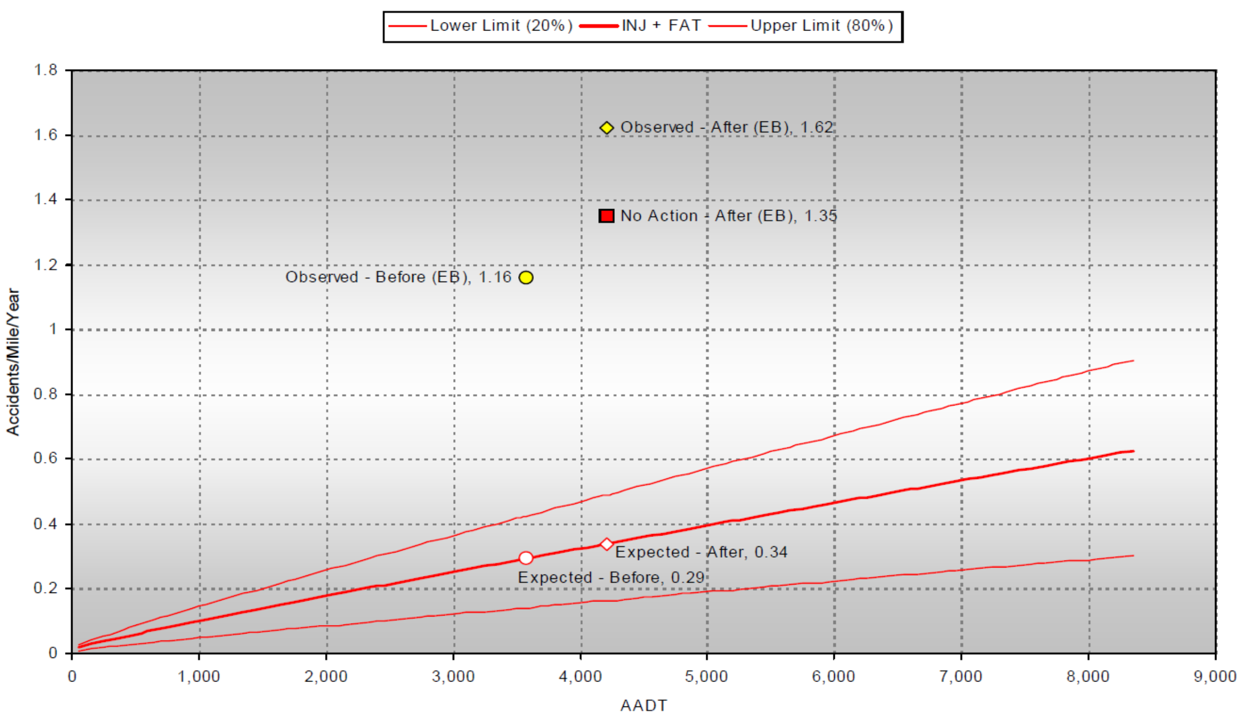


Table 2 provides a summary of the crashes per year (CPY) for Boyd Lake Avenue along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	No	Yes
SPF Graph	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)
Total Crashes			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPYPM	2.90	5.70	3.38
Expected CPYPM	1.13	1.32	1.32
Proportion of Mean	2.56	4.32	2.56
Severe (Injury & Fatal) Crashes			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPYPM	1.15	1.62	1.35
Expected CPYPM	0.29	0.34	0.34
Proportion of Mean	3.97	4.76	3.97

Crash Type Analyses

A more detailed review of the before and after crash record shows that even though off-road were most affected by the roadway improvements, other issues have arisen due to the concrete barrier. **Table 3** shows a comparison of the total, fatal and injury crashes.

The No-Build After crashes were estimated using the change in traffic volumes on Boyd Lake Ave/ 5th St between the before and after period, as found in **Table 1** (approximately 18% increase).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2006 – 12/31/2010 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)
Total Crashes	**4**	**8**	**4**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	3 (4)	4 (4)	3 (4)
PDO	1	4	1
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 0% / -300%	--

Crash Modification Factors

The CMFs identified in the original Benefit Cost Analysis are not available for this analysis.

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The anticipated service life of the project was assumed to be 10 years. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of –1.02 was ultimately realized**.

This outcome indicates that this safety improvement project did not improve safety and could possibly have created unanticipated issues. One likely reason for the decline in safety performance could be inadequate lateral clearance from the edge of travel to the concrete barrier in concert with the sharp turning radius.

Figure 3. Benefit-Cost Analysis Summary

Location: Accident History for All Locations **From:**01/01/2006 **To:**12/31/2010

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	1		Weighted PDO:	0.25	-300% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	3	4 :Injured	Weighted INJ:	0.98	0% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	-24% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
	Cost:	$ 100,000				Service Life:	20
	From:	01/01/2006				Capital Recovery Factor:	0.080
	To:	12/31/2010	Days:	1826		Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: **-1.02** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Guradrail Installation, Centerline Rumble Strips, Warning Signs

Special Notes: Type 7 Concrete Barrier

Project Information

Project Name: Larimer CR 38E MP 8-9 Culvert Repair

Project Description: Culvert Repair

CDOT Region: 4 Project Def: 17568 County: Larimer

Location: LCR 38E Mile Points: N/A Length: 0.17 Miles

Schedule: Work Start Date: Aug 2010 Work End Date: Dec 2010

Problem Description:

The project area includes the segment of Larimer County Road (LCR) 38E approximately between Antlers Court and Cheney Drive in Larimer County, Colorado, west of Fort Collins. This segment had inadequate roadside design and witnessed significantly high number of crashes and severity of crashes, including one fatality. Run Off the Road crash type was of special concern in this segment of LCR 38E.

County Road 38E in Larimer County, Colorado

Improvement Description:

The project involved replacement of a drainage structure, removal of boulders, minor widening and flattening of side slopes of approximately 0.16 miles of LCR 38E, west of the City of Fort Collins. The cost of construction was $122,222.

LCR 38E – Facing Northeast – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements along LCR 38E were constructed shows a significant decrease in the total number and severity of crashes. A comparison of all crash types before and after the improvements were made showed that there was a significant decrease in off-road crashes.

The total number of crashes reduced from 9 to 4, and Injuries + Fatalities (severe crashes) decreased from 5 to 1. The number injuries reduced from 8 to 1; the number of fatalities reduced from 1 to 0. Off-Road crashes reduced from 4 in the before period to 2 in the after period. The AADT decreased by approximately 10% in the after period.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 20 years for this project was 101.6:1. The result is an improvement that was justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – LCR 38E

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at along LCR 38E in the project area shows an approximate 55% decrease in the number of crashes from the three-year before period (2006-2008) to the three-year after period (2011-2013). The number of severe (fatal and injury) crashes decreased by approximately 83%.

- Before Period: 6 severe crashes, 8 injured, 1 fatality
- After Period: 1 severe crashes, 1 injured

The crash rate for all crashes at this intersection decreased by 51% between the before period and after period. It should be noted the crash rates calculated are for a very short, 0.17-mile segment.

- Before Period: 6.9 crashes per million vehicle miles traveled
- After Period: 3.4 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses

		Before	After
Time Period:		01/01/2006 – 12/31/2008 (3 yr)	01/01/2011 – 12/31/2013 (3 yr)
AADT	LCR 38E	7,029	6,315
Crash Filters:		None	
Total Crashes:		**9**	**4**
Fatal Crashes (Fatalities):		1 (1)	0 (0)
Injury Crashes (Injuries):		5 (8)	1 (1)
PDO Crashes:		3	3

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for LCR 38E in the project area reflect a decrease in the crash record for this project. The intersection is LOSS IV for total frequency of crashes in both the before and after periods and LOSS IV for the severity of crashes in both the before and after periods.

It should be noted that SPF methodology is usually applied to segments that are a minimum of one mile in length and the crashes per mile per year for the study segment is likely inaccurate for LCR 38E.

Figure 1. SPF For Total Crashes

Before: 2006–2008 After: 2011–2013

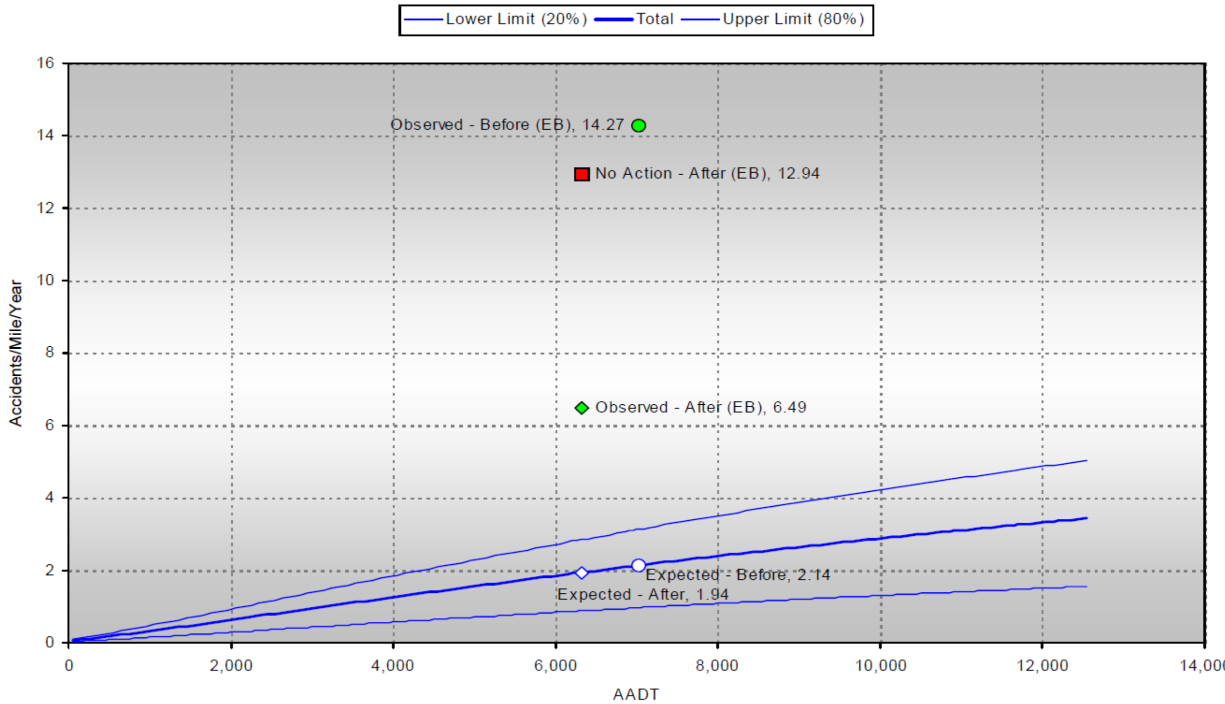


Figure 2. SPF For Severe Crashes

Before: 2006–2008 After: 2011–2013

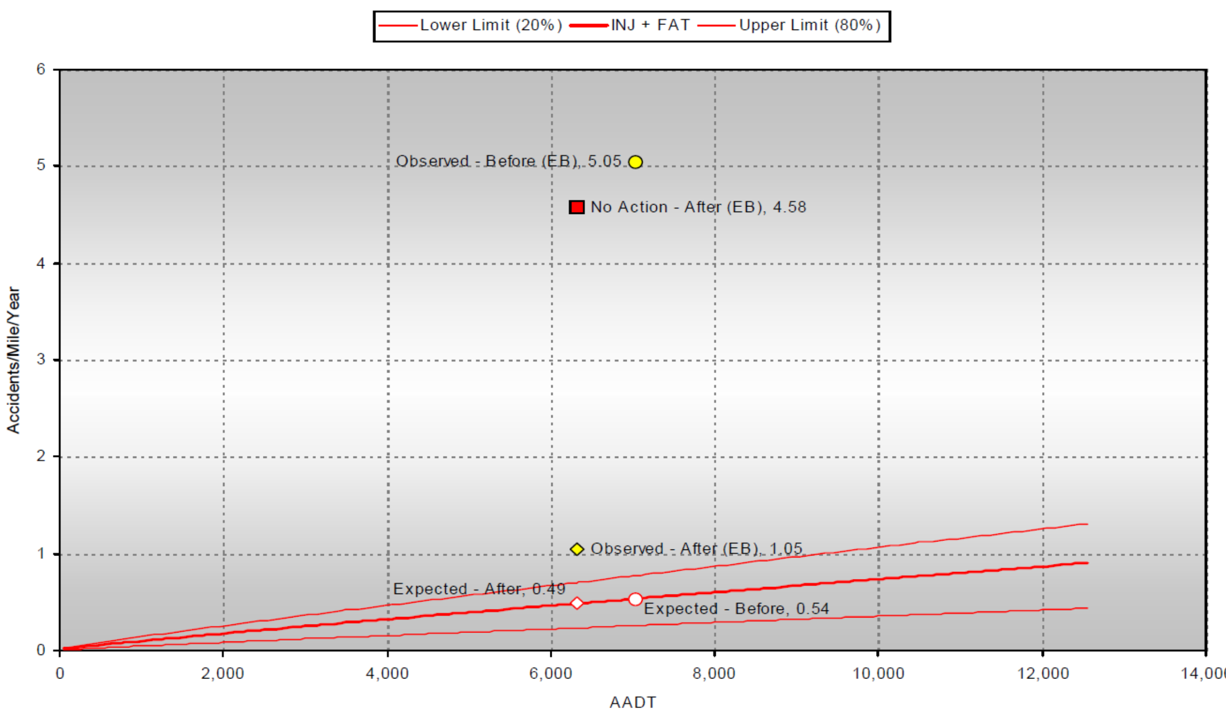


Table 2 provides a summary of the crashes per year (CPY) for LCR 38E along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)
Total Crashes			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPYPM	14.27	6.49	12.94
Expected CPYPM	2.14	1.94	1.94
Proportion of Mean	6.67	3.35	6.67
Severe (Injury & Fatal) Crashes			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPYPM	5.05	1.05	4.58
Expected CPYPM	0.54	0.49	0.49
Proportion of Mean	9.35	2.14	9.35

Crash Type Analyses

A more detailed review of the before and after crash record shows the off-road and off-road-right crash types that were most affected by the roadway improvements. **Table 3** shows a comparison of the total, fatal and injury crashes.

The No-Build After crashes were estimated using the change in traffic volumes on LCR 38E between the before and after period, as found in **Table 1** (approximately 10% decrease).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2006 – 12/31/2008 (3 yr)	01/01/2011 – 12/31/2013 (3 yr)	01/01/2011 – 12/31/2013 (3 yr)
Total Crashes	**9**	**4**	**8**
Fatal (Fatalities)	1 (1)	0 (0)	1 (1)
Injury (Injuries)	5 (8)	1 (1)	4 (7)
PDO	3	3	3
% Reduction in Total (Fatal/Injury/PDO)	--	100% / 86% / 0%	--

Crash Modification Factors

The CMFs identified in the original Benefit Cost Analysis assumed a CMF of 0.8 for all crashes, i.e., a reduction of 20% in PDO and severe crashes. This CMF was based on flattening of roadway side slopes to improve roadside design.

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of 101.6 was ultimately realized** and is largely attributed to significant decrease in number of injury and fatal crashes. This outcome displays that this safety improvement project was justified.

Following minor widening, removal of boulders and flattening of side slopes, crash data suggests a reduction in the targeted crashes. The Resulting B/C analysis would also suggest an effective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: 50 B **Begin:** 318.00 **End:** 359.00 **From:** 01/01/2013 **To:** 12/31/2017

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	3		Weighted PDO:	1.23	0% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	5	7 :Injured	Weighted INJ:	2.87	86% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	1	1 :Killed	Weighted FAT:	0.41	100% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	3.00	58% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
	Cost:	$ 122,222				Service Life:	20
	From:	01/01/2006				Capital Recovery Factor:	0.080
	To:	12/31/2008	Days: 1096			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: **101.60** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Curve Reconstruction

Special Notes: Widen Shoulders, Flatten Side Slopes Remove Boulders, Replace Culvert

Project Information

Project Name:	LCR 27 & LCR 74 E Guardrail				
Project Description:	Install Guardrail				
CDOT Region: 4	Project Def:	17571	County:	Larimer	
Location A: LCR 27	Mile Points:	N/A	Length:	1.50 mi	
Location B: LCR 74E	Mile Points:	N/A	Length:	0.16 mi	
Schedule:	Work Start Date:	Jul 2010	Work End Date:	Jun 2011	

Problem Description:

No problem description was provided for the original HSIP funding application for the intersection improvement project.

Improvement Description:

Between 2010 and 2011, guardrail was installed along several segments of Larimer County Road (LCR) 27 (Buckhorn Road) and LCR 74E (Red Feather Lakes Road Road) in Larimer County, Colorado, west of Fort Collins. The total cost of the project was $117,285.88, approximately $86,791.55 for LCR 27 improvements and $30,494.33 for LCR 74E improvements.

LCR 27 (Buckhorn Road) – Between Ohana Way and Patience Way

LCR 27 (Buckhorn Road) – Before (left) and After (right) improvements

LCR 74E (Read Feather Lakes Road) – Between Mt Axtell Drive and Mt Moriah Rd

LCR 74E (Read Feather Lakes Road) – Facing East – Before (left) and After (right) improvements

Summary & Findings

LCR 27 (Buckhorn Road): The analysis of safety conditions before and after improvements along the LCR 27 corridor were constructed shows a decrease in the total number of crashes. The rate of crashes decreased by 80%, and the number of severe crashes decreased by 100%. Overturning crashes represented 80% of all crashes in the before period but were not observed in the after period.

LCR 74E (Red Feather Lakes Road): The analysis of safety conditions before and after improvements along the LCR 74E corridor were constructed shows a decrease in the total number of crashes. The rate of crashes decreased by 50%, and the number of severe crashes decreased by 100%. Overturning crashes represented 50% of all crashes in the before period but were not observed in the after period.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections and/or segments were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections/segments in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – LCR 27 (Buckhorn Rd)

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records along the approximately 1.5-mile LCR 27 (Buckhorn Road) corridor shows a slight decrease in the total number of crashes from the three-year before period (2006-2008) to the three-year after period (2013-2015). The number of severe (fatal and injury) crashes also decreased.

- Before Period: 5 crashes; 3 severe (3 injured)
- After Period: 1 crash; 0 severe

The crash rate for all crashes along this corridor decreased by 80% between the before and after period.

- Before Period: 0.54 rashes per million vehicle miles traveled
- After Period: 0.29 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses – LCR 27

		Before	After
Time Period:		01/01/2006 – 12/31/2008 (3 yr)	01/01/2013 – 12/31/2015 (3 yr)
AADT	LCR 27:	950	965
Crash Filters:		None	
Total Crashes:		**5**	**1**
Fatal Crashes (Fatalities):		0 (0)	0 (0)
Injury Crashes (Injuries):		3 (3)	0 (0)
PDO Crashes:		2	1

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) along LCR 27 (Buckhorn Road) reflect a decrease in the crash record for this project. The corridor is LOSS IV for total and severe frequency of crashes in the before and LOSS III for total frequency and LOSS II for severe frequency in the after period.

Figure 1. SPF For Total Crashes

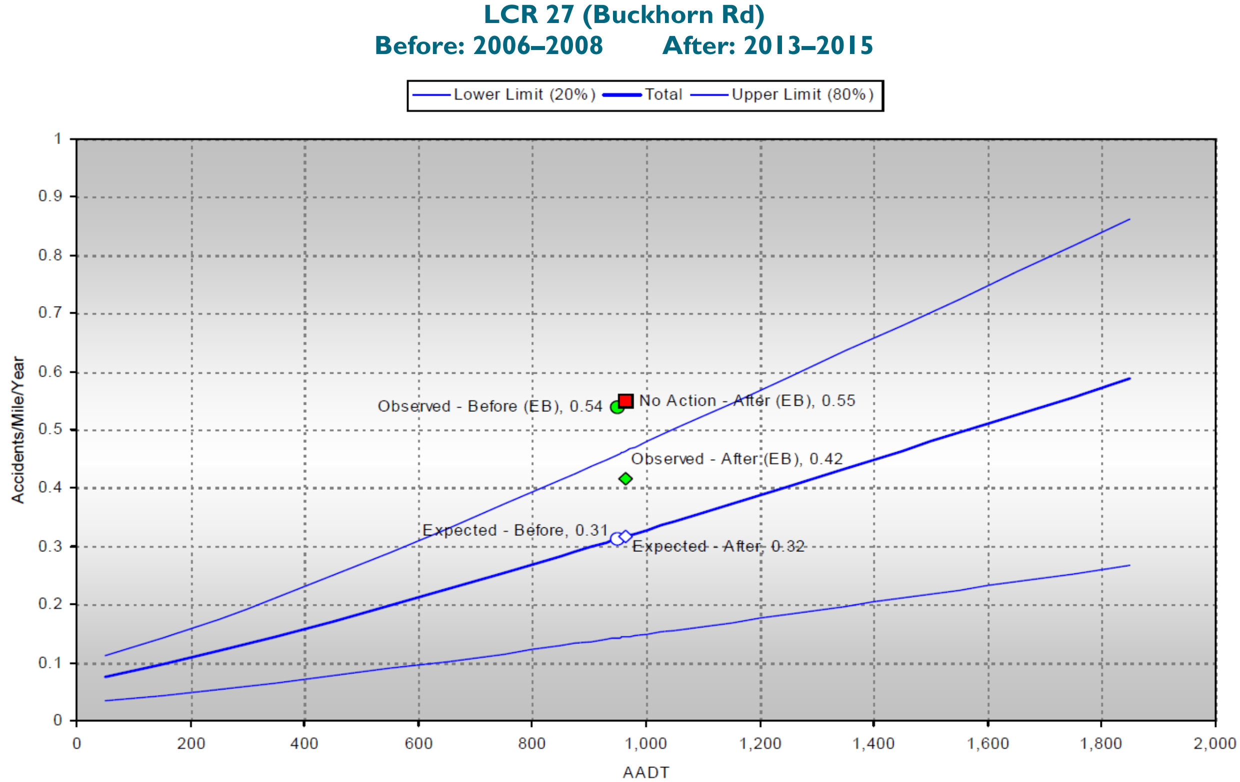


Figure 2. SPF For Severe Crashes

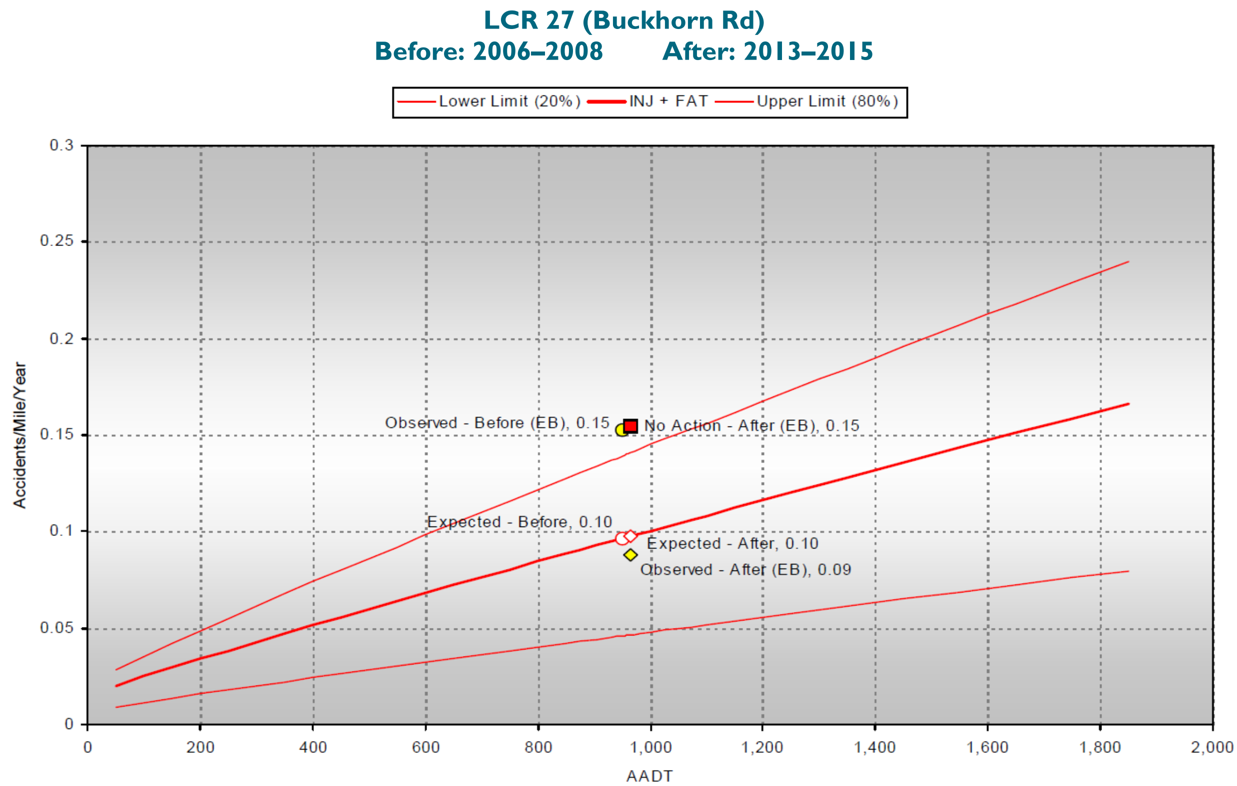


Table 2 provides a summary of the crashes per mile per year (CPMPY) and a comparison with the mean (expected) CPMPY for the before and after periods along the LCR 27 (Buckhorn Road) corridor.

Table 2. Safety Performance Function (SPF) Summary – LCR 27

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)
Total Crashes			
LOSS	LOSS IV	LOSS III	LOSS IV
CPMPY	0.54	0.29	0.55
Mean CPMPY	0.31	0.32	0.32
Proportion of Mean	1.72	0.90	1.72
Severe (Injury & Fatal) Crashes			
LOSS	LOSS IV	LOSS II	LOSS IV
CPMPY	0.15	0.09	0.15
Mean CPMPY	0.10	0.10	0.10
Proportion of Mean	1.58	0.90	1.58

Crash Type Analyses

A more detailed review of the before and after crash record shows the crash types that were most affected by guardrail improvements along LCR 27 (Buckhorn Road). **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: Overturning and Off-Road. After the improvements, no Overturning crashes occurred (100% reduction). There was also a decrease in Off-Road crashes (80% reduction). One Sideswipe (Opposite) and one Head-On crash occurred in the after period. These crash types were not observed in the before period.

The No-Build After crashes were estimated using the change in traffic volumes along LCR 27 between the before and after period, as found in **Table 1** (approximately 1.6%).

Table 3. Results of Crash Analyses – LCR 27

	Before	After	No Action After
Time Period	01/01/2006 – 12/31/2008 (3 yr)	01/01/2013 – 12/31/2015 (3 yr)	01/01/2013 – 12/31/2015 (3 yr)
Total Crashes	**5**	**1**	**5**
Injury (Injuries)	3 (3)	0 (0)	3 (3)
PDO	2	1	2
% Reduction in Total (Injury/PDO)	--	100% / 50%	--
Overturning	**4**	**0**	**4**
Injury (Injuries)	2 (2)	0 (0)	2 (2)
PDO	2	0	2
% Reduction in Total (Injury/PDO)	--	100% / 100%	--
Off Road	**5**	**1**	**5**
Injury (Injuries)	3 (3)	0 (0)	3 (3)
PDO	2	1	2
% Reduction in Total (Injury/PDO)	--	100% / 50%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the corridor. The increased PDO crashes experienced during the After period are represented by negative CMF in the VZS module. **A calculated B/C ratio of 18.61 was ultimately realized**. This indicates that the guardrail improvement resulted in a positive safety benefit that outweighs the construction cost associated with the project.

Figure 3. Benefit-Cost Analysis Summary – LCR 27

Location: Accident History for All Locations **From:**01/01/2013 **To:**12/31/2015

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors				Other Information	
PDO:	2		Weighted PDO:	0.82	50%	:CRF for PDO	Cost of PDO:	$ 11,100
INJ:	3	3 :Injured	Weighted INJ:	1.23	100%	:CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0%	:CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	3.00	80%	:Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
							Service Life:	20
							Capital Recovery Factor:	0.080
							Annual Maintenance/Delay Cost:	$ 0

Cost:	$ 86,792
From:	01/01/2006
To:	12/31/2008
Days:	1095

Benefit Cost Ratio: 18.61 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: LCR 27 - Gaurdrail Construction

Special Notes: Off Road Crashes

Results of Safety Analyses – LCR 74E (Red Feather Lakes Road)

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records along the approximately 0.17-mile LCR 74E (Red Feather Lakes Road) corridor shows a decrease in the total number of crashes from the three-year before period (2006-2008) to the three-year after period (2013-2015). The number of severe (fatal and injury) crashes also decreased.

- Before Period: 4 crashes; 3 severe (4 injured, 2 killed)
- After Period: 2 crashes; 0 severe

The crash rate for all crashes along this corridor decreased by 50% between the before and after period.

- Before Period: 4.28 crashes per million vehicle miles traveled
- After Period: 2.45 crashes per million vehicle miles traveled

Table 4. Results of Overall Crash Analyses – LCR 74E

		Before	After
Time Period:		01/01/2006 – 12/31/2008 (3 yr)	01/01/2013 – 12/31/2015 (3 yr)
AADT	LCR 27:	2,450	2,700
Crash Filters:		None	
Total Crashes:		**4**	**2**
Fatal Crashes (Fatalities):		2 (2)	0 (0)
Injury Crashes (Injuries):		1 (4)	0 (0)
PDO Crashes:		1	2
Crash Types: # (%) [Significance]			
Overturning		2 (50.00%) [97.91%]	0 (0.00%)
Off Road		4 (100.00%) [100.00%]	2 (100.00%)

Safety Performance Functions

SPF plots for both total crashes (**Figure 4**) and for severe (injury and fatal) crashes (**Figure 5**) along LCR 74E (Red Feather Lakes Road) reflect an decrease in the crash record for this project. The corridor is LOSS IV for total frequency of crashes in both the before and after period, LOSS IV for severe frequency of crashes in the before period, and LOSS II for severe frequency of crashes in the after period.

Figure 4. SPF For Total Crashes

LCR 74E (Red Feather Lakes Rd)
Before: 2006–2008 After: 2013–2015

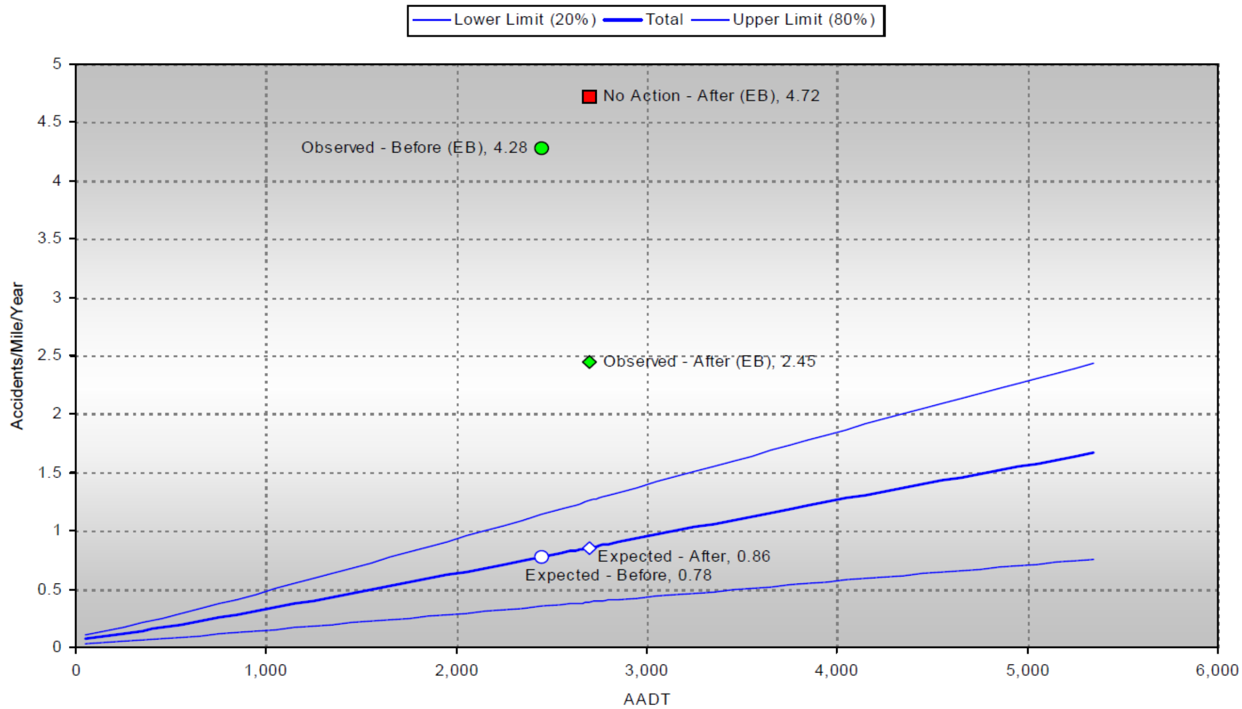


Figure 5. SPF For Severe Crashes

LCR 74E (Red Feather Lakes Rd)
Before: 2006–2008 After: 2013–2015

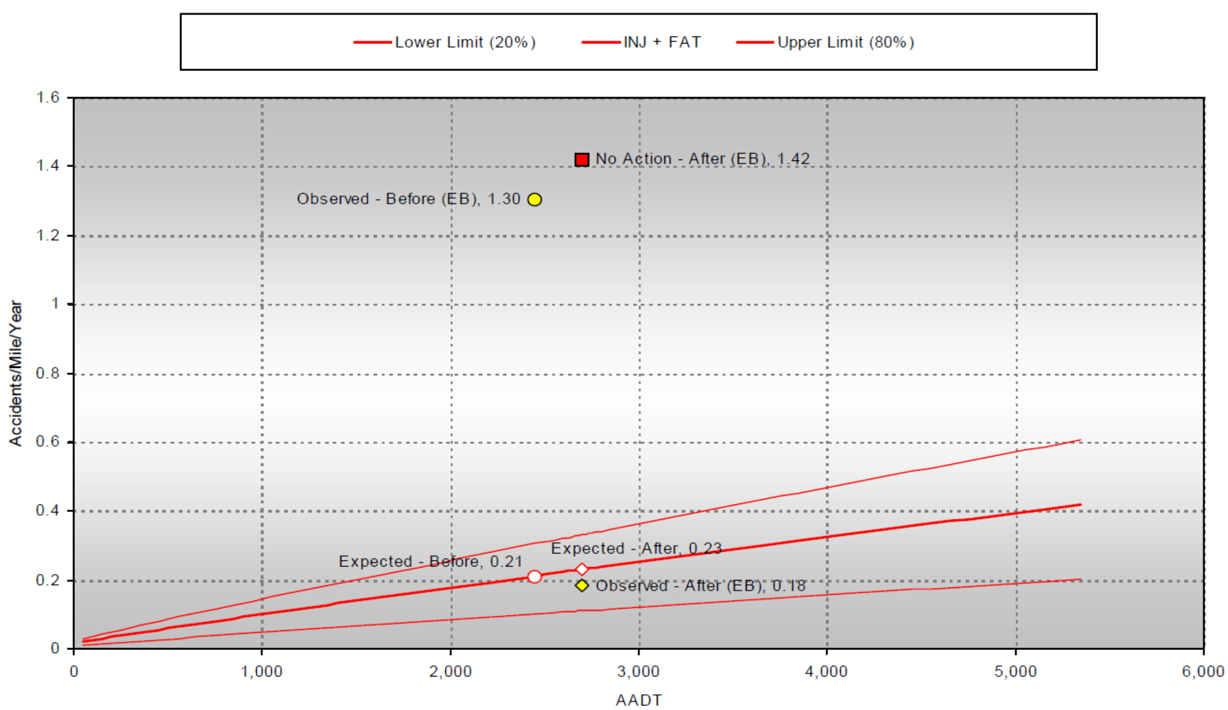


Table 5 provides a summary of the crashes per mile per year (CPMPY) and a comparison with the mean (expected) CPMPY for the before and after periods along the LCR 74E (Red Feather Lakes Road) corridor.

Table 5. Safety Performance Function (SPF) Summary – LCR 74E

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)
Total Crashes			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPMPY	4.28	2.45	4.72
Mean CPMPY	0.78	0.86	0.86
Proportion of Mean	5.51	2.86	5.51
Severe (Injury & Fatal) Crashes			
LOSS	LOSS IV	LOSS II	LOSS IV
CPMPY	1.30	0.18	1.42
Mean CPMPY	0.21	0.23	0.23
Proportion of Mean	6.17	0.79	6.17

Crash Type Analyses

A more detailed review of the before and after crash record shows the crash types that were most affected by guardrail improvements along LCR 74E (Red Feather Lakes Road). **Table 6** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: Overturning and Off-Road. After the improvements, no Overturning crashes occurred (100% reduction). There was also a decrease in Off-Road crashes (50% reduction). Two fixed-object crashes occurred in the after period. These crash types were not observed in the before period.

The No-Build After crashes were estimated using the change in traffic volumes along LCR 74E between the before and after period, as found in **Table 4** (approximately 10.2%).

Table 6. Results of Crash Analyses – LCR 74E

	Before	After	No Action After
Time Period	01/01/2006 – 12/31/2008 (3 yr)	01/01/2013 – 12/31/2015 (3 yr)	01/01/2013 – 12/31/2015 (3 yr)
Total Crashes	**4**	**2**	**4**
Fatal (Fatalities)	2 (2)	0 (0)	2 (2)
Injury (Injuries)	1 (4)	0 (0)	1 (4)
PDO	1	2	1
% Reduction in Total (Fatal/Injury/PDO)	--	100% / 100% / –100%	--
Overturning	**2**	**0**	**2**
Fatal (Fatalities)	2 (2)	0 (0)	2 (2)
Injury (Injuries)	0 (2)	0 (0)	0 (2)
PDO	0	0	0
% Reduction in Total (Fatal/Injury/PDO)	--	100% / 100% / --	--
Off Road	**4**	**2**	**4**
Fatal (Fatalities)	2 (2)	0 (0)	2 (2)
Injury (Injuries)	1 (4)	0 (0)	1 (4)
PDO	1	2	1
% Reduction in Total (Fatal/Injury/PDO)	--	100% / 100% / –100%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 6** for all crashes along the corridor. The increased PDO crashes experienced during the After period are represented by negative CMF in the VZS module. **A calculated B/C ratio of 675.62 was ultimately realized**. This indicates that the guardrail improvement resulted in a positive safety benefit that outweighs the construction cost associated with the project.

It should be noted that the primary drivers in this large B/C ratio are the fatalities that occurred in the before period, when there were no fatalities in the after period. There is some randomness in whether a severe crash becomes an injury or a fatality, especially when looking at a short time period.

Figure 6. Benefit-Cost Analysis Summary – LCR 74E

Location: Accident History for All Locations **From:**01/01/2013 **To:**12/31/2015

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	1		Weighted PDO:	0.41	-99% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	1	4 :Injured	Weighted INJ:	1.64	100% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	2	2 :Killed	Weighted FAT:	0.82	100% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	3.00	50% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
	Cost:	$ 30,494				Service Life:	20
	From:	01/01/2006				Capital Recovery Factor:	0.080
	To:	12/31/2008	Days:	1096		Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: **675.62** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: LCR 74E - Gaurdrail Construction

Special Notes: Off Road Crashes

Project Information

Project Name: Weld Co Rd 34 at Weld Co Rd 17

Project Description: Roadway Geometry Improvements

CDOT Region: 3 Project Def: 17582 County: Weld

Location: Weld Co Rd 34 at Weld Co Rd 17

Schedule: Work Start Date: 7/1/2011 Completion Date: 1/3/2012

Problem Description: As described in the Federal Hazard Elimination Program (FHEP) application for this project, the six-year crash history (2003 – 2008) showed that there was a total of 5 broadside crashes with 1 PDO crash and 4 injury crashes, however our data query in VZS revealed that a total of 10 crashes occurred during that period, including 6 injury crashes and 1 fatal crash, injuring a total of 16 people and killing one. 7 of the 10 crashes were broadsides. The broadside crashes accounted for 11 of the injured people as well as the person that was killed.

Improvement Description: Between August 2011 and January 2012, the grade of Co Rd 17 south of the intersection was flattened to improve sight distance. The cost of construction was $147,181. **Figure 1** shows a plan view of the project location.

Figure 1: CR 17 at CR 34 in Weld County

The FHEP application anticipated that an 35% reduction in broadside crashes might be realized by the improvement. The expected benefit/cost ratio was estimated to be 1.02 based on the 5 crashes they considered. Had they applied this reduction to the number and severity of crashes we are seeing in VZS, the predicted B/C would have been much greater.

Summary and Findings

The analysis of safety before and after the improvements were made on this portion of the corridor shows an increase in both overall crashes and in broadside crashes. There were 6 total crashes at the intersection during the five-year period before the improvements were made (2006 – 2010). In the five years after construction (2013 – 2017), the number of crashes increased to 11, an increase of 83%. Broadside crashes increased in number from 4 during 2006-2010 to 8 during 2013-2017, an increase of 100%.

Even though the only traffic counts we could find for this location (MS2 counts on Co Rd 17 north of the intersection) show a substantial decrease in the traffic volume from 4,609 vpd in 2012 to 2,156 vpd in 2014, we believe it is more likely that traffic stayed near the 4,000-car range throughout the study period. No counts were available for Co Rd 34, but we estimate that the volume on Co Rd 34 is similar to that on Co Rd 17. Therefore, we will assume a volume of 4,000 vpd for both roads for all years examined.

A comparison of all types of crashes before and after the improvements, showed that there was a 100% increase in injury crashes from 3 crashes (7 injuries) in five years before, to 6 crashes (10 injuries) in the five years after. The number of PDO crashes increased 67% from 3 to 5. There were no fatalities in either the before or the after period. Since the number of crashes in all categories of interest increased, it is not meaningful to calculate a benefit/cost ratio for this project.

A comparison of broadside crashes before and after the improvements, showed that there was a 150% increase in injury crashes with a 17% increase in the number of people injured, from 2 crashes (6 injuries) in five years before, to 5 crashes (7 injuries) in the five years after. The number of PDO crashes increased 50% from 2 to 3. There were no fatal broadsides in either the before or the after period.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records at the intersection shows an increase in the number of crashes from 6 during the five-year period (2006 to 2010) before the improvements to 11 during the five-year after period (2013 to 2017) (see **Table 1**). The number of serious crashes also showed an increase in the after period:

- Before (2006 – 2010) – no fatal crashes and 3 injury crashes with 7 injuries
- After (2013 – 2017) – no fatal crashes and 6 injury crash with 10 injuries

There was no measurable change in traffic volumes at the intersection from the before period to the after period that we could determine from the available sources. As a result, the same volumes are used to compute the crash rates in both the before and after periods.

- Before (2006 – 2010): 0.41 crashes per million entering vehicles (cpmev)
- After (2013 – 2017): 0.75 cpmev

Table 1 – Weld Co Rd 34 at Weld Co Rd 17 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2006 to 12/31/2010 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	4,000/4,000	4,000/4,000
Filters:	Intersection Related Crashes	Intersection Related Crashes
Total Crashes	**6**	**11**
Fatal Crashes (Fatalities)	0 (0)	0 (0)
Injury Crashes (Injuries)	3 (7)	6 (10)
Property Damage Only	3	5
Crash Type: # (%) [Significance]		
Broadside	4 (57%) [98.7%]	8 (73%) [99.9%]

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. An 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 2**) and for fatal and injury crashes (see **Figure 3**) reflect the increased crash rate in terms of both total crashes and severe crashes. The LOSS for the after period has increased from LOSS-III in the before period to LOSS-IV in the after period for both total and severe crashes. Since there was not an identifiable change in traffic volume, the before period LOSS also reflects the predicted No-Work after period LOSS.

Figure 2 – SPF for Total Crashes
Weld Co Rd 34 at Weld Co Rd 17
Before: 2006 to 2010 After: 2013 to 2017

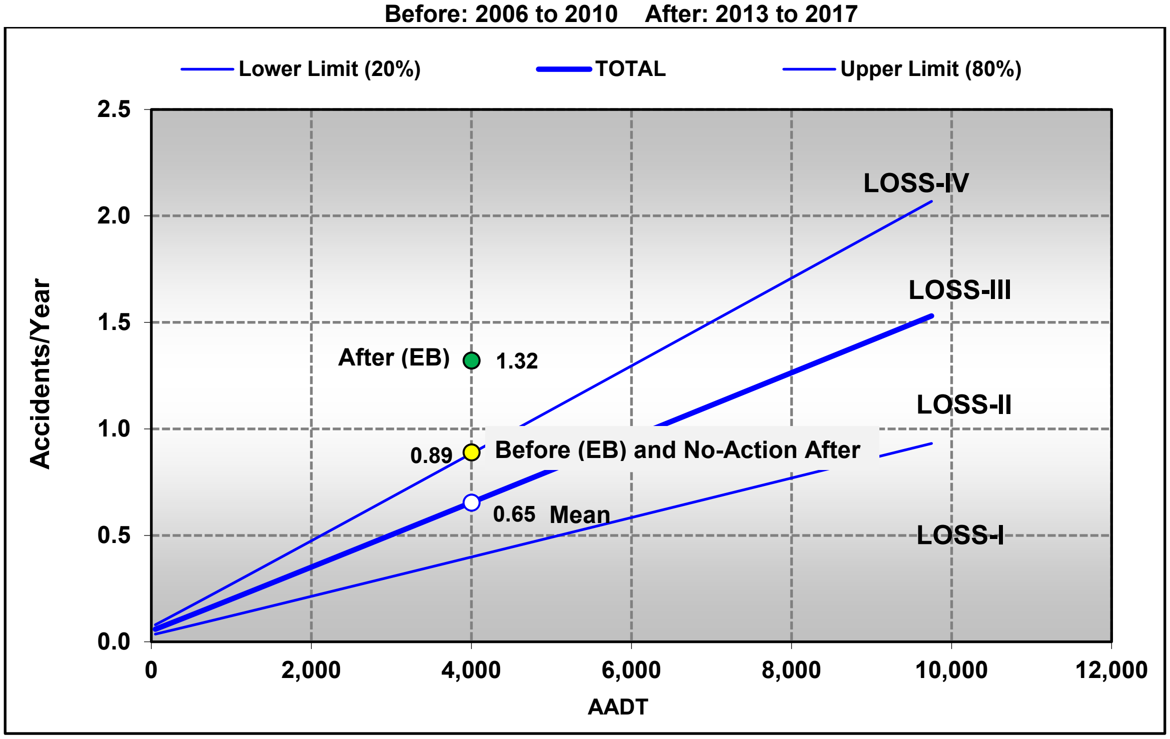


Figure 3 – SPF for Injury and Fatal Crashes
Weld Co Rd 34 at Weld Co Rd 17
Before: 2006 to 2010 After: 2013 to 2017

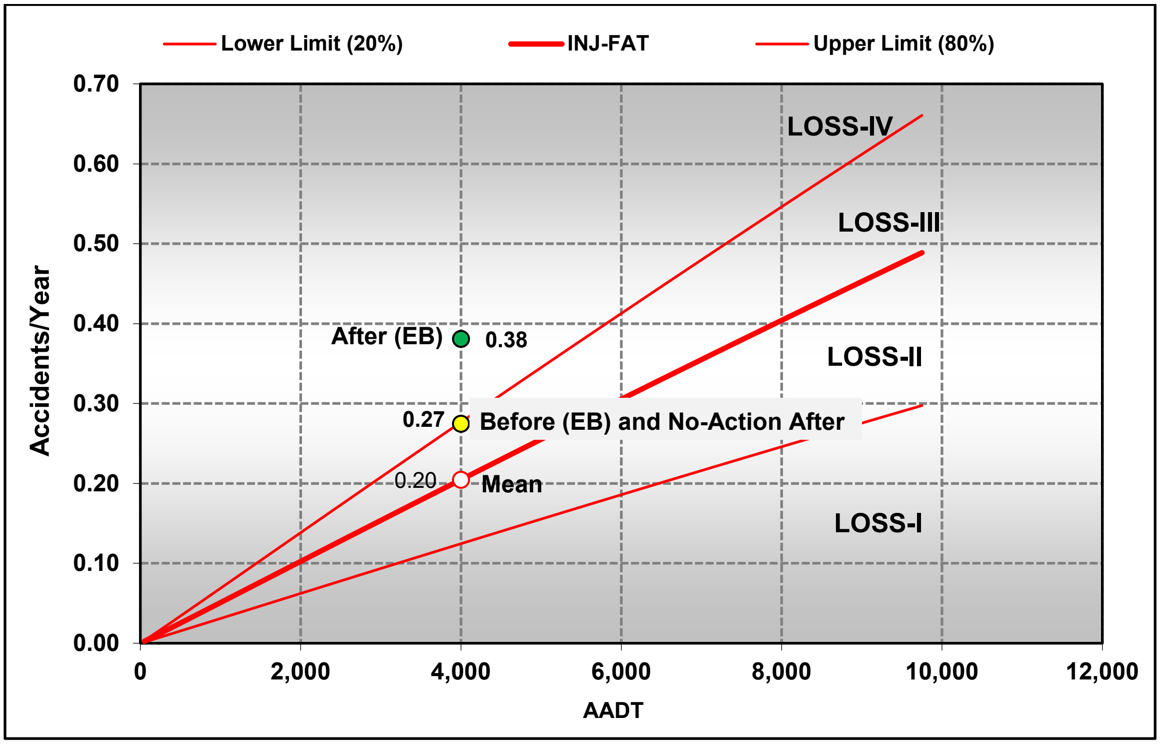


Table 2 provides a summary of the crashes per year CPY and a comparison with the mean (expected) CPY for the before and after periods.

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	Yes	Yes
SPF Graph	Urban, 2-lane, Undivided, Unsignalized, 4-Leg Intersection	Urban, 2-lane, Undivided, Unsignalized, 4-Leg Intersection	Urban, 2-lane, Undivided, Unsignalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS III	LOSS-IV	LOSS III
CPY	0.89	1.32	0.89
Mean CPY	0.65	0.65	0.65
Proportion of Mean	1.37	2.03	1.37
Fatal & Injury Crashes:			
LOSS	LOSS IV	N/A	LOSS IV
CPY	0.27	0.38	0.27
Mean CPY	0.20	0.20	0.20
Proportion of Mean	1.35	1.90	1.35

Vision Zero Suite includes benefit/cost (B/C) analyzes within its procedures. However, as mentioned earlier, since the number of crashes increased, B/C analysis is not meaningful.

It does not appear that any safety benefit was derived from the construction of this project. It was difficult to detect any change in the sight distance using Google Map Street View between the before and after periods and it appears to be adequate in both periods as shown in **Figures 4a-4d**, so it is not surprising that the improvement was not effective. However, it is also unlikely that the increase in crash numbers is related to the improvement. We don't know what the increase is attributable to, but it is possible that traffic volumes have actually increased even though that is not reflected in the counts that were available.
We believe a more effective improvement for this location is to convert it to a 4-way stop intersection or a roundabout. This low-cost improvement is expected to reduce broadside crashes by approximately 60% and overall injuries by about 65%.

Figure 4a: View of Co Rd 17 South of Intersection from Westbound Stop Sign (Before)

Figure 4b: View of Co Rd 17 South of Intersection from Westbound Stop Sign (After)

Figure 4c: View of Co Rd 17 South of Intersection from Eastbound Stop Sign (Before)

Figure 4d: View of Co Rd 17 South of Intersection from Eastbound Stop Sign (After)

Project Information

Project Name: Interstate 70A and State Highways 40A and 82A

Project Description: R3 Radar, VMS, Icing Detection

CDOT Region: 3 Project Def: 17601 Counties: Garfield, Route and Pitkin

Locations: WB I-70, West of Hanging Lake Tunnel Mile Points: 124.00 to 125.00
Length: 1.0 miles

WB SH 40, West of Rabbit Ears Pass Mile Points: 136 to 142.00
Length: 6.0 miles

WB SH 82, South of Snowmass Mile Points: 27.50 to 30.50
Length: 1.5 miles

Schedule: Work Start Date: 2011 Completion Date: 9/6/2012

This project dealt with three locations. The total project cost was $746,933. The work on the project was done during 2011 and 2012. The before period for I-70 and SH 40 in this report will be the 5 years prior to the construction (2006 to 2010), and the after period will be the 5 years following construction (2013-2017). For SH 82 the before period will be the 4 years prior to construction (2007-2010) and the 4 years after the VMS system was implemented (2012-2015), due to problems that occurred with the system beginning in 2016 that would obscure the results. While the improvements for all locations involved some form of signing upgrades, the specific improvements differed. Therefore, we will address each location separately.

Location #1, Westbound I-70 West of Hanging Lake Tunnel

Problem Description: Crashes during adverse wintry road conditions (snowy, icy or slushy roads with and without icy road treatment). I-70 is a four lane Interstate Freeway through this section with no interchanges. However, there is an entrance ramp only from Hanging Lake to the westbound portion of I70 at MP 125.00, and an exit ramp to Hanging Lake from eastbound I70 at about MP 124.95.

Improvement Description: This portion of the project involved the upgrading of Variable Message Signing (VMS) for the purpose of providing warnings relative to conditions ahead. New VMS was provided for westbound traffic on the existing sign bridge structure at MP 124.97. Two VMS panels were provided back-to-back on the existing sign bridge. One of the panels serves eastbound traffic during periods when construction activities require it to be routed to the westbound side of the freeway. There is provision for a crossover at MP 124.95 which enables the running of both directions of traffic on the same side during construction. We estimate that the improvements for this location comprised about $400,000 of the project's total cost.

The FHEP application anticipated that a 25% reduction in relevant types of crashes might be realized by the improvement. The expected benefit/cost ratio was estimated to be 1.28.

Summary and Findings

Traffic counts indicate that the average ADT on this portion of I-70 remained nearly the same for the before and after periods at around 16,000 vehicles per day (16,220 in the before period and 15,800 in the after period).

The analysis of safety before and after the improvements were made on this portion of the corridor shows a reduction in the total number or crashes, but an increase in the number of severe crashes (although there were no fatalities in the after period and 1 in the before period and the number of injured people decreased). There were 121 total crashes on the segment during the five-year period before the improvements were made (2006 – 2010). Among the 121 crashes, 21 resulted in injuries and 1 resulted in fatalities. A total of 40 people were injured and 2 were killed. The remaining 99 crashes involved property damage only. 70 of the crashes (58%) occurred when roads were snowy, icy or slushy.

In the five years after construction (2013 – 2017), the number of crashes decreased to 92, a reduction of 31%. The number of injury related crashes increased from 21 to 24 (14%) and there were no fatal crashes. The number of injured people decreased from 40 to 33 (18%). The remaining 68 crashes involved property damage only. The percentage of crashes that occurred on snowy, icy or slushy roads remained at 58% in the after period.

It is noted that the after period was characterized by increased construction activities that involved the merging of opposing directions of traffic to the same side of the freeway. It is likely that the effects of these conditions played a significant role in the frequency and types of crashes that occurred during that period.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 124.00 to 125.00 shows a decrease in the number of crashes from 121 during the five-year period (2006 to 2010) before the improvements to 92 during the five-year after period (2013 to 2017) (see **Table 1**). The number of serious crashes showed a small increase in the after period:

- Before (2006 – 2010) – one fatal crash with 2 killed and 21 injury crashes with 40 injuries
- After (2013 – 2017) – no fatal crashes and 24 injury crashes with 33 injuries

It is difficult to make a conclusion based on the mixed results in the traffic history, especially considering the variance in conditions between the before and after periods, relative to how the improvements affected the crash rates and severities in the study section.

Table 1 – I-70, West of Hanging Lake (MP 124.00 – 125.00) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2006 to 12/31/2010 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	16,220 vpd	15,800 vpd
Filters:	All Non-Intersection Related Mainline Crashes	All Non-Intersection Related Mainline Crashes
Total Crashes	**121**	**92**
Fatal Crashes (Fatalities)	1 (2)	0
Injury Crashes (Injuries)	21 (40)	24 (33)
Property Damage Only	99	68

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. An 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 of safety quantitatively assesses and qualitatively describes the degree of safety of a roadway segment or intersection in reference to its expected frequency 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**) reflect an improvement in the crash record in terms of total crashes and a worsening in terms of the number of severe crashes, however the fatal and injury SPF does not reflect the reduction in the number of people killed or injured, which decreased. LOSS remained high in the LOSS IV range for both total and severe crashes. **Figures 1** also shows that the number of crashes during the period after construction was only slightly improved in comparison to what it could have been without the project and **Figure 2** shows that the number of severe crashes was worse than what it could have been without the project. Again, it is noted that these comparisons do not account for the influence that construction activities may have had during the after period, so it is not safe to conclude that the project itself contributed to the increase in severe crashes. **Table 2** provides a summary of the crashes per mile per year (CPMPY) and a comparison with the mean (expected) CPMPY for the before and after periods.

Figure 1 – SPF for Total Crashes
I-70A, MP 124.00 to 125.00
Before: 2006 to 2010 After: 2013 to 2017

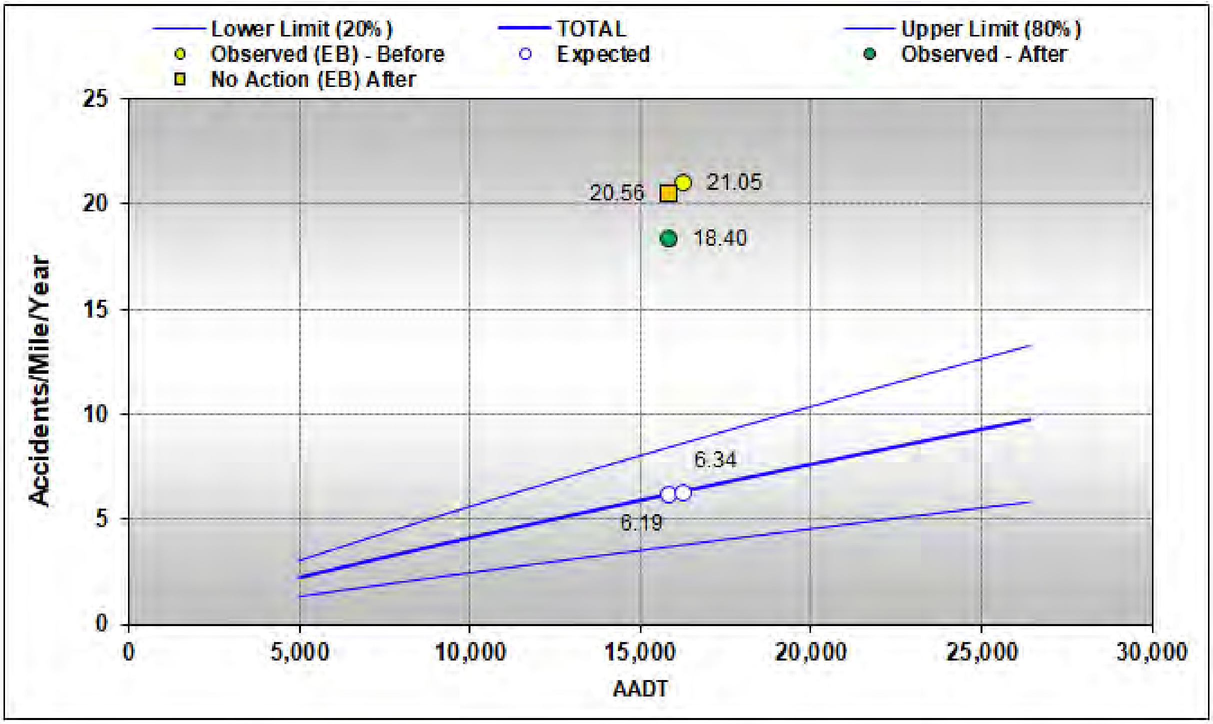


Figure 2 – SPF for Injury and Fatal Crashes
I-70A, MP 124.00 to 125.00
Before: 2006 to 2010 After: 2013 to 2017

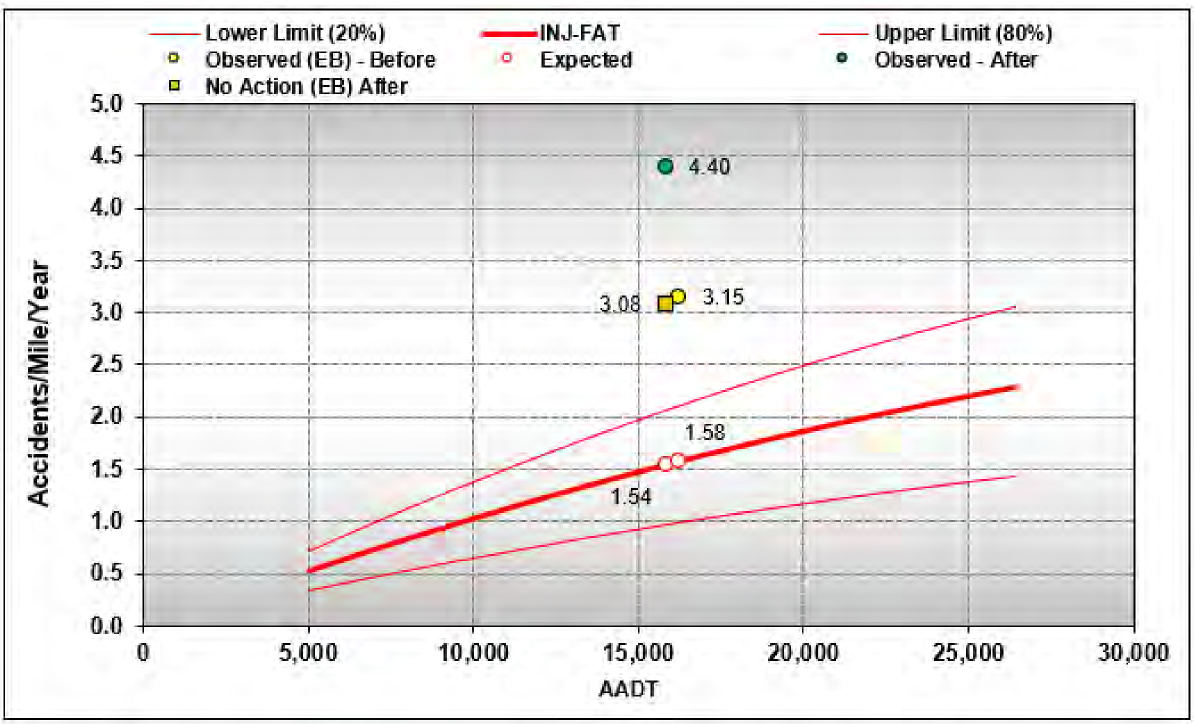


Table 2 – I-70, West of Hanging Lake (MP 124.00 – 125.00) - Safety Performance Function (SPF)

	Before	After	No Action After
EB Correction:	Yes	No	Yes
SPF Graph	Rural Mountainous 4-Lane Divided Freeway	Rural Mountainous 4-Lane Divided Freeway	Rural Mountainous 4-Lane Divided Freeway
Total Crashes:			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPMPY	21.05	18.40	20.56
Mean CPMPY	6.34	6.19	6.19
Proportion of Mean	3.32	2.97	3.32
Fatal & Injury Crashes:			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPMPY	3.15	4.40	3.08
Mean CPMPY	1.58	1.54	1.54
Proportion of Mean	1.99	2.86	1.99

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes in the segment. No annual maintenance is included in the cost since the project only upgraded the existing VMS. **Figure 3** shows the result of the Benefit/Cost calculation is a B/C ratio of **10.54.** This highly positive result is based on the reduced number of people injured and killed, however since the actual number of severe crashes increased some uncertainty remains about the effectiveness of the project from the safety standpoint.

Figure 3 – I-70, West of Hanging Lake (MP 124.00 – 125.00) – Benefit Cost Analysis

Colorado Department of Transportation
DiExSys™ Vision Zero Suite
Economic Analysis Report

08/31/2021
Job #: 20210831111225

Location: 70 A **Begin:** 124.00 **End:** 125.00 **From:** 01/01/2006 **To:** 12/31/2010

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	99		Weighted PDO:	20.62	31% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	21	40 :Injured	Weighted INJ:	8.33	17% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	1	2 :Killed	Weighted FAT:	0.42	100% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	29% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	5
						Capital Recovery Factor:	0.230
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 400,000
From: 01/01/2006
To: 12/31/2010 Days: 1826

Benefit Cost Ratio: 10.54 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: VMS and Signing Upgrades, Weather Monitoring System
Special Notes:

Location #2, Westbound SH 40 West of Rabbit Ears Pass

Problem Description: Crashes during adverse wintry road conditions (snowy, icy or slushy roads with and without icy road treatment). SH 40 is a 2-lane undivided highway through this section with one major junction with SH 131 at MP 136.61 and frequent minor junctions with local road and driveways.

Improvement Description: This portion of the project involved the upgrading of advance signing for the truck ramp at MP 142.20 and grade and curve warning signs for westbound traffic, which included providing flashing beacons for many of the existing signs. Although most of the actual flashing beacon installations were done east of the truck ramp, the area that was anticipated to experience the resultant crash reduction is beyond (west of) the ramp. We estimate that the improvements for this location comprised about $200,000 of the project's total cost.

The FHEP application anticipated that a 25% reduction in relevant types of crashes (i.e. those that occurred on snowy, icy or slushy roads) might be realized by the improvement. The expected benefit/cost ratio was estimated to be 2.81.

Summary and Findings

Traffic counts indicate that the average ADT on this portion of SH 40 decreased from 4,902 vpd in the before period to 4,674 in the after period.

The analysis of safety before and after the improvements were made on this portion of the corridor shows a reduction in both the total number of crashes, and in the number of severe crashes. There were 114 total crashes on the segment during the five-year period before the improvements were made (2006 – 2010). Among the 114 crashes, 26 resulted in injuries and 2 resulted in fatalities. A total of 37 people were injured and 2 were killed. The remaining 86 crashes involved property damage only. 41 of the crashes (36%) occurred when roads were snowy, icy or slushy.

In the five years after construction (2013 – 2017), the number of crashes decreased to 82, a reduction of 28%. The number of injury related crashes increased from 26 to 10 (62%) and there were there was only 1 fatal crash for a reduction of 50%. The number of injured people decreased from 37 to 16 (58%), and the number of people killed decreased to 1 (50%). The remaining 71 crashes involved property damage only, a reduction of 17%. The percentage of crashes that occurred on snowy, icy or slushy roads only decreased 1 percentage point, from 36% to 35%.

It is noted that other features of this section of highway have been altered. The pavement width has been reallocated to provide more shoulder width for eastbound traffic at the expense of shoulder width for westbound traffic, and the vehicle paths were slightly altered as a result. It is likely that these alterations may have influenced the frequency and types of crashes that occurred during the after period. Therefore, the comparisons made in this report may not be completely attributable to the project.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 124.00 to 125.00 shows a decrease in the number of crashes from 114 during the five-year period (2006 to 2010) before the improvements to 82 during the five-year after period (2013 to 2017) (see **Table 1**). The number of serious crashes shows a decrease from 28 in the before period to 11 in the after period:

- Before (2006 – 2010) – 2 fatal crashes and 26 injury crashes with 2 killed and 37 injured
- After (2013 – 2017 – 1 fatal crash and 10 injury crashes with 1 person killed and 16 injured

Table 1 – WB SH 40 West of Rabbit Ears Pass, (MP 36.00 – 42.00) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2006 to 12/31/2010 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	4,902 vpd	4,674 vpd
Filters:	All Mainline Crashes	All Mainline Crashes
Total Crashes	**114**	**82**
Fatal Crashes (Fatalities)	2 (2)	1 (1)
Injury Crashes (Injuries)	26 (37)	10 (16)
Property Damage Only	86	71

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. An 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 of safety quantitatively assesses and qualitatively describes the degree of safety of a roadway segment or intersection in reference to its expected frequency 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**) reflect an improvement in the crash record in terms of both total and severe crashes. LOSS dropped from LOSS-III to LOSS-II for both total and severe crashes. **Figures 1** also shows that the number of crashes during the period after construction was improved in comparison to what it could have been without the project and **Figure 2** shows that the number of severe crashes was significantly lower than what it could have been without the project. Again, it is noted that these comparisons do not account for the influence that subsequent geometrical alterations might have had on the crash history. **Table 2** provides a summary of the crashes per mile per year (CPMPY) and a comparison with the mean (expected) CPMPY for the before and after periods.

Figure 1 – SPF for Total Crashes
SH 40A, MP 36.00 to 42.00
Before: 2006 to 2010 After: 2013 to 2017

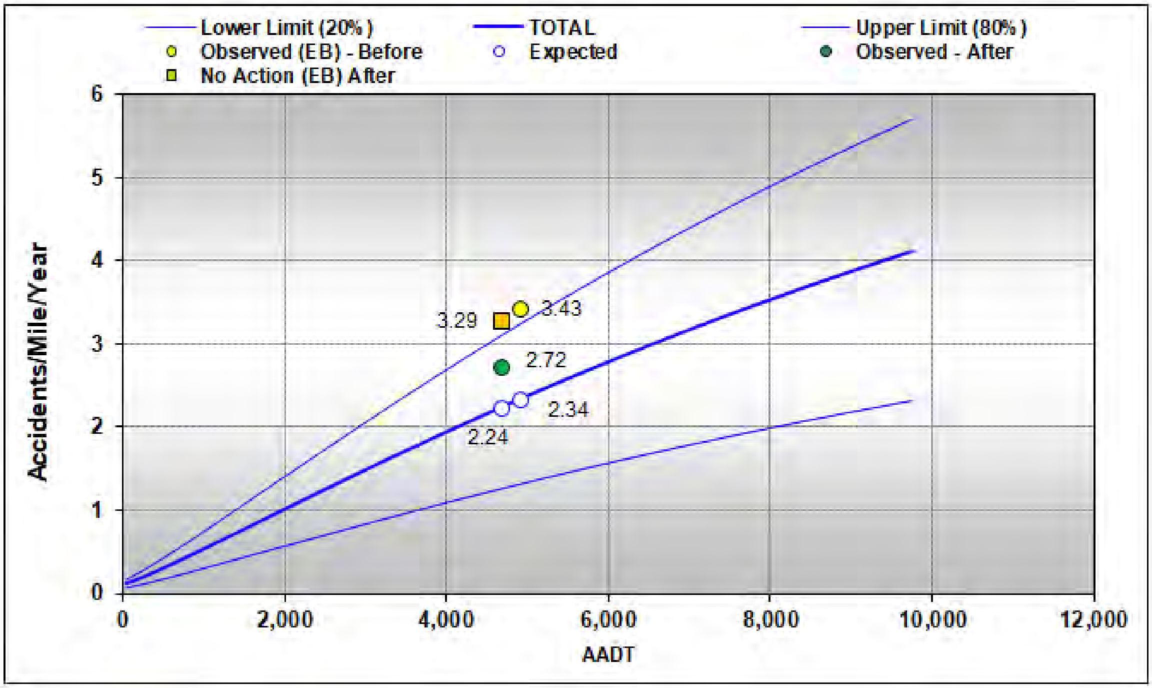


Figure 2 – SPF for Injury and Fatal Crashes
SH 40A, MP 36.00 to 42.00
Before: 2006 to 2010 After: 2013 to 2017

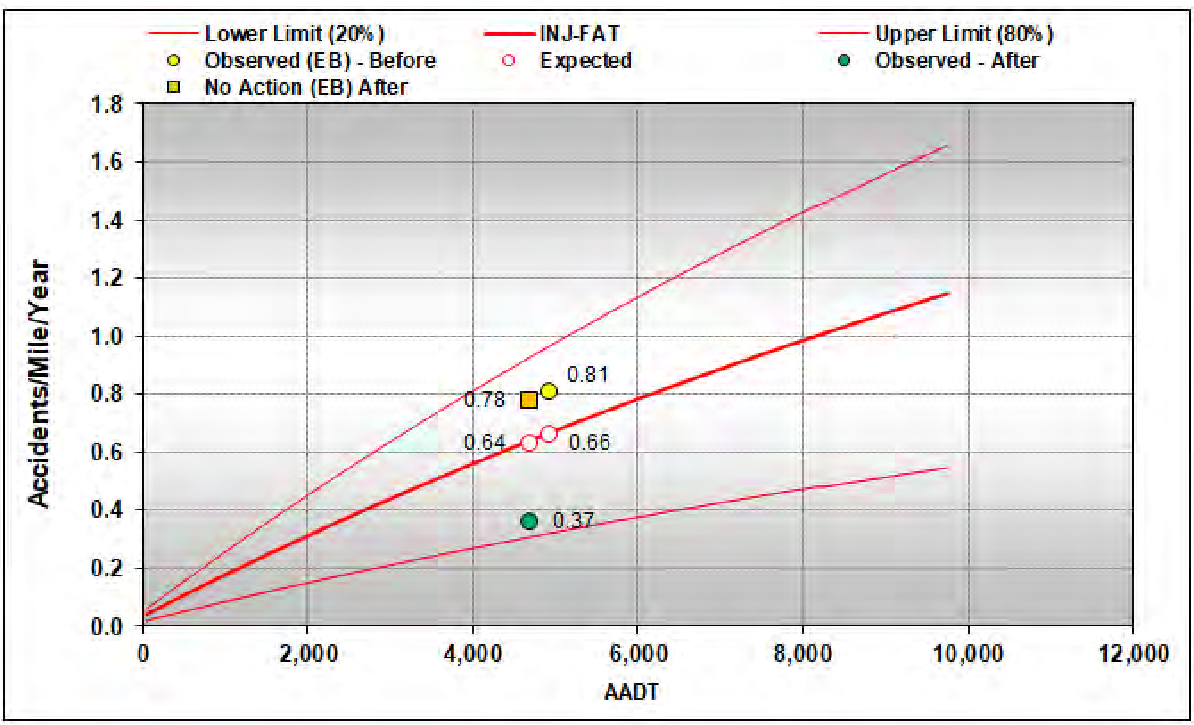


Table 2 – SH 40A (MP 36.00 to 42.00) - Safety Performance Function (SPF)

	Before	After	No Action 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 IV	LOSS IV	LOSS IV
CPMPY	3.429	2.724	3.286
Mean CPMPY	2.338	2.240	2.240
Proportion of Mean	1.46	1.22	1.46
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS II	LOSS III
CPMPY	.812	.365	.781
Mean CPMPY	.664	.638	.638
Proportion of Mean	1.22	0.57	1.22

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes in the segment. **Figure 3** shows the result of the Benefit/Cost calculation is a B/C ratio of **19.47.** This result strongly suggests that the project was justified from cost-effectiveness standpoint even if some of the safety improvement is related to the other noted factors.

Figure 3 – SH 40A (MP 36.00 to 42.00) – Benefit Cost Analysis

Colorado Department of Transportation
DiExSys™ Vision Zero Suite
Economic Analysis Report

08/31/2021

Job #: 20210831161417

Location: 40 A **Begin:** 136.00 **End:** 142.00 **From:** 01/01/2006 **To:** 12/31/2010

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	86		Weighted PDO:	17.91	17% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	26	37 :Injured	Weighted INJ:	7.70	62% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	2	2 :Killed	Weighted FAT:	0.42	50% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	27% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	5
						Capital Recovery Factor:	0.230
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 200,000
From: 01/01/2006
To: 12/31/2010 Days: 1826

Benefit Cost Ratio: 19.47 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Signing upgrades Including flashing beacons
Special Notes:

Location #3, Westbound SH 82 South of Snowmass

Problem Description: Crashes during adverse wintry road conditions (snowy, icy or slushy roads with and without icy road treatment). SH 82 is a 4-lane divided highway through this section with no major junctions. There are several minor access roads and one crossover.

Improvement Description: This portion of the project involved the installation of a Variable Message Sign at MP 30.45 and a supporting weather and roadway surface monitoring system at MP 29.78. We estimate that the improvements for this location comprised about $160,000 of the project's total cost.

The FHEP application anticipated that a 25% reduction in relevant types of crashes (i.e., those that occurred on snowy, icy or slushy roads) might be realized by the improvement. The expected benefit/cost ratio was estimated to be 0.62.

Summary and Findings

We used an influence zone of 3 miles for the study (MP 27.50 to 30.50). The system became functional in February of 2011 so the first full year of use was 2012, which will be the first year of our after period. There were a number of technical difficulties with the system from 2016 to 2018 resulting in an unknown amount of system down-time. In order to get the best comparison between having a properly functioning system and not having it, 2015 will be the last year we use in the after period (4 years total). The before period will be the 4 full years prior to the system's installation (2007-2010).

We will consider only crashes that occurred in the westbound direction on icy, snow or slushy roads since these are the targeted crashes. Traffic counts indicate that the average ADT on this portion of SH 82 decreased from 18,700 vpd in the before period to 17,500 in the after period.

The analysis of safety before and after the improvements were made on this portion of the corridor shows a reduction in both the total number of crashes and in the number of severe crashes. There were 50 total qualifying crashes on the segment during the four-year period before the improvements were made (2007 – 2010). Among the 50 crashes, 13 resulted in injuries with a total of 16 people injured. The remaining 37 crashes involved property damage only. There were no fatal crashes.

In the four years after construction (2012 – 2015), the number of qualifying crashes decreased to 32, a reduction of 36%. The number of injury related crashes decreased from 13 to 8 (38%) with 13 people injured (a decrease of 3 people or 19%). The remaining 24 crashes in the after period involved property damage only, a reduction of 35%. There were no fatal crashes in the after period.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 27.50 to 30.50 shows a decrease in the qualifying number of crashes from 50 during the four-year period (2007 to 2010) before the improvements to 32 during the four-year after period (2012 to 2015) (see **Table 1**). The number of serious crashes shows a decrease from 13 in the before period to 8 in the after period:

- Before (2006 – 2010) – 0 fatal crashes and 13 injury crashes with 16 injured
- After (2012 – 2016) – 0 fatal crashes and 8 injury crashes with 13 injured

Table 1 – WB SH 82 South of Snowmass, (MP 27.50 – 30.50) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2007 to 12/31/2010 (4 yr.)	1/1/2012 to 12/31/2015 (4 yr.)
AADT	18,700 vpd	17,500 vpd
Filters:	Mainline Crashes Non-Intersection Westbound (including North and Northwest) Icy, Snowy or Slushy Roads (with or without treatment)	Mainline Crashes Non-Intersection Westbound (including North and Northwest) Icy, Snowy or Slushy Roads (with or without treatment)
Total Crashes	**50**	**32**
Fatal Crashes (Fatalities)	0 (0)	0 (0)
Injury Crashes (Injuries)	13 (16)	8 (13)
Property Damage Only	37	24

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. An 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.

Because SPFs are calibrated to include crashes that occurred under all roadway conditions, it is not appropriate to use these models to evaluate the subset of crashes that this study is focused on. Therefore, SPFs are not included for this location.

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all westbound crashes that occurred on icy, snowy or slushy roads in the segment. **Figure 3** shows the result of the Benefit/Cost calculation is a B/C ratio of **3.19.** This result strongly suggests that the project was justified from cost-effectiveness standpoint.

Figure 3 – WB SH 82 South of Snowmass, (MP 27.50 – 30.50) – Benefit Cost Analysis

Colorado Department of Transportation
DiExSys™ Vision Zero Suite
Economic Analysis Report

09/02/2021

Job #: 20210902154408

Location: 82 A **Begin:** 27.50 **End:** 30.50 **From:** 01/01/2007 **To:** 12/31/2010

Benefit Cost Ratio Calculations

Crashes			**Projected Crashes and Reduction Factors**			**Other Information**	
PDO:	37		Weighted PDO:	9.63	35% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	13	16 :Injured	Weighted INJ:	4.16	19% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	30% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	4.00	30% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	5
						Capital Recovery Factor:	0.230
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 160,000
From: 01/01/2007
To: 12/31/2010 Days: 1461

Benefit Cost Ratio: 3.19 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Installation of VMS and Weather and Road Condition Station
Special Notes:

Project Information

Project Name: S. Carefree Roundabout Improvements

Project Description: Lane reduction from 2 lanes to 1 lane to remove overlap

CDOT Region: 2 Project Def: 17608 County: El Paso

Location: At S. Carefree Circle and N New Center Point in Colorado Springs

Schedule: Work Start Date: Not Shown Completion Date: 6/10/2014

Problem Description: As described in the Federal Hazard Elimination Program (FHEP) application for this project, the five-year crash history (2005 – 2008) showed that there was a total of 1 injury crashes, 47 PDO crashes, and 0 fatal crashes. S. Carefree Circle and N. New Center Point

Improvement Description: Between September 2013 and June 2014, the approaches to the roundabout were reconfigured and the roundabout was re-striped so that the outer lanes are all right turn only lanes. The cost of construction was $116,350.

The FHEP application anticipated that a 30% reduction in all types of crashes might be realized by the improvement. The expected benefit/cost ratio was estimated to be 4.42.

Summary and Findings

The analysis of safety before and after the improvements were made on this portion of the corridor shows a reduction in the number and severity of all crash types. There were 53 total crashes at the roundabout during the five-year period before the improvements were made (2008 – 2012). In the five years after construction (2015 – 2019), the number of crashes decreased to 17, a reduction of 68%. Traffic counts were not available for either of the involved roadways. However, comparisons of traffic counts for nearby roadways suggest that the volume of traffic would likely have increased substantially between the before and after periods.

A comparison of all types of crashes before and after the improvements were made, showed that there was an 80% decrease in injury crashes from 5 crashes (5 injuries) in five years before to 1 crash (1 injury) in the five years after. The number of PDO crashes was reduced from 48 to 16. There were no fatalities either the before or the after period. The ratio of benefits of crash reduction to the cost of construction over the life cycle of 20 years for this project is **20.11** to one. The result is an improvement that certainly was justified from the safety improvement as well as cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records at the roundabout shows a decrease in the number of crashes from 53 during the five-year period (2008 to 2012) before the improvements to 17 during the five-year after period (2015 to 2019) (see **Table 1**). The number of serious crashes also showed a decrease in the after period:

- Before (2008 – 2012) – no fatal crashes and 5 injury crashes with 5 injuries
- After (2015 – 2019) – no fatal crashes and 1 injury crash with 1 injury

Even though there are no SPFs and overdispersion parameters available for roundabouts in Colorado at present, the correction for the Regression to the Mean bias is expected to be minimal given the length of the before period (5 years) and observed number of crashes (53). It is reasonable to conclude that the observed significant decrease in the frequency and severity of crashes is attributed to the various safety improvements constructed on this project.

Table 1 – S. Carefree Circle and New Center Point Roundabout - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2008 to 12/31/2012 (3 yr.)	1/1/2015 to 12/31/2019 (3 yr.)
AADT	Unknown	Unknown
Filters:	All Intersection/Roundabout Related Crashes	All Intersection/Roundabout Related Crashes
Total Crashes	**53**	**17**
Fatal Crashes (Fatalities)	0 (0)	0
Injury Crashes (Injuries)	5 (5)	1 (1)
Property Damage Only	48	16

The magnitude of safety problems on select highway sections and intersections can be assessed thought 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. However, SPF Analysis requires that the functions be calibrated specifically for the facility type and region being evaluated. At this time, these functions have not been derived for roundabouts in the State of Colorado or the City of Colorado Springs, so SPF analysis cannot be provided for this project.

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 2** for all crashes in the segment. **Figure 2** shows that the result of the Benefit/Cost calculation is a B/C ratio of **20.11.** This result shows that the project was justified from cost-effectiveness standpoint.

Figure 2 – S. Carefree Circle and New Center Point Roundabout – Benefit Cost Analysis

COLORADO SPRINGS

Colorado Springs Colorado
DiExSys™ Vision Zero Suite
Economic Analysis Report

08/20/2021

Job #: 20210820123533

Location: Accident History for CAREFREE and CENTER **From:**01/01/2008 **To:**12/31/2012

Benefit Cost Ratio Calculations

Crashes			**Projected Crashes and Reduction Factors**			**Other Information**	
PDO:	48		Weighted PDO:	11.79	67% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	5	5 :Injured	Weighted INJ:	1.23	80% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	10% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	68% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
		Cost: $ 116,350				Capital Recovery Factor:	0.080
		From: 01/01/2008				Annual Maintenance/Delay Cost:	$ 0
		To: 12/31/2012	Days: 1827				

Benefit Cost Ratio: 20.11 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Roundabout Improvements

Special Notes: Roundabout was reconfigured to provide only 1 lane to prevent overlaps.

Project Information

Project Name: US 6 and SH 139 Signal in Loma

Project Description: Signal Design and Intersection Geometry Improvements

CDOT Region: 3 Project Def: 17627 County: Mesa

Location: Intersection of US 6 with SH 139 in the Town of Loma

Schedule: Work Start Date: 2/2/2016 Completion Date: 7/28/2016

Problem Description: As described in the Federal Hazard Elimination Program (FHEP) application for this project, the three-year crash history (2003 – 2005) showed that there was a total of 16 crashes with 7 PDO crashes, 9 injury crashes (15 people injured), and 0 fatal crashes. All of the 16 crashes were broadsides.

Improvement Description: Between February 2015 and July 2015, the approaches to the intersection were widened, adding left turn lanes for all 4 directions, and traffic signals were installed. The cost of construction was $2,600,155. **Figures 1a and 1b** shows plan views of the project location before and after the improvements were made.

Figure 1a: SH 6 and SH 139 in 2011

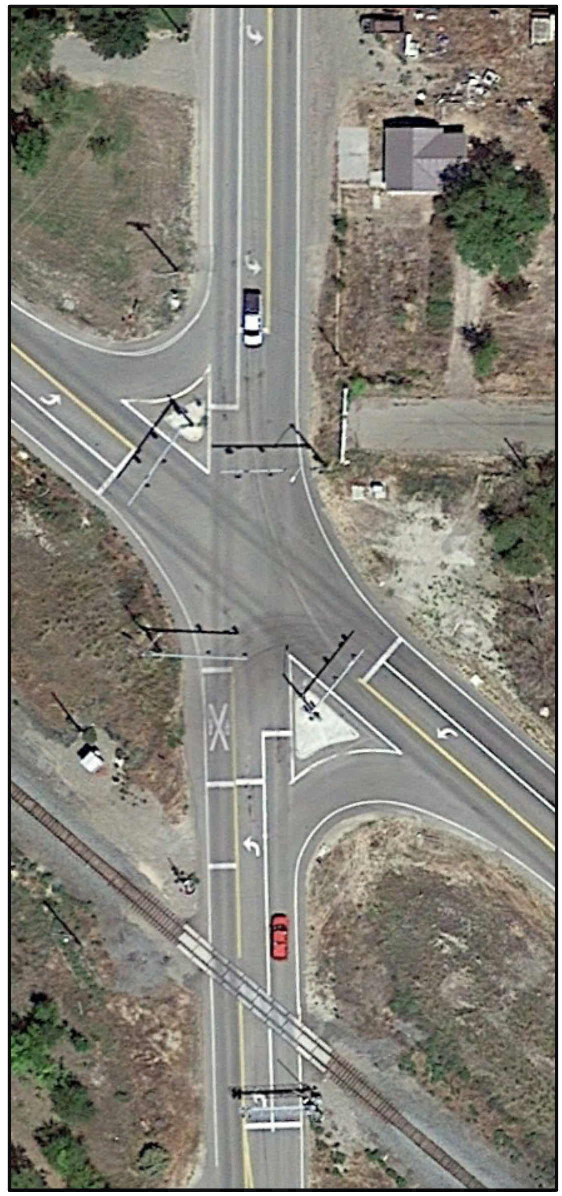


Figure 1b: SH 6 and SH 139 in 2019

The FHEP application anticipated that an 80% reduction in broadside crashes might be realized by the improvement. The expected benefit/cost ratio was estimated to be 1.02.

Summary and Findings

The analysis of safety before and after the improvements were made on this portion of the corridor shows a reduction in the number and severity of all crash types. There were 11 total crashes at the intersection during the four-year period before the improvements were made (2010 – 2014). In the four years after construction (2016 – 2019), the number of crashes decreased to 4, a reduction of 64%. Traffic counts suggest that the total traffic through the intersection decreased slightly between the before and after period, however the variance between available count sources was greater than average decreases, so we will consider the traffic volume to be unchanged at approximately 2,000 vpd for each roadway entering the intersection, so the projected no-work crashes will equal the number of crashes in the before period.

A comparison of all types of crashes before and after the improvements, showed that there was a 50% decrease in injury crashes from 6 crashes (12 injuries) in four years before to 3 crashes (3 injuries) in the four years after. The number of PDO crashes was reduced from 5 to 1. There were no fatalities either the before or the after period. The ratio of benefits of crash reduction to the cost of construction over the life cycle of 20 years for this project is **1.41** to one. The result is an improvement that appears justified from the safety improvement as well as cost effectiveness standpoints.

A comparison of broadside crashes before and after the improvement showed an 80% reduction in broadsides from 10 crashes in the before period to only 2 crashes in the after period. The number of injury-related broadside crashes decreased 83% from 6 in the before period to 1 in the after period. There were 12 people injured in broadside crashes in the before period and only 1 injured in the after period, a reduction of about 92%.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records at the intersection shows a decrease in the number of crashes from 11 during the four-year period (2011 to 2014) before the improvements to 4 during the four-year after period (2016 to 2019) (see **Table 1**). The number of serious crashes also showed a decrease in the after period:

- Before (2011 – 2014) – no fatal crashes and 6 injury crashes with 12 injuries
- After (2016 – 2019) – no fatal crashes and 3 injury crash with 3 injuries

There was no measurable change in traffic volumes at the intersection from the before period to the after period that we could determine from the available sources. As a result, the same volumes are used to compute the crash rates in the both the before and after periods. If there were in fact an increasing trend in the volume of traffic, the conclusions that follow would show a somewhat more pronounced degree of safety improvement.

- Before (2011 – 2014): 1.88 crashes per million entering vehicles (cpmev)
- After (2016 – 2019): 0.58 cpmev

Table 1 – US 6 at SH 139 in Loma - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2016 to 12/31/2019 (4 yr.)
AADT	2000/2000	2000/2000
Filters:	Intersection Related Crashes	Intersection Related Crashes
Total Crashes	**11**	**4**
Fatal Crashes (Fatalities)	0 (0)	0
Injury Crashes (Injuries)	6 (12)	3 (3)
Property Damage Only	5	1
Crash Type: # (%) [Significance]		
Broadside	10 (91%) [>99.9%]	2 (50%) [99.1%]

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. An 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 2**) and for fatal and injury crashes (see **Figure 3**) reflect an improvement in the crash record in terms of both total crashes and severe crashes. Although the LOSS remained in the LOSS IV range for both total and severe crashes, it both were substantially reduced. Since there was not an identifiable change in traffic volume, the before period LOSS also reflects the predicted No-Work after period LOSS.

Figure 1 – SPF for Total Crashes
US 6 at SH 139 in Loma
Before: 2011 to 2014 After: 2016 to 2019

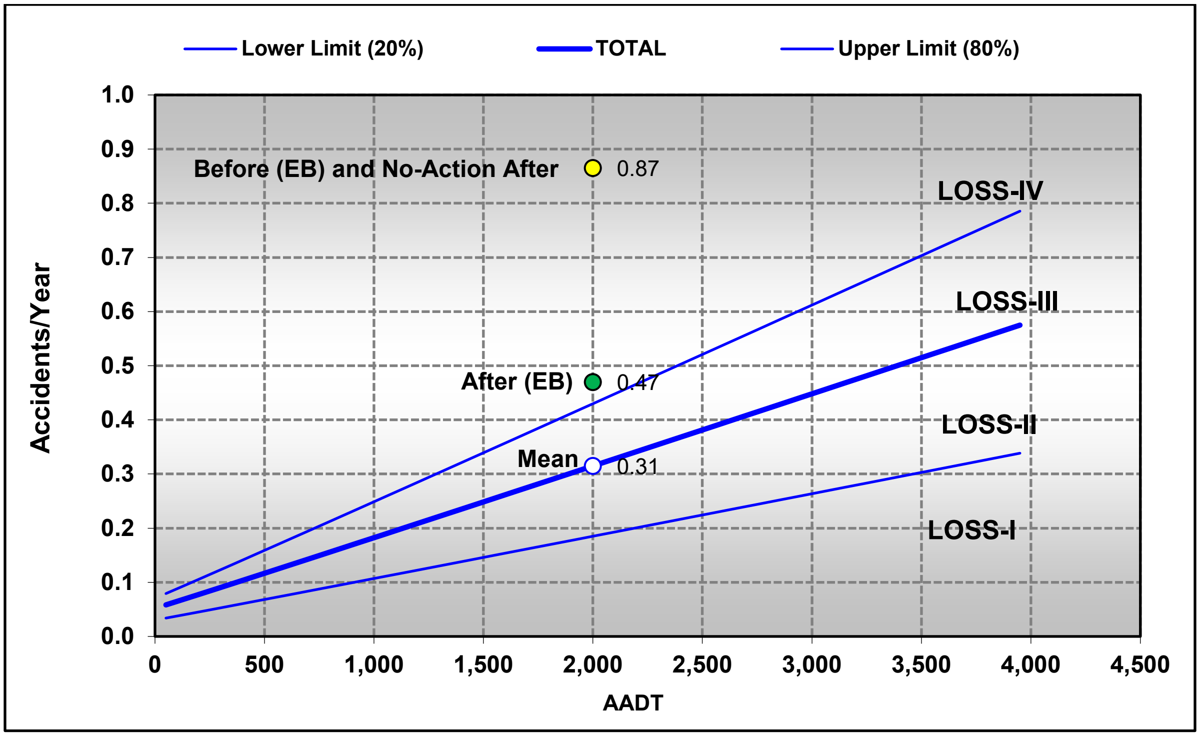


Figure 2 – SPF for Injury and Fatal Crashes
US 6 at SH 139 in Loma
Before: 2011 to 2014 After: 2016 to 2019

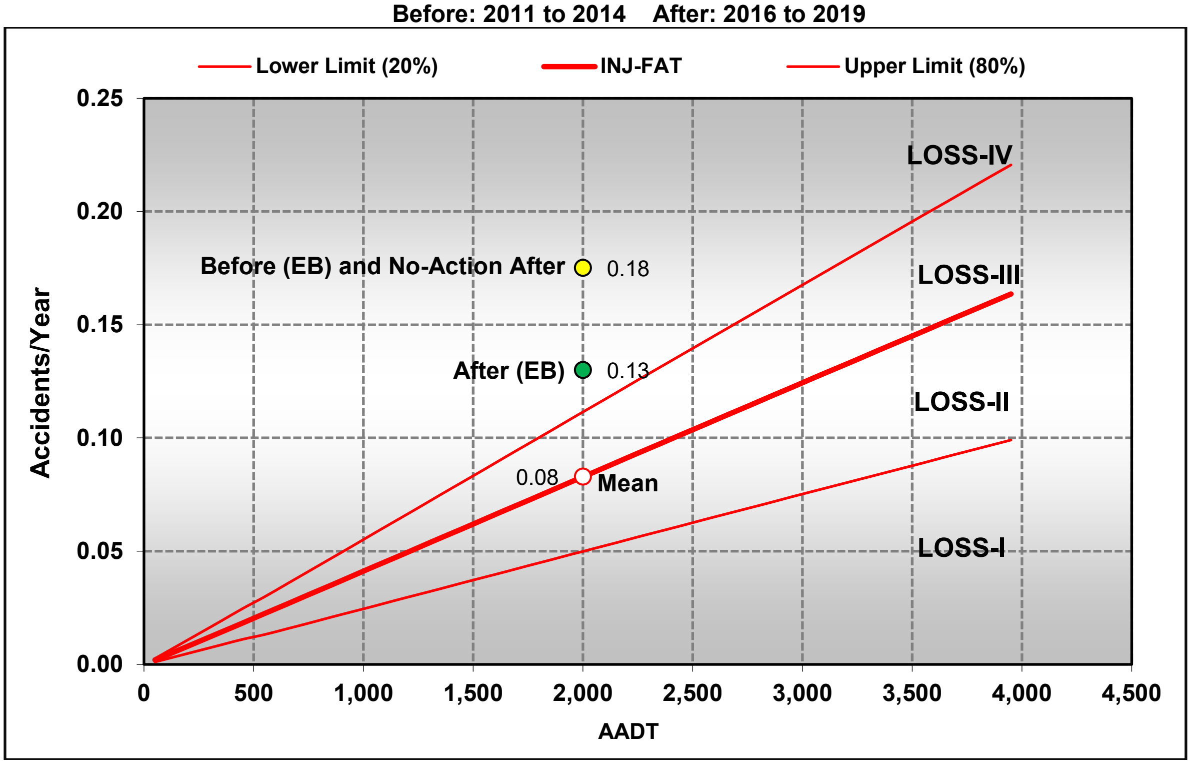


Table 2 provides a summary of the crashes per year CPY and a comparison with the mean (expected) CPY for the before and after periods.

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	Yes	Yes
SPF Graph	Urban, 2-lane, Undivided, Unsignalized, 4-Leg Intersection	Urban, 2-lane, Undivided, *Unsignalized, 4-Leg Intersection	Urban, 2-lane, Undivided, Unsignalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS IV	LOSS-IV	LOSS IV
CPY	0.87	0.47	0.87
Mean CPY	0.31	0.31	0.31
Proportion of Mean	2.81	1.52	2.81
Fatal & Injury Crashes:			
LOSS	LOSS IV	N/A	LOSS IV
CPY	0.18	0.13	0.18
Mean CPY	0.08	0.08	0.08
Proportion of Mean	2.25	1.63	2.25

*For purposes of comparison, the undivided unsignalized baseline was used even though the intersection was divided and signalized in the after period.

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Table 3** for all crashes in the intersection. **Table 3** shows that the result of the Benefit/Cost calculation is a B/C ratio of **1.41.** This result shows that the project seems to have been justified from cost-effectiveness standpoint.

Table 3 – US 6 at SH 139 in Loma – Benefit Cost Analysis

Colorado Department of Transportation
DiExSys™ Vision Zero Suite
Economic Analysis Report

10/18/2021

Job #: 20211018102342

Location: 6 A **Begin:** 15.08 **End:** 15.18 **From:** 01/01/2011 **To:** 12/31/2014

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	5		Weighted PDO:	1.54	80% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	6	12 :Injured	Weighted INJ:	3.69	75% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	4.00	77% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 2,600,000
From: 01/01/2011
To: 12/31/2014 Days: 1461

Benefit Cost Ratio: 1.41 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SIGNAL DESIGN AND INTERSECTION GEOMETRY IMPROVEMENTS
Special Notes: Based on reduction in crashes from 2011-2014 to 2016-2019 (4-Yr periods surrounding construction)

Project Information

Project Name: US 85 MP 235.0-250.5 Cable Rail Installation

Project Description: Cable Rail Installation

CDOT Region:	4	Project Def:	17647	County:	Weld
Location:	US 85	Mile Points:	235-250.5	Length:	15.5 Miles
Schedule:		Work Start Date:	Aug 2011	Work End Date:	Jun 2012

Problem Description:

The project area includes the segment of United States (US) 85 between Mile Points (MP) 235.0 and 250.5 in Weld County, Colorado. This segment had inadequate roadside design and witnessed significantly high number of crashes and severity of crashes. Run Off the Road crash type was of special concern in this segment of US 85.

US 85 in Weld County, Colorado

Improvement Description:

The project involved installation of cable rail in the median over approximately 15.5 miles of US 85. The cost of construction was $5,323,460.

US 85– Facing North – Before (Left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements along US 85 were constructed shows a significant increase in the total number of crashes. A comparison of off median, off-road left, head-on, and sideswipe opposite crash types before and after the improvements were made showed that there was a significant increase in all analyzed crashes.

The total number of crashes increased from 181 to 294, and Injuries + Fatalities (severe crashes) decreased from 89 to 59. The number injuries decreased from 121 to 73, and the number of fatalities reduced from 8 to 3. Off-Road crashes increased from 133 in the before period to 245 in the after period. The AADT increased by approximately 4% in the after period.

When looking specifically at off-road left, off-road in median, head-on, and sideswipe (opposite) crashes that were affected by the improvements, the ratio of benefits of crash reduction to the cost of construction over the life cycle of 20 years for this project was 6.00:1.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 regarding its expected crash frequency or severity at a specific level of ADT.

The study corridor was examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – US 85

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records along US 85 in the project area shows an approximate 62% increase in the number of crashes from the five-year before period (2006-2010) to the five-year after period (2013-2017). The number of severe (fatal and injury) crashes decreased by approximately 34%.

- Before Period: 89 severe crashes, 121 injured, 8 fatalities
- After Period: 59 severe crashes, 73 injured, 3 fatalities

The crash rate for all crashes at this intersection increased by 62% between the before period and after period.

- Before Period: 2.63 crashes per million vehicle miles traveled
- After Period: 3.91 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses – US 85

		Before	After
Time Period:		01/01/2006 – 12/31/2010 (5 yr)	01/01/2013 – 12/31/2017 (5 yr)
AADT	US 85	16,914	20,398
Crash Filters:		Off Road Left, Head On, Sideswipe Opposite, Overturning	
Total Crashes:		**58**	**294**
Fatal Crashes (Fatalities):		4 (4)	0 (0)
Injury Crashes (Injuries):		35 (54)	21 (28)
PDO Crashes:		19	140

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for US 85 in the project area reflect an increase in the crash record for this project. The intersection is LOSS II for total frequency of crashes in the before period and LOSS III in the after period. The severe frequency of crashes is LOSS III in both the before and after periods.

Figure 1. SPF For Total Crashes

Before: 2006–2010 After: 2013–2017

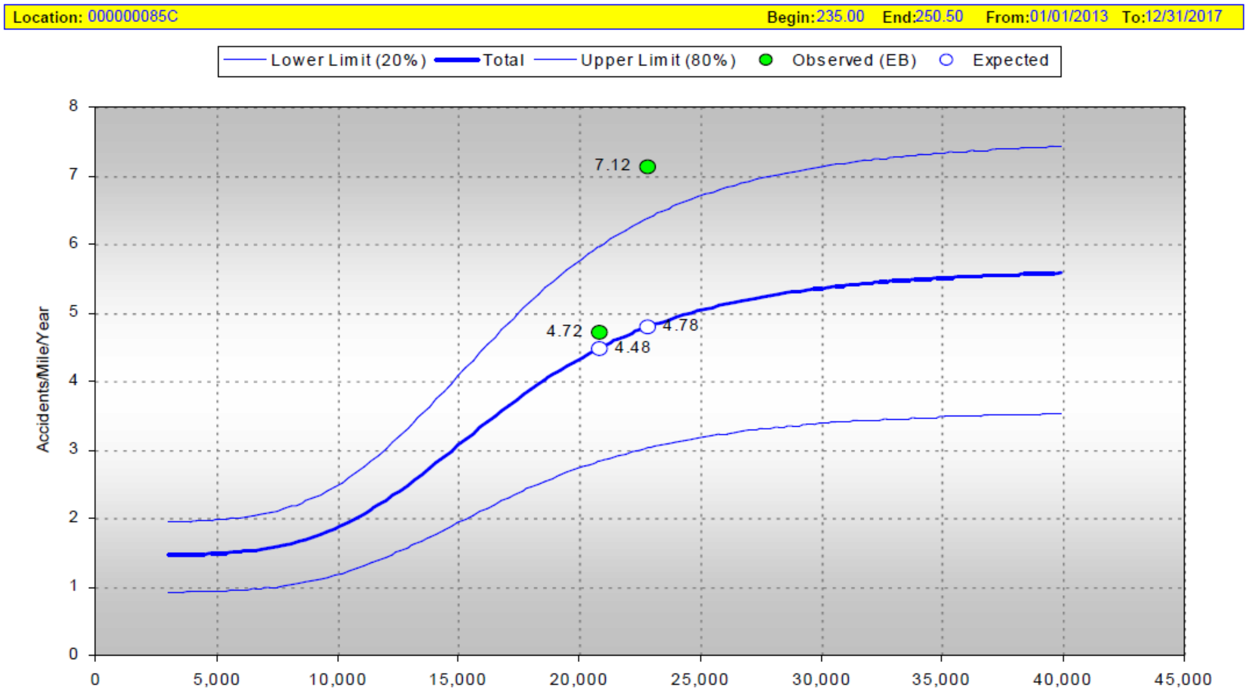


Figure 2. SPF For Severe Crashes

Before: 2006–2010 After: 2013–2017

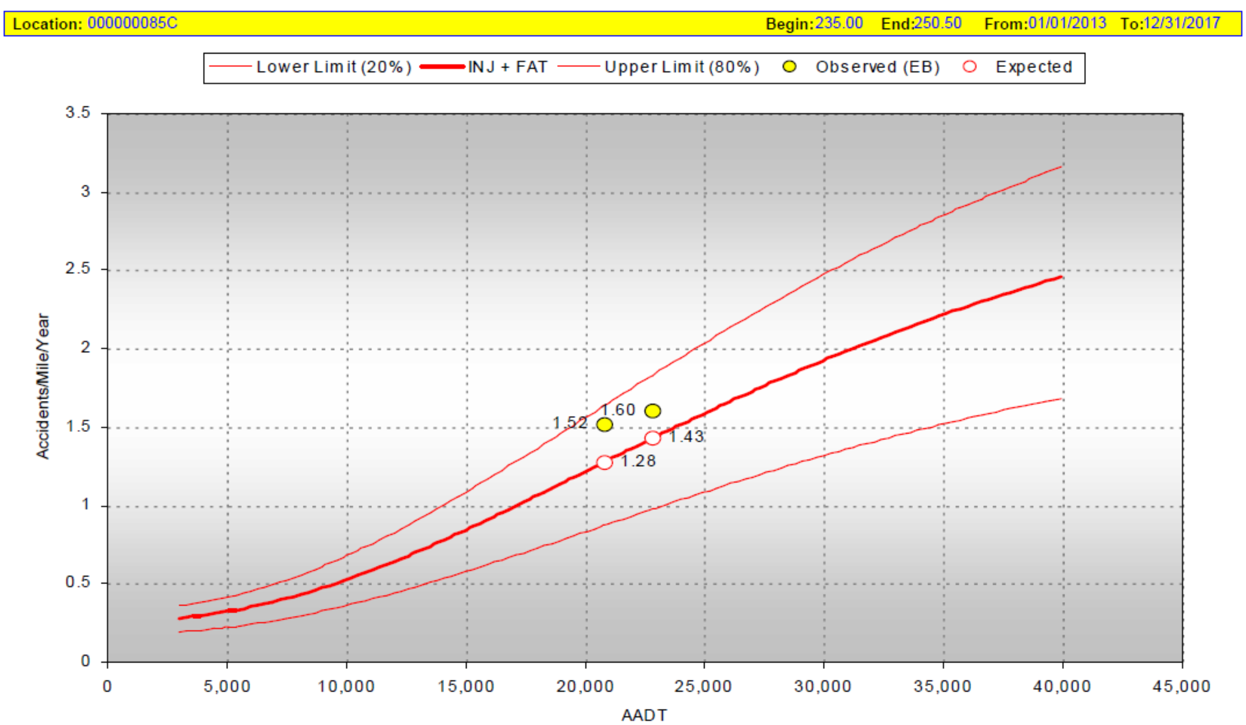


Table 2 provides a summary of the crashes per year (CPY) for US 85 along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Flat and Rolling 4-Lane Divided Highways (2016)	Rural Flat and Rolling 4-Lane Divided Highways (2016)	Rural Flat and Rolling 4-Lane Divided Highways (2016)
Total Crashes			
LOSS	LOSS III	LOSS IV	LOSS III
CPYPM	4.72	7.12	3.21
Expected CPYPM	4.48	4.78	5.5
Proportion of Mean	1.05	1.49	0.58
Severe (Injury & Fatal) Crashes			
LOSS	LOSS III	LOSS III	LOSS III
CPYPM	1.52	1.60	1.33
Expected CPYPM	1.28	1.43	1.73
Proportion of Mean	1.19	1.12	0.77

Crash Type Analyses

A more detailed review of the before and after crash record shows the off-road-left, off-road-in median, head-on, and sideswipe opposite crash types that were most affected by the roadway improvements. **Table 3** shows a comparison of the total, fatal and injury crashes.

The No-Build After crashes were estimated using the change in traffic volumes on US 85 between the before and after period, as found in **Table 1** (approximately 4% increase). Over the design life of 20 years for the improvements.

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2006 – 12/31/2010 (5 yr)	01/01/2013 – 12/31/2017 (5 yr)	01/01/2013 – 12/31/2017 (5 yr)
Total Crashes	**58**	**161**	**73**
Fatal (Fatalities)	4 (4)	0 (0)	5 (5)
Injury (Injuries)	35 (54)	21 (28)	44 (68)
PDO	19	140	24
% Reduction in Total (Fatal/Injury/PDO)	--	100% / 58% / -448%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of 6.00 was ultimately realized** and is largely attributed to a decrease in severe crashes on the corridor. This outcome displays that this safety improvement project was justified.

Following cable rail installation, crash data showed a drastic increase in the number of cable rail crashes in the median; however, the severity of crashes went down significantly. The before period showed the majority of crashes being with fixed objects such as trees, fences, embankments, etc., but the after period resulted in more crashes hitting the barrier in the median. However, this improvement resulted in significantly less fatalities going from 8 in the before period to 3 in the after period. The improvement also lowered head on crashes from 9 in the before period to 5 in the after period. The resulting B/C analysis suggests an effective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: 85 C **Begin:** 226.80 **End:** 265.76 **From:** 01/01/1986 **To:** 12/31/2020

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors				Other Information	
PDO:	27		Weighted PDO:	6.63	-448%	:CRF for PDO	Cost of PDO:	$ 11,100
INJ:	0	76 :Injured	Weighted INJ:	18.67	58%	:CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	4 :Killed	Weighted FAT:	0.98	100%	:CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	-99%	:Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
							Service Life:	20
							Capital Recovery Factor:	0.080
							Annual Maintenance/Delay Cost:	$ 0

Cost: $ 5,323,460
From: 01/01/2006
To: 12/31/2010 Days: 1826

Benefit Cost Ratio: **6.00** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: US 85 Cable Rail MP 235-250.5
Special Notes: Off Road Left, Head On, Sideswipe Opposite, Overturning

Project Information

Project Name:	US 6 MP 272.5 - 274.1 Wild Animal Fencing				
Project Description:	Wild Animal Fencing and Crossing				
CDOT Region: 1	Project Def:	17656	County:	Jefferson	
Location: US 6	Mile Points:	272.5 – 274.1	Length:	1.6 Miles	
Schedule:	Work Start Date:	Jun 2010	Work End Date:	Mar 2011	

Problem Description:

The project area includes the segment of United States (US) 6 between Mile Points (MP) 272.5 and 274.1 in Jefferson County, Colorado. This segment had a high number of wild animal crashes.

US 6 in Jefferson County, Colorado

Improvement Description:

The project involved installation of wildlife fencing over approximately 1.6 miles of US 6. The cost of construction was $590,421.

US 6 – Facing Northwest – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements along US 6 shows a significant decrease in the total number and severity of crashes. A comparison of wild animal crash types before and after the improvements were made showed that there was a significant decrease in wild animal crashes.

The total number of crashes reduced from 82 to 62, and Injuries + Fatalities (severe crashes) decreased from 6 to 3. The number of injuries reduced from 6 to 4. The AADT decreased by approximately 3% in the after period.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 15 years for this project was 1.44:1. The result is an improvement that was justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections and/or segments were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections/segments in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – US 6

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records along US 6 in the project area shows an approximate 24% decrease in the total number of crashes from the five-year before period (2006-2010) to the five-year after period (2012-2016). The number of severe (fatal and injury) crashes decreased by 50%.

- Before Period: 6 severe crashes, 6 injured
- After Period: 3 severe crashes, 4 injured

The crash rate for all crashes along this corridor decreased by 24% between the before period and after period.

- Before Period: 9.49 crashes per million vehicle miles traveled
- After Period: 7.39 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses – US 6

		Before	After
Time Period:		01/01/2006 – 12/31/2010 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)
AADT	US 6	38,830	37,489
Crash Filters:		None	
Total Crashes:		**82**	**62**
Fatal Crashes (Fatalities):		0 (0)	0 (0)
Injury Crashes (Injuries):		6 (6)	3 (4)
PDO Crashes:		76	62

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for US 6 in the project area reflect a decrease in the crash record for this project. The intersection is LOSS IV for total frequency of crashes in both the before and after periods and LOSS I for the severity of crashes in the before period and after period.

Figure 1. SPF For Total Crashes

Before: 2006–2010 After: 2012–2016

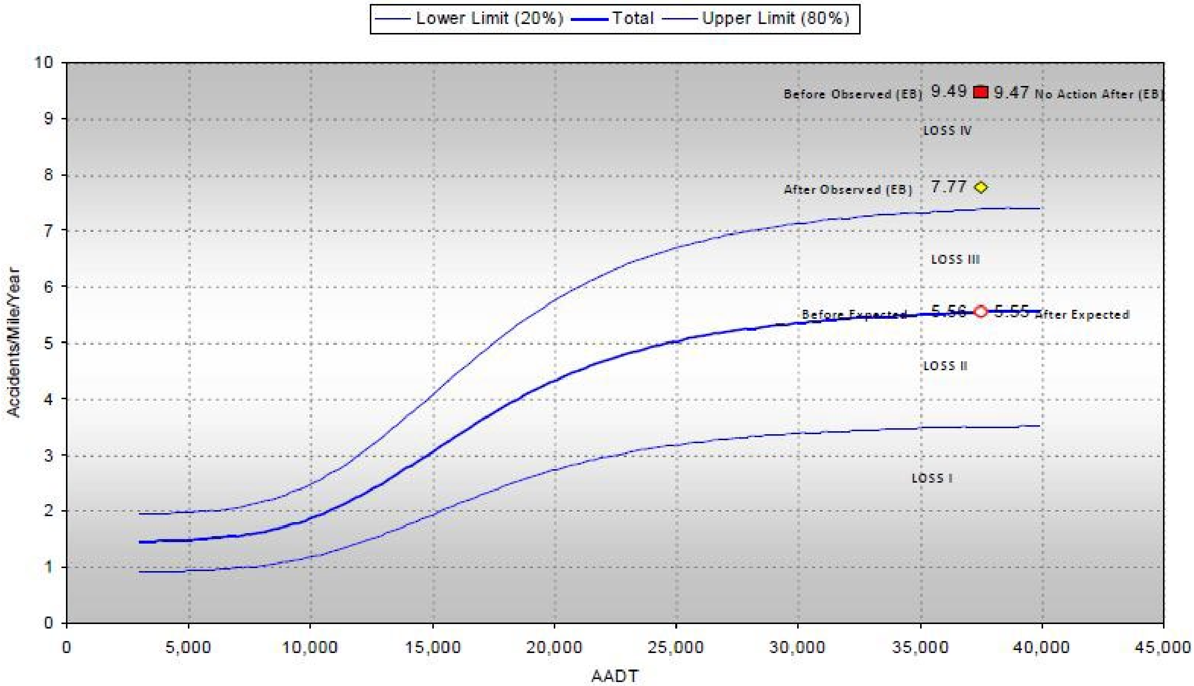


Figure 2. SPF For Severe Crashes

Before: 2006–2010 After: 2012–2016

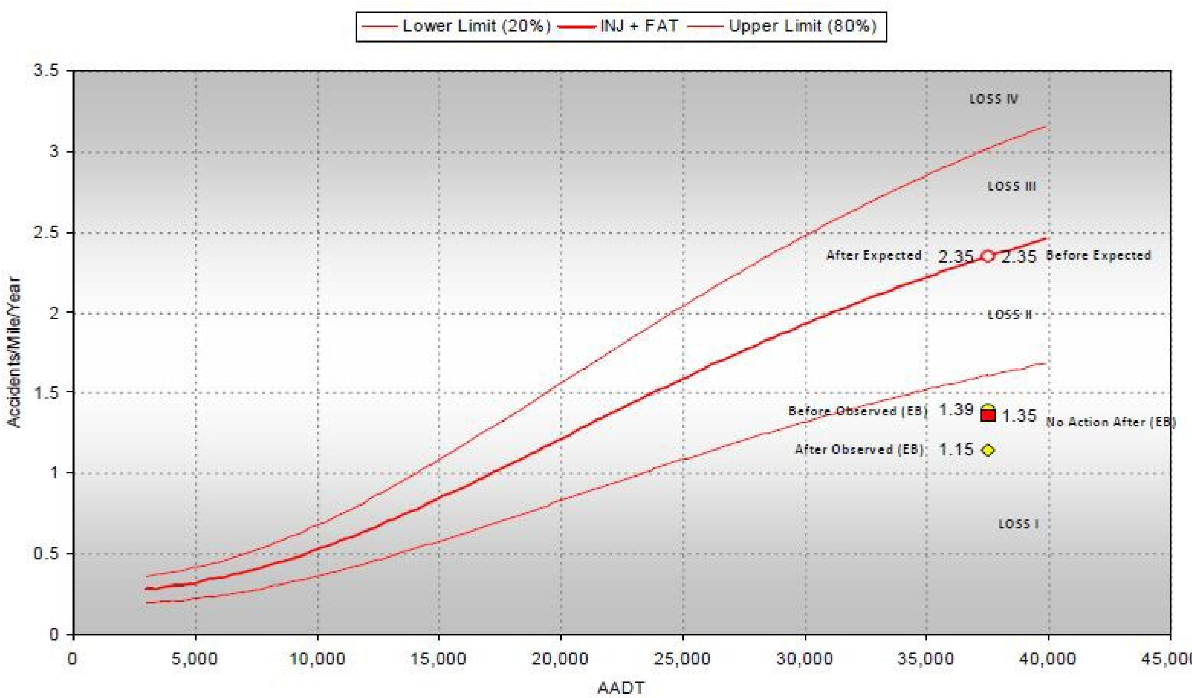


Table 2 provides a summary of the crashes per year (CPY) for US 6 along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Flat and Rolling 4-Lane Divided Highways (2016)	Rural Flat and Rolling 4-Lane Divided Highways (2016)	Rural Flat and Rolling 4-Lane Divided Highways (2016)
Total Crashes			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPYPM	9.49	7.39	9.47
Expected CPYPM	5.56	5.55	5.55
Proportion of Mean	1.71	1.33	1.71
Severe (Injury & Fatal) Crashes			
LOSS	LOSS I	LOSS I	LOSS I
CPYPM	1.39	1.14	1.35
Expected CPYPM	2.41	2.35	2.35
Proportion of Mean	0.58	0.49	0.58

Crash Type Analyses

A more detailed review of the before and after crash record shows the wild animal crash types that were most affected by the roadway improvements. **Table 3** shows a comparison of the total, fatal and injury crashes.

The No-Build After crashes were estimated using the change in traffic volumes on US 6 between the before and after period, as found in **Table 1** (approximately 3% decrease).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2006 – 12/31/2010 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)
Total Crashes	**82**	**62**	**82**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	6 (6)	3 (4)	6 (6)
PDO	76	62	76
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 33% / 18%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of 1.44 was ultimately realized** and is largely attributed to significant decreases in PDO and injury crashes. This outcome displays that this safety improvement project was justified.

Following implementation of wild animal fencing, crash data suggests a reduction in the targeted crashes. The Resulting B/C analysis would also suggest an effective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: 6 G **Begin:** 272.50 **End:** 274.10 **From:** 01/01/2006 **To:** 12/31/2010

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	76		Weighted PDO:	17.63	18% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	6	6 :Injured	Weighted INJ:	1.39	33% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	6	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	17% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	15
	Cost:	$ 590,421				Capital Recovery Factor:	0.096
	From:	01/01/2006					
	To:	12/31/2010	Days:	1826		Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: **1.44** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: US 6 MP 272.5-274.1

Special Notes: Wild Animal Crashes

Project Information

Project Name:	470 MP 19.5 – 24.5 Variable Message Signing				
Project Description:	Variable Message Signing (VMS)				
CDOT Region: 1	Project Def:	17664	County:	Douglas	
Location: C-470 A	Mile Points:	19.5 – 24.5	Length:	5 Miles	
Schedule:	Work Start Date:	May 2011	Work End Date:	Apr 2012	

Problem Description:

No problem description was provided for the original HSIP funding application for the intersection improvement project.

Improvement Description:

The project area includes the segment of C-470 between Mile Points (MP) 19.5 and 24.5 in Douglas County, Colorado.

C-470 in Douglas County, Colorado

The project involved installation of Variable Message Signing (VMS) over approximately 5 miles of C-470. The cost of construction was $451,061.

C-470 Westbound – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements along C-470 shows a significant increase in the total number and severity of crashes; however, the WB direction exclusively showed an increase in the total number and severity of crashes.

The total number of crashes increased from 623 to 706, and Injuries + Fatalities (severe crashes) increased from 187 to 229. The number of injuries increased from 255 to 318; however, the number of fatalities decreased from 4 to 1. The WB direction showed an increase from 323 to 367 in total crashes, 102 to 121 in severe crashes, and the number of injuries increased from 131 to 165. The AADT increased by approximately 9% in the after period.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 10 years for this project was -11.41:1 using the WB direction crash summary. The result is an improvement that was not justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections and/or segments were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections/segments in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – C-470

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records along C-470 in the project area shows an approximate 13% increase in the total number of crashes from the five-year before period (2006-2010) to the five-year after period (2013-2017). The number of severe (fatal and injury) crashes increased by approximately 22%.

- Before Period: 187 severe crashes, 255 injured, 4 fatalities
- After Period: 229 severe crashes, 318 injured, 1 fatality

The crash rate for all crashes along this corridor increased by 13% between the before period and after period.

- Before Period: 25.21 crashes per million vehicle miles traveled
- After Period: 28.45 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses – C-470A

		Before	After
Time Period:		01/01/2007 – 12/31/2011 (5 yr)	01/01/2013 – 12/31/2017 (5 yr)
AADT	C-470	95,818	103,410
Crash Filters:		None	
Total Crashes:		**623**	**766**
Fatal Crashes (Fatalities):		3 (4)	1 (1)
Injury Crashes (Injuries):		184 (255)	226 (312)
PDO Crashes:		436	539

Safety Performance Functions

SPF plots for total crashes (**Figure 1**) for C-470 in the project area reflect an increase in the crash record for this project. SPF plots for severe (injury and fatal) crashes (**Figure 2**) reflect an increase as well. The intersection is LOSS II for total and severe frequency of crashes in the before period and LOSS IV for the total and severe frequency of crashes in the after period.

Figure 1. SPF For Total Crashes

Before: 2007–2011 After: 2013–2017

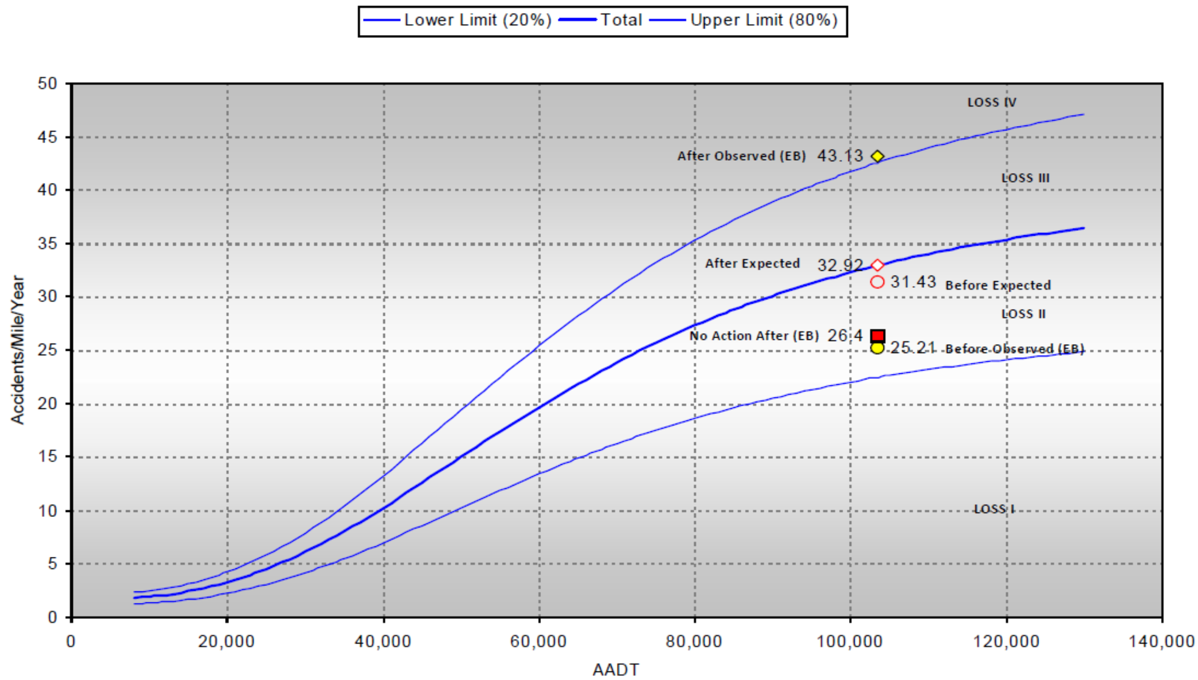


Figure 2. SPF For Severe Crashes

Before: 2007–2011 After: 2013–2017

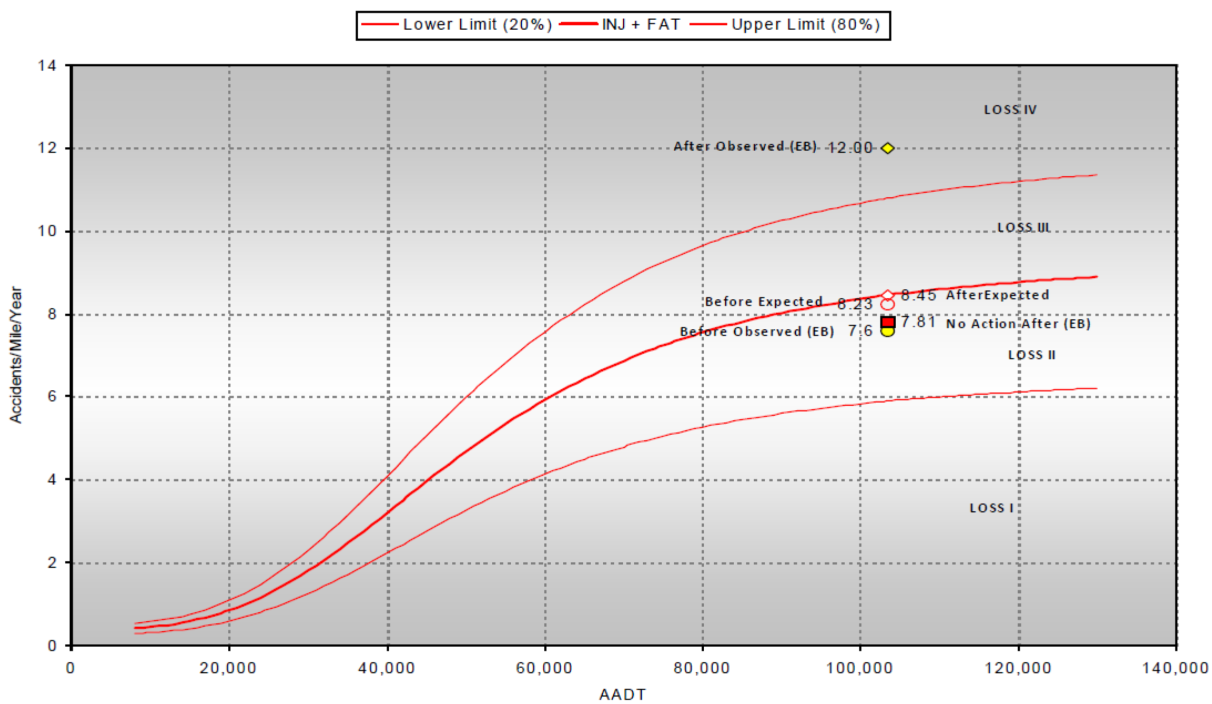


Table 2 provides a summary of the crashes per year (CPY) for C-470 along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Flat and Rolling 4-Lane Divided Highways (2016)	Rural Flat and Rolling 4-Lane Divided Highways (2016)	Rural Flat and Rolling 4-Lane Divided Highways (2016)
Total Crashes			
LOSS	LOSS II	LOSS IV	LOSS II
CPYPM	25.21	43.13	26.40
Expected CPYPM	31.43	32.92	32.92
Proportion of Mean	0.80	1.31	0.80
Severe (Injury & Fatal) Crashes			
LOSS	LOSS II	LOSS IV	LOSS II
CPYPM	7.60	12.00	7.60
Expected CPYPM	8.23	8.45	8.45
Proportion of Mean	0.92	1.42	0.92

Crash Type Analyses

Table 3 shows a comparison of the total, fatal and injury crashes for mainline crashes in the Westbound directions, as these crashes were most effected by the project.

The No-Build After crashes were estimated using the change in traffic volumes on C-470 between the before and after period, as found in **Table 1** (approximately 9% increase).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2007 – 12/31/2011 (5 yr)	01/01/2013 – 12/31/2017 (5 yr)	01/01/2013 – 12/31/2017 (5 yr)
Total Crashes	**323**	**367**	**342**
Fatal (Fatalities)	1 (1)	1 (1)	1 (1)
Injury (Injuries)	101 (131)	120 (165)	105 (136)
PDO	221	246	234
% Reduction in Total (Fatal/Injury/PDO)	--	0% / -21% / -5%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of -11.41 was ultimately realized** and is largely attributed to an increases in PDO and injury crashes. This outcome displays that this safety improvement project was not justified.

Following implementation of variable message signing, crash data suggests an increase in total crashes. The Resulting B/C analysis would also suggest an ineffective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: 470 A **Begin:** 19.50 **End:**24.50 **From:**01/01/2013 **To:**12/31/2017

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	234		Weighted PDO:	51.37	-5% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	105	136 :Injured	Weighted INJ:	29.85	-21% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	1	1 :Killed	Weighted FAT:	0.22	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	-9% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	10
	Cost:	$ 451,061				Capital Recovery Factor:	0.129
	From:	01/01/2007				Annual Maintenance/Delay Cost:	$ 0
	To:	12/31/2011	Days:	1826			

Benefit Cost Ratio: **-11.41** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: C-470 MP 19.5 - 24.5

Special Notes: All Crash Types - WB Direction, Mainline, Non-intersection crashes

Project Information

Project Name: Railroad Avenue & SH 13 Bypass Intersection Improvements

Project Description: Intersection Safety Improvements

CDOT Region:	3	Project Def:	17763	County:	Garfield
Location:	Railroad Avenue	Mile Points:	N/A	Length:	N/A
Schedule:		Work Start Date:	Mar 2011	Work End Date:	Sep 2011

Problem Description:

The project area is the intersection of Railroad Avenue with State Highway (SH) 13 Bypass in Garfield, Colorado. This segment has inadequate grading leading to trucks overturning as well as the current geometry allowing EB right turns to take the curve at a high rate of speed. This intersection experiences higher than average rear ends, broadsides, and overturning vehicles.

Improvement Description:

Railroad Avenue & SH 13 Bypass in Garfield, Colorado

The project involved correcting the superelevation of the EB to NB curve, increasing the deflection angle of the EB right turn movement, and implementing a median between the NB and SB SH 13A traffic. The cost of construction was $1,415,078.04.

Railroad Avenue – Facing Northeast – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements at the intersection of Railroad Avenue with SH 13 Bypass show a significant decrease in the total number and severity of crashes. A comparison of broadside, approach turn, and overturning types before and after the improvements were made showed that there was a significant decrease in affected crashes.

The total number of crashes reduced from 34 to 17, and Injuries + Fatalities (severe crashes) decreased from 15 to 4. The number injuries reduced from 19 to 7. Off-Road crashes reduced from 9 in the before period to 1 in the after period. The AADT increased by approximately 0.1% in the after period.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 20 years for this project was 2.78:1. The result is an improvement that was justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections and/or segments were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections/segments in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at the intersection of Railroad Avenue with SH 13 Bypass shows an approximate 50% decrease in the number of crashes from the five-year before period (2006-2010) to the five-year after period (2012-2016). The number of severe (fatal and injury) crashes decreased by approximately 73%.

- Before Period: 15 severe crashes, 19 injured
- After Period: 4 severe crashes, 7 injured

The crash rate for all crashes at this intersection decreased by 50% between the before period and after period.

- Before Period: 5.76 crashes per million vehicle miles traveled
- After Period: 2.98 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses

		Before	After
Time Period:		01/01/2006 – 12/31/2010 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)
AADT	Railroad Avenue	13,472	13,492
	US 13 Bypass	4,909	4,770
Crash Filters:		None	
Total Crashes:		**34**	**17**
Fatal Crashes (Fatalities):		0 (0)	0 (0)
Injury Crashes (Injuries):		15 (19)	4 (7)
PDO Crashes:		19	13

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for the intersection of Railroad Avenue with SH 13 Bypass reflect a decrease in the crash record for this project. The intersection is LOSS IV for total frequency of crashes in both the before and after periods and LOSS IV for the severity of crashes in both the before and after periods.

It should be noted that SPF methodology is usually applied to segments that are a minimum of one mile in length and the crashes per mile per year for the study segment is likely inaccurate an intersection.

Figure 1. SPF For Total Crashes

Before: 2006–2010 After: 2012–2016

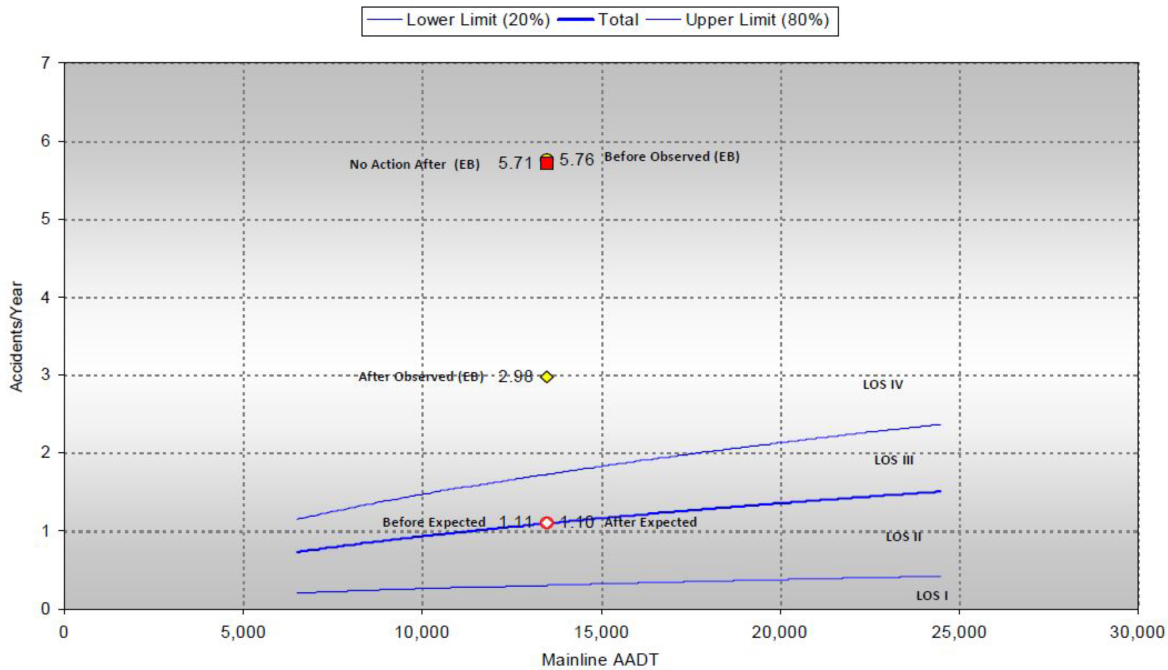


Figure 2. SPF For Severe Crashes

Before: 2006–2010 After: 2012–2016

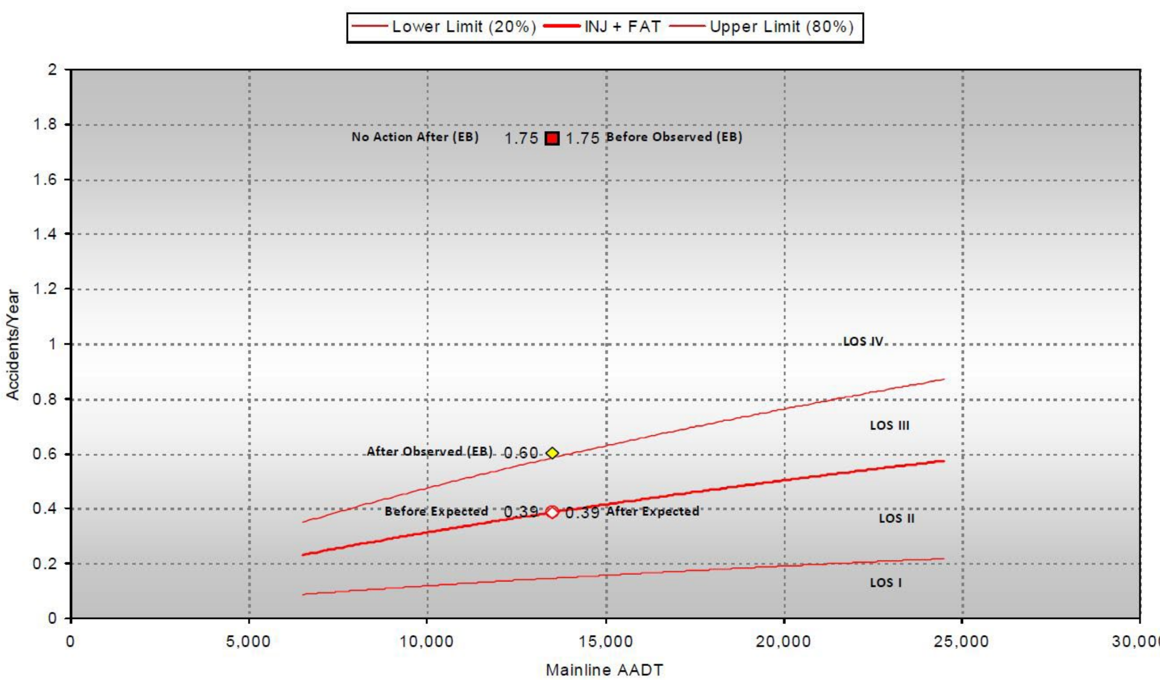


Table 2 provides a summary of the crashes per year (CPY) for the study intersection along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural 4-Lane Divided Unsignalized 3-leg Intersection (2018)	Rural 4-Lane Divided Unsignalized 3-leg Intersection (2018)	Rural 4-Lane Divided Unsignalized 3-leg Intersection (2018)
Total Crashes			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPYPM	5.76	2.98	5.71
Expected CPYPM	1.11	1.10	1.10
Proportion of Mean	5.19	2.71	5.19
Severe (Injury & Fatal) Crashes			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPYPM	1.75	0.6	1.75
Expected CPYPM	0.39	0.39	0.39
Proportion of Mean	4.49	1.54	4.49

Crash Type Analyses

A more detailed review of the before and after crash record shows the overturning, approach turn, and broadside crash types that were most affected by the roadway improvements. **Table 3** shows a comparison of the total, fatal and injury crashes.

The No-Build After crashes were estimated using the change in traffic volumes on Railroad Avenue between the before and after period, as found in **Table 1** (approximately 0.1% increase).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2006 – 12/31/2010 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)
Total Crashes	**34**	**17**	**34**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	15 (19)	4 (7)	15 (19)
PDO	19	13	19
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 63% / 32%	--
Broadside Crashes	**16**	**4**	**16**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	8 (10)	1 (1)	8 (10)
PDO	8	3	8
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 90% / 63%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of 2.78 was ultimately realized** and is largely attributed to significant decrease in number of injury and PDO crashes. This outcome displays that this safety improvement project was justified.

Following the previously mentioned intersection improvements, crash data suggests a reduction in the targeted crashes. The resulting B/C analysis would also suggest an effective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: Accident History for All Locations **From:**01/01/2006 **To:**12/31/2010

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	19		Weighted PDO:	4.67	32% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	15	19 :Injured	Weighted INJ:	4.67	63% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	45% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 1,415,079
From: 01/01/2006
To: 12/31/2010 Days: 1826

Benefit Cost Ratio: **2.78** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SH 13 & Railroad Avenue - Intersection Safety Improvements
Special Notes: All Intersection Related Crashes

Project Information

Project Name:		SH 392 & WCR 35 Intersection Improvements			
Project Description:		Widening SH 392 for left turn lanes to WCR 35			
CDOT Region:	4	Project Def:	17779	County:	Weld
Location:	SH 392	Mile Points:	N/A	Length:	N/A
Schedule:		Work Start Date:	Sep 2010	Work End Date:	Dec 2010

Problem Description:

The project area is the intersection of State Highway (SH) 392 with Weld County Road (WCR) 35 in Weld County, Colorado. This intersection experiences high volumes of rear ends and overtaking turns on SH 392 due to the lack of left turn lanes at WCR 35.

Improvement Description:

The project involved adding left turn lanes on SH 392 in Weld County, Colorado. The cost of construction was $339,927.85.

SH 392 & WCR 35 in Weld County, Colorado

SH 392 Eastbound – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements at the intersection of SH 392 with WCR 35 show a significant decrease in the total number and severity of crashes. A comparison of broadside, approach turn, rear end, and overtaking turn types before and after the improvements were made showed that there was a significant decrease in affected crashes.

The total number of crashes reduced from 37 to 8, and Injuries + Fatalities (severe crashes) decreased from 16 to 2. The number injuries reduced from 29 to 3, and fatalities reduced from 1 to 0. Broadside crashes reduced from 10 to 2. The AADT increased by approximately 27.7% in the after period.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 10 years for this project was 38.57:1. The result is an improvement that was justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections and/or segments were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections/segments in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at the intersection of Railroad Avenue with SH 13 Bypass shows an approximate 78% decrease in the number of crashes from the five-year before period (2005-2009) to the five-year after period (2011-2015). The number of severe (fatal and injury) crashes decreased by approximately 87%.

- Before Period: 16 severe crashes, 29 injured, 1 killed
- After Period: 2 severe crashes, 3 injured

The crash rate for all crashes at this intersection decreased by 75% between the before period and after period.

- Before Period: 6.42 crashes per million vehicle miles traveled
- After Period: 1.60 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses

		Before	After
Time Period:		01/01/2005 – 12/31/2009 (5 yr)	01/01/2011 – 12/31/2015 (5 yr)
AADT	SH 392	4,720	6,026
	WCR 35	1,789	1,441
Crash Filters:		None	
Total Crashes:		**37**	**8**
Fatal Crashes (Fatalities):		1 (1)	0 (0)
Injury Crashes (Injuries):		15 (29)	2 (3)
PDO Crashes:		21	6

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for the intersection of SH 392 & WCR 35 reflect a decrease in the crash record for this project. The intersection is LOSS IV for total frequency of crashes in the before period. The after period is LOSS II for total crashes. The intersection is LOSS IV for the severity of crashes in the before period, and LOSS II in the after period.

It should be noted that although this analysis shows a drastic decrease in the number of broadside crashes, broadside crashes have shown an increase at this intersection since 2018. This means that the decrease of broadside crashes shown in this analysis may not be due to the improvements analyzed in this study. Further, it should be noted that SPF methodology is usually applied to segments that are a minimum of one mile in length and the crashes per mile per year for the study segment is likely inaccurate for an intersection.

Figure 1. SPF For Total Crashes

Before: 2005–2009 After: 2011–2015

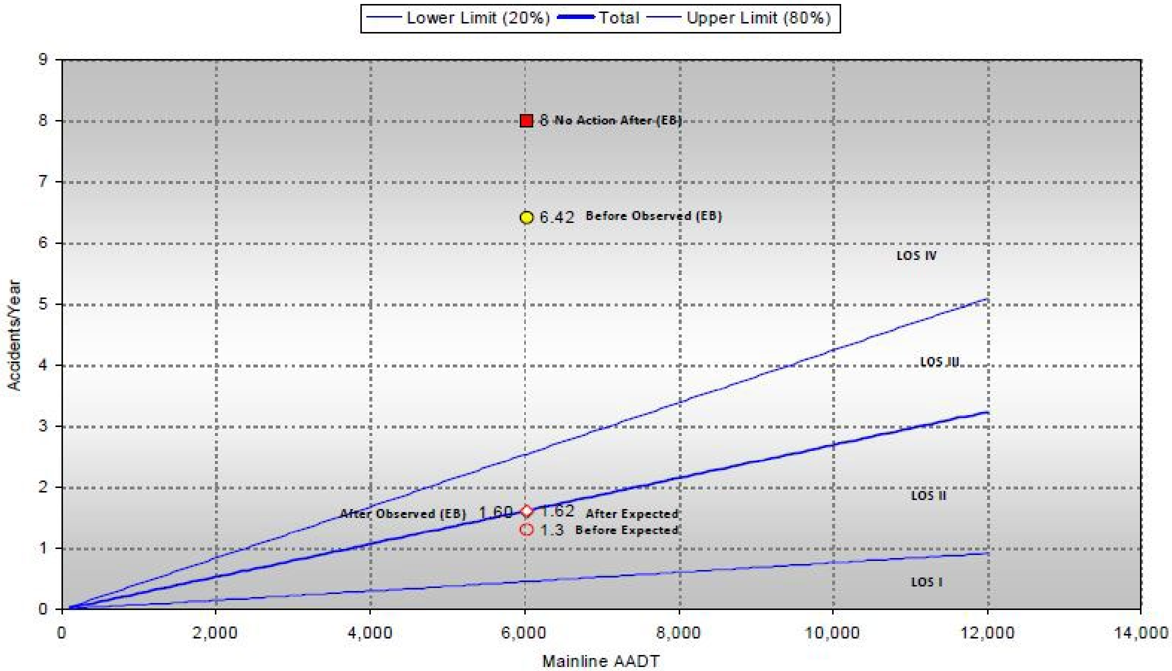


Figure 2. SPF For Severe Crashes

Before: 2005–2009 After: 2011–2015

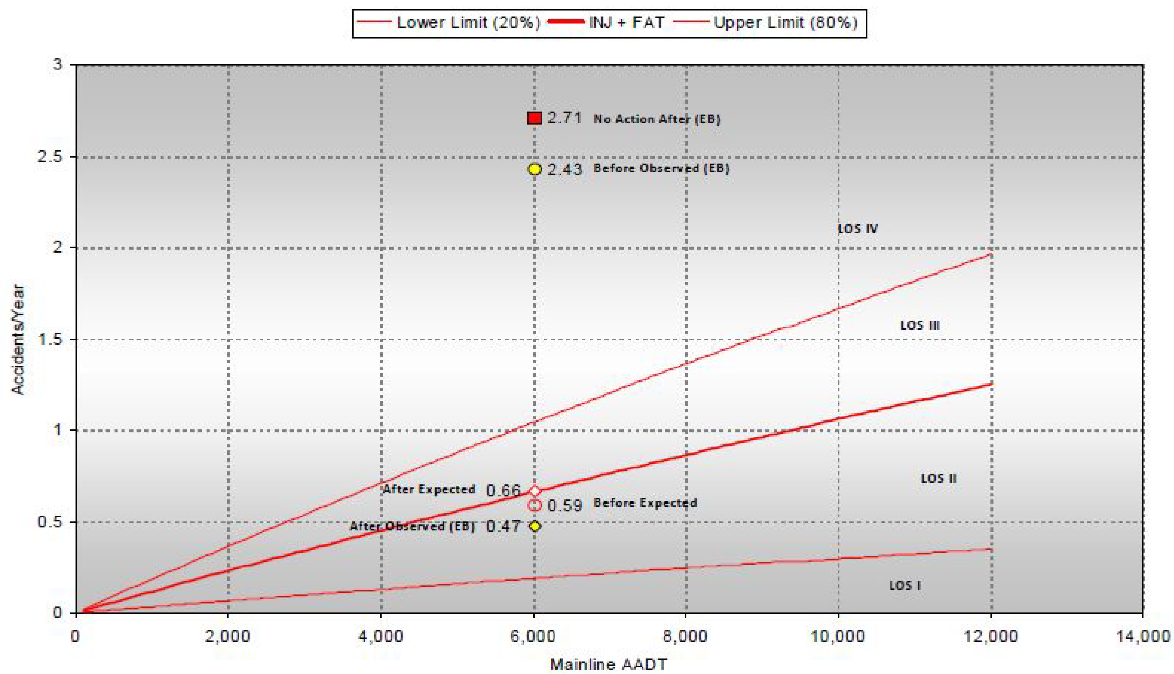


Table 2 provides a summary of the crashes per year (CPY) for the study intersection along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural 2-Lane Undivided Unsignalized 4-leg Intersection (2018)	Rural 2-Lane Undivided Unsignalized 4-leg Intersection (2018)	Rural 2-Lane Undivided Unsignalized 4-leg Intersection (2018)
Total Crashes			
LOSS	LOSS IV	LOSS II	LOSS IV
CPYPM	6.42	1.6	8.00
Expected CPYPM	1.30	1.62	1.62
Proportion of Mean	4.94	0.99	4.94
Severe (Injury & Fatal) Crashes			
LOSS	LOSS IV	LOSS II	LOSS IV
CPYPM	2.42	0.47	2.71
Expected CPYPM	0.59	0.66	0.66
Proportion of Mean	4.10	0.71	4.10

Crash Type Analyses

A more detailed review of the before and after crash record shows the overtaking turn, approach turn, rear end, and broadside crash types that were most affected by the roadway improvements. **Table 3** shows a comparison of the total, fatal, and injury crashes.

The No-Build After crashes were estimated using the change in traffic volumes on Railroad Avenue between the before and after period, as found in **Table 1** (approximately 27.7% increase).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2005 – 12/31/2009 (5 yr)	01/01/2011 – 12/31/2015 (5 yr)	01/01/2011 – 12/31/2015 (5 yr)
Total Crashes	**31**	**6**	**38**
Fatal (Fatalities)	1 (1)	0 (0)	1 (1)
Injury (Injuries)	14 (28)	1 (1)	15 (31)
PDO	16	5	19
% Reduction in Total (Fatal/Injury/PDO)	--	100% / 97% / 74%	--
Broadside Crashes	10	2	12
Fatal (Fatalities)	1 (1)	0 (0)	1 (1)
Injury (Injuries)	7 (20)	0 (0)	8 (22)
PDO	2	2	2
% Reduction in Total (Fatal/Injury/PDO)	--	100% / 100% / 0%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of 38.57 was ultimately realized** and is largely attributed to significant decrease in number of total crashes. This outcome displays that this safety improvement project was justified.

Following the addition of left turn lanes on SH 392, crash data suggests a reduction in the targeted crashes. The resulting B/C analysis would also suggest an effective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: 50 B **Begin:** 318.00 **End:** 359.00 **From:** 01/01/2013 **To:** 12/31/2017

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	19		Weighted PDO:	4.67	74% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	15	31 :Injured	Weighted INJ:	7.62	97% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	1	1 :Killed	Weighted FAT:	0.25	100% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	84% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 399,927
From: 01/01/2005
To: 12/31/2009 Days: 1826

Benefit Cost Ratio: 38.57 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SH 392 & WCR 35 - Intersection Safety Improvements
Special Notes: All Intersection Related Crashes

Project Information

Project Name:	SH 115A Center Turn Lane Extension, & Intersection Improvements				
Project Description:	Center Turn Lane Extension & Intersection Improvements				
CDOT Region:	2	Project Def:	17821	County:	Fremont
Location:	SH 115A	Mile Points:	0.85 – 1.6 & 115A & Elm Ave	Length:	0.75mi & N/A
Schedule:		Work Start Date:	Feb 2012	Work End Date:	Jan 2014

Problem Description:

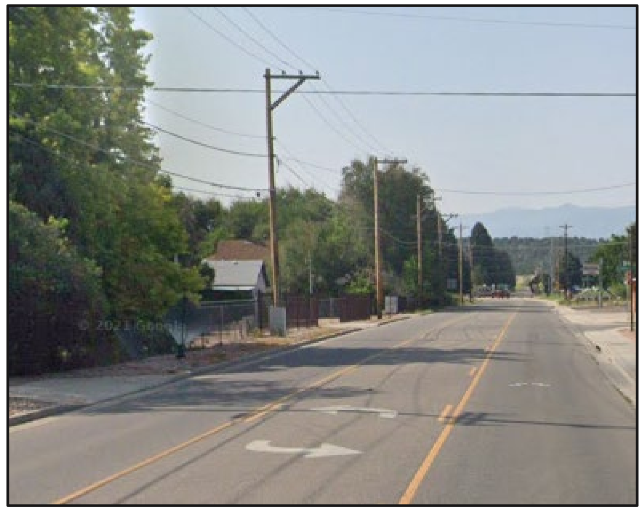
No problem description was provided for the original HSIP funding application for the intersection and segment improvement project.

Improvement Description:

A center turn lane was extended along US 115A between mile points 0.85 and 1.60. Intersection improvements were made to better align Elm Avenue and US 115A for sight distance. The total cost of the project was $2,510,553.00.

115A 0.85 – 1.6MP Fremont County, Colorado

115A & Elm Avenue Fremont County, Colorado



115A 0.85 – 1.6MP Southbound - Before (left) and After (right) improvements

115A & Elm Avenue Eastbound - Before (left) and After (right) improvements

Summary & Findings

US 115A 0.85 - 1.6 MP: The analysis of safety conditions before and after improvements along the segment shows a decrease in the total number of crashes as well as a decrease in targeted crashes. Targeted crashes decreased by 50%, and the number of severe crashes decreased by 57%.

US 115A & Elm Avenue Intersection: The analysis of safety conditions before and after improvements along the segment shows a decrease in the total number and severity of crashes. The rate of crashes decreased by 45% and the number of severe crashes decrease by 50%.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections and/or segments were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections/segments in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – US 115A 0.85 – 1.6 MP

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records along the 0.85 – 1.6 MP segment on US 115A show a decrease in the number of crashes from the five-year before period (2007-2011) to the five-year after period (2015-2019). The number of severe (fatal and injury) crashes also decreased.

- Before Period: 14 severe crashes, 25 injuries, 0 fatalities
- After Period: 6 severe crashes, 7 injured, 1 fatality

The crash rate for all crashes at this intersection decreased by 46% between the before period and after period.

- Before Period: 4.06 crashes per million entering vehicles
- After Period: 2.18 crashes per million entering vehicles

Table 1. Results of Overall Crash Analyses – 0.85 – 1.6 MP

		Before	After
Time Period:		01/01/2007 – 12/31/2011 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)
AADT	US 115A MP 0.85-1.6	8,568	7,370
Crash Filters:		None	
Total Crashes:		**44**	**28**
Fatal Crashes (Fatalities):		0 (0)	0 (0)
Injury Crashes (Injuries):		13 (23)	10 (12)
PDO Crashes:		31	18

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) along the 0.85 – 1.6 MP segment reflect a decrease in the crash record for this project. The segment is LOSS IV for total and severe frequency of crashes in both the before and after periods.

Figure 1. SPF For Total Crashes

US 115A 0.85 – 1.6MP
Before: 2007–2011 After: 2015–2019

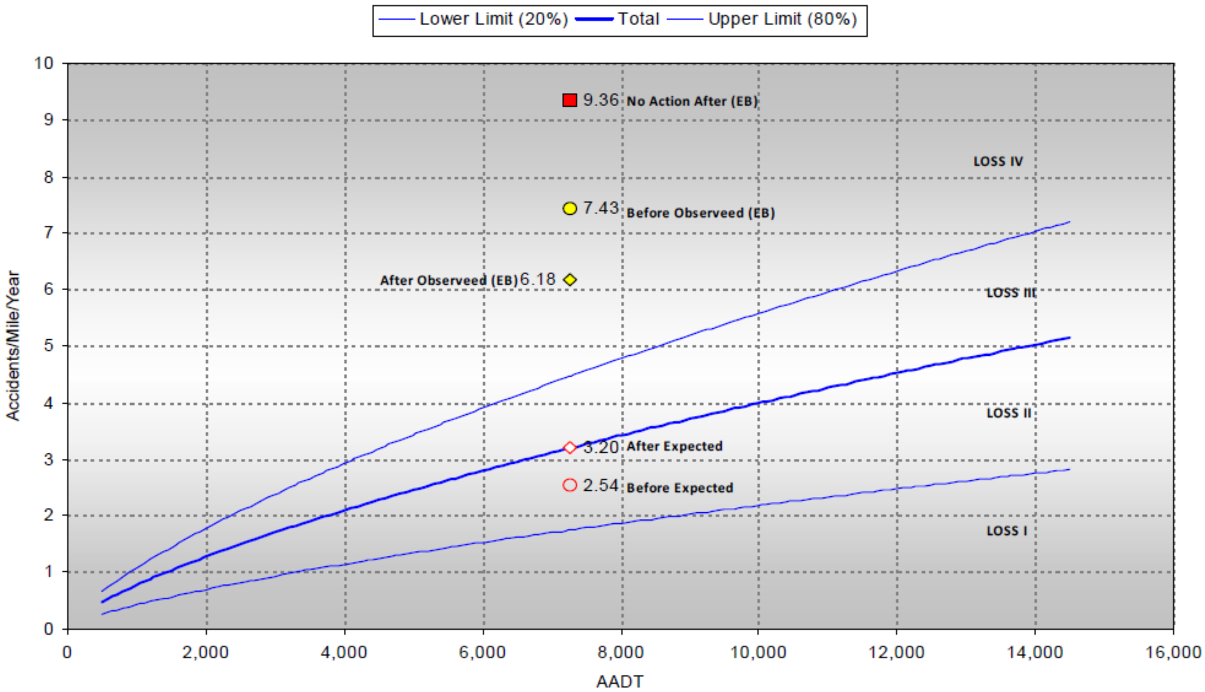


Figure 2. SPF For Severe Crashes

US 115A 0.85 – 1.6 MP
Before: 2007–2011 After: 2015–2019

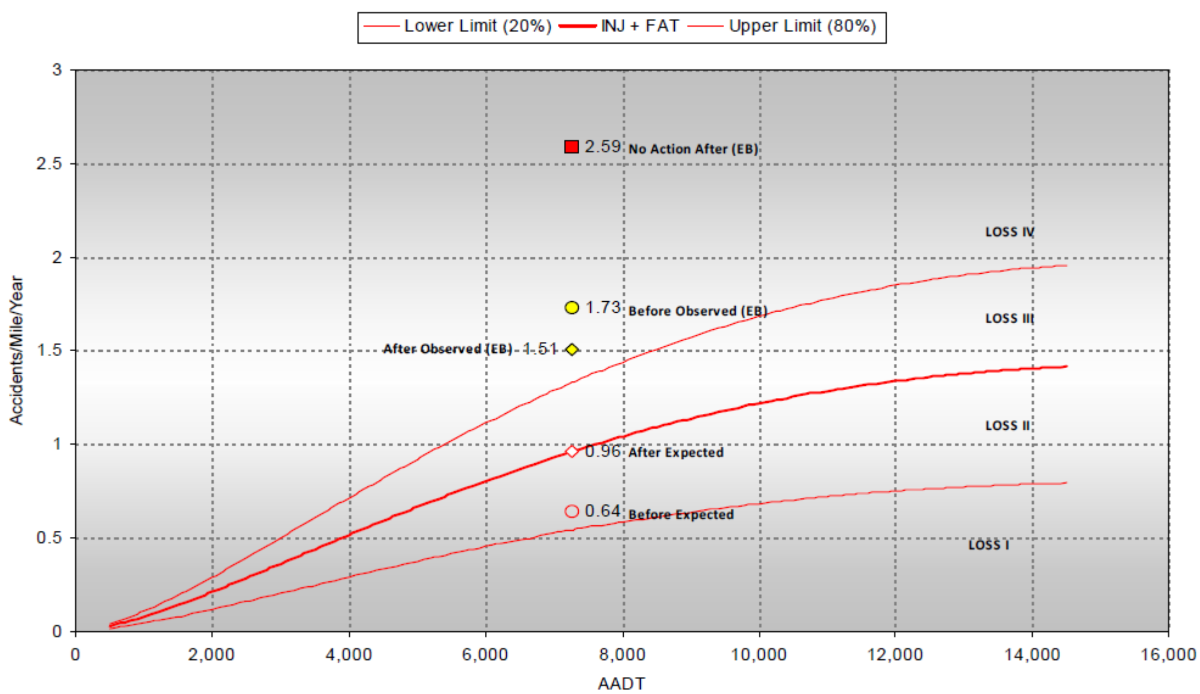


Table 2 provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods at the 0.85 – 1.6 MP segment.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)
Total Crashes			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPY	7.43	6.18	9.36
Mean CPY	2.54	3.20	3.20
Proportion of Mean	2.93	1.93	2.93
Severe (Injury & Fatal) Crashes			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPY	1.73	1.51	2.59
Mean CPY	0.64	0.96	0.96
Proportion of Mean	2.70	1.57	2.70

Crash Type Analyses

A more detailed review of the before and after crash record shows the crash types that were most affected by the improvements including approach turns, broadsides, rear ends, overturning, and sideswipe opposite crashes. **Table 3** shows a comparison of the targeted crashes.

The No-Build After crashes were estimated using the change in traffic volumes on US 115A between the before and after period, as found in **Table 1** (approximately 14% decrease).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2007 – 12/31/2011 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)
Total Crashes	**38**	**19**	**34**
Injury (Injuries)	14 (25)	6 (7)	13 (23)
PDO	24	13	21
% Reduction in Total (Injury/PDO)	--	70% / 38%	--

Results of Safety Analyses – US 115A & Elm Ave

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at the US 115A/Elm Avenue intersection shows a decrease in the number of severe crashes from the five-year before period (2007-2011) to the five-year after period (2015-2019).

- Before Period: 2 severe crashes, 2 injured
- After Period: 0 severe crashes, 0 injured

The crash rate for all crashes at this intersection decreased by 33% between the before period and after period.

- Before Period: 0.39 crashes per million entering vehicles
- After Period: 0.26 crashes per million entering vehicles

Table 4. Results of Overall Crash Analyses – US 115A/Elm Ave

		Before	After
Time Period:		01/01/2007 – 12/31/2011 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)
AADT	Major: 115A	5128	4812
	Minor: Elm Ave	512	481
Crash Filters:		Intersection Related	
Total Crashes:		**4**	**1**
Fatal Crashes (Fatalities):		0 (0)	0 (0)
Injury Crashes (Injuries):		2 (2)	0 (0)
PDO Crashes:		2	1

Safety Performance Functions

SPF plots for both total crashes (**Figure 3**) and for severe (injury and fatal) crashes (**Figure 4)** at the 115A/Elm Avenue intersection reflect a decrease in the crash record for this project. The intersection is LOSS IV for total frequency of crashes in the before period, LOSS II for total frequency of crashes in the after period, LOSS III for severe frequency of crashes in the before period, and LOSS II for severe crash frequency in the after period.

Figure 3. SPF For Total Crashes

US 115A/Elm Avenue
Before: 2007–2011 After: 2015–2019

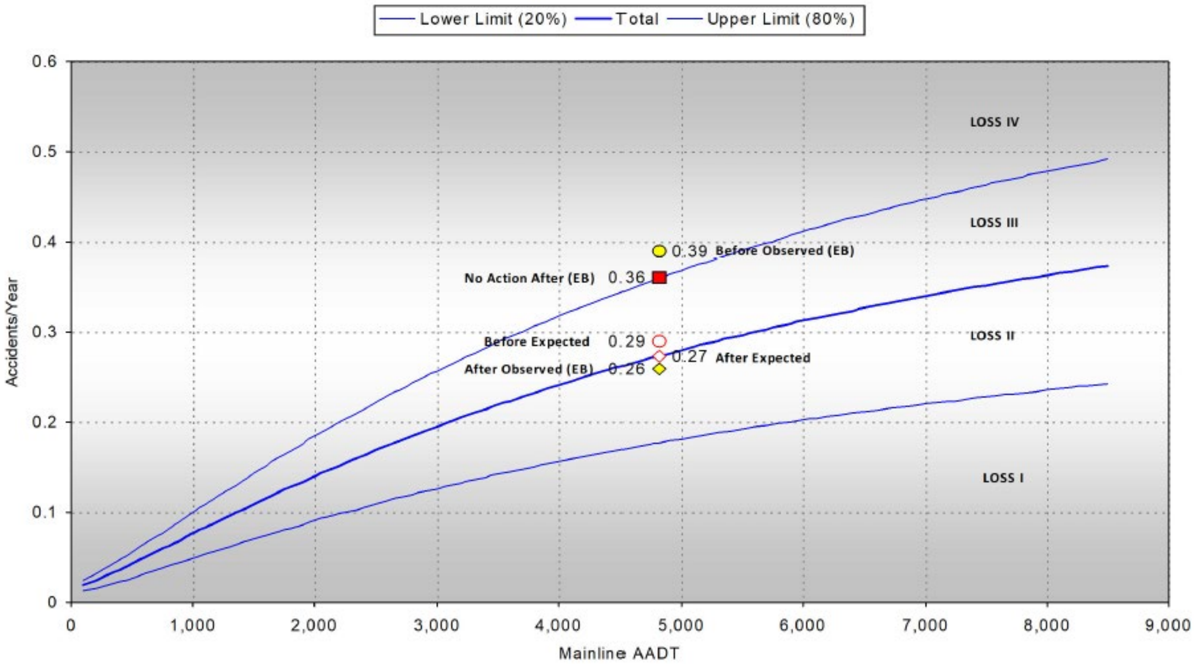


Figure 4. SPF For Severe Crashes

US 115A/Elm Avenue
Before: 2007–2011 After: 2015–2019

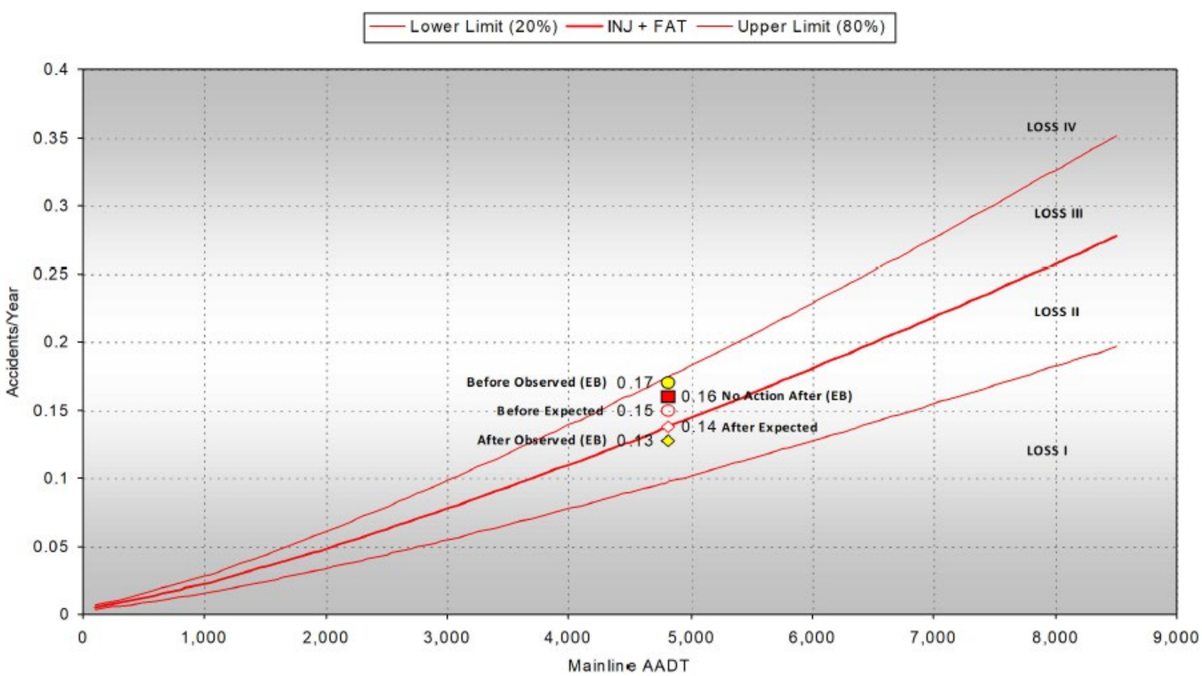


Table 5 provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods at the intersection of 115A with Elm Avenue.

Table 5. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural 2-Lane Undivided Unsignalized 3-Leg Intersections (2018)	Rural 2-Lane Undivided Unsignalized 3-Leg Intersections (2018)	Rural 2-Lane Undivided Unsignalized 3-Leg Intersections (2018)
Total Crashes			
LOSS	LOSS IV	LOSS II	LOSS IV
CPY	0.39	0.26	0.36
Mean CPY	0.29	0.27	0.27
Proportion of Mean	1.34	0.96	1.34
Severe (Injury & Fatal) Crashes			
LOSS	LOSS III	LOSS II	LOSS III
CPY	0.17	0.13	0.16
Mean CPY	0.15	0.14	0.14
Proportion of Mean	1.13	0.93	1.13

Crash Type Analyses

A more detailed review of the before and after crash record shows the crash types that were most affected by the improvements including broadsides, rear ends, approach turns, and overtaking turns. **Table 6** shows a comparison of the targeted crashes.

Table 6. Results of Crash Analyses – US 115A/Elm Ave

	Before	After	No Action After
Time Period	01/01/2007 – 12/31/2011 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)
Total Crashes	**2**	**0**	**2**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	1 (1)	0 (0)	1 (1)
PDO	1	0	1
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 100% / 100%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 2.29 was ultimately realized** and is largely attributed to the decrease in all crash types.

Following the previously mentioned improvements, crash data suggests a reduction in the targeted crashes; however, the resulting B/C analysis would suggest an effective safety project.

Figure 5. Benefit-Cost Analysis Summary

Location: 50 B **Begin:** 318.00 **End:** 359.00 **From:** 01/01/2013 **To:** 12/31/2017

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	22		Weighted PDO:	5.40	59% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	14	24 :Injured	Weighted INJ:	5.90	71% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	63% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 2,510,549
From: 01/01/2007
To: 12/31/2011 Days: 1826

Benefit Cost Ratio: 2.29 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SH 115A MP 0.85 - 2.6 & Elm/115A Intersection
Special Notes: All Intersection Related Crashes

Project Information

Project Name:	SH 30A and SH 83A Raised Medians	
Project Description:	Raised Medians Various Locations, Access Control	
CDOT Region: 6	Project Def: 17936	Counties: Arapahoe, Denver
Locations:	SH 30A, Iliff Ave to Evans Ave Length: 0.25 miles	Mile Points: 4.28 to 4.53
	SH 30A, Idaho to Kentucky Length: 0.56 miles	Mile Points: 5.47 to 6.03
	SH 30A, Virginia Ave Length: 0.09 miles	Mile Points: 6.44 to 6.53
	SH 30A, Billings St to Dillon Way Length: 0.10 miles	Mile Points: 10.06 to 10.16
	SH 83A, Quebec St to Oneida St Length: 0.33 miles	Mile Points: 74.85 to 75.18
Schedule:	Work Start Date: 8/27/2012	Completion Date: 10/19/2012

This project dealt with five locations. The total project cost was $599,376. The work on the project was done during 2012. The before period for SH 30A and SH 83A in this report will be the 5 years prior to the construction (2007 to 2011), and the after period will be the 5 years following construction (2013-2017). While the improvements for all locations involved some form of median installation and access control, the specific improvements differed. Therefore, we will address each location separately. Furthermore, the as-built mile points for some improvements differed from what was included in the application and have been adjusted for analysis accordingly.

Location #1, SH 30A Iliff Ave to Evans Ave

Problem Description: Broadside (left turn and thru) and approach turn crashes. SH 30A is a six-lane urban principal arterial through this section with 3 unsignalized intersections and frequent business driveway accesses. As described in the Federal Hazard Elimination Program (FHEP) application for this project, the five-year crash history (2000 – 2004) showed that there was a total of 26 broadside crashes and 16 approach turn crashes. Our data query in VZS revealed similar results with a total of 27 broadside crashes and 17 approach turn crashes during that period, including 14 injury crashes, injuring a total of 20 people. Broadside and approach turn crashes made up 42% of all injury crashes. There were no sideswipe opposite direction crashes recorded during that period, however our search revealed 1 head-on collision resulting in 1 injury.

Improvement Description: This portion of the project involved the installation of raised medians along SH 30 (Havana St) beginning just north of Iliff Ave at approximately MP 4.36 and continuing north of Evans Ave until approximately MP 4.55 (the analysis is based on these as-built mile points and not the proposed mile points in the application documents). Also included were NO

LEFT TURN and DO NOT ENTER signs, for the purpose of restricting access at different points. The measures eliminated left turns and thru movements from Evans Avenue and driveway accesses between these mile points, they also eliminated left turns from Warren Avenue. Improvements for this location comprised about $230,000 of the project's total cost.

The FHEP application anticipated that a 90% reduction in relevant types of crashes (broadside left turn and through, approach turns, sideswipe opposite direction and head on) might be realized by the improvement. The expected benefit/cost ratio was estimated to be 9.31.

Summary and Findings

Traffic counts indicate that the average ADT on this portion of SH 30 increased slightly between the before and after periods (44,800 in the before period and 46,200 in the after period).

The analysis of safety before and after the improvements were made on this portion of the corridor shows the total number or crashes remained stable, while there was an increase in the number of severe crashes (although there were no fatalities in the after period and 1 in the before period). There were 97 total crashes between MP 4.36 and MP 4.55 during the five-year period before the improvements were made (2007 – 2011). Among the 97 crashes, 26 resulted in injuries and 1 resulted in fatalities. A total of 39 people were injured and 2 were killed. The remaining 70 crashes involved property damage only. 16 of the crashes were broadsides involving left turns and through movements, 13 were approach turns, and 2 were head-on collisions, with no sideswipe opposite direction crashes. Proportionally, these crash types represent about 32% of all crashes in the before period, 100% of fatalities in the before period and about 35% of all injury level crashes in the before period.

In the five years after construction (2013 – 2017), the number of crashes remained at 97. The number of injury related crashes however, increased from 26 to 35 (35%) and there were no fatal crashes. The number of injured people also increased from 39 to 55 (about 41%). The remaining 62 crashes involved property damage only. 4 of the crashes were broadsides involving left turns and through movements, 17 were approach turns, there were no head on or sideswipe opposite direction collisions. Proportionally, these crash types represent about 22% of all crashes and about 9% of all injury level crashes in the after period.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 4.36 to 4.55 shows the same number of crashes, 97, during the five-year period (2007 to 2011) before the improvements and during the five-year after period (2013 to 2017) (see **Table 4**). The number of serious crashes showed a significant increase in the after period (although there was 1 fatal in the before period and none in the after period):

- Before (2007 – 2011) – one fatal crash with 2 killed and 26 injury crashes with 39 injuries
- After (2013 – 2017) – no fatal crashes and 35 injury crashes with 55 injuries

There was a slight increasing trend in the volume of traffic on the corridor from the before period to the after period that we could determine from available sources, so that the conclusions that follow show a somewhat more pronounced degree of safety improvement.

Tables 1 through **3** following, show the changes in crash frequency and severity along the study segment as a whole looking at non-intersection crashes and driveway access crashes, and for the intersections of Havana Avenue with Warren Avenue and Evans Avenue.

Table 1 – SH 30A (Havana St), Iliff Ave to Evans Ave (MP 4.36 – 4.55) - Results of Crash Analysis

	Before	**After**
Time Period:	1/1/2007 to 12/31/2011 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	44,800/5,000 (est.) vpd	46,200/6,000 (est.) vpd
Filters:	All Non-Intersection Related Crashes and Driveway Access Crashes	All Non-Intersection Related Crashes and Driveway Access Crashes
Total Crashes	**54**	**44**
Fatal Crashes (Fatalities)	0 (0)	0 (0)
Injury Crashes (Injuries)	15 (22)	18 (29)
Property Damage Only	39	26
Crash Type: # (%)		
Broadside (Left Turn and Thru)	5 (9.25%) [3 INJ, 3 Injured]	4 (9%) [2 INJ, 2 Injured]
Approach Turn	4 (7.4%) [PDO]	17 (38.6%) [7 INJ, 9 Injured]
Head On	0 (0%)	0 (0%)
Sideswipe Opposite Direction	0 (0%)	0 (0%)
Crash Rate (Crashes Per Million Miles of Vehicle Travel, CPMMVT)	3.48	2.75

Table 1 shows that for the segment as a whole, considering non-intersection and driveway related crashes, broadside crashes involving left turns and through movements were reduced by 20%, while both the number of injury crashes and people injured as part of broadside crashes were reduced by about 33%. Approach turn crashes showed an increase of over 4-fold, from 4 to 17, with injury crashes increasing from zero in the before period to 7 (9 injured) in the after period.

Table 2 – SH 30A (Havana St) and E Warren Ave (MP 4.38 – 4.44) - Results of Crash Analysis

	Before	**After**
Time Period:	1/1/2007 to 12/31/2011 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	44,800/5,000 (est.) vpd	46,200/6,000 (est.) vpd
Filters:	Intersection and Related Crashes	Intersection and Related Crashes
Total Crashes	**28**	**38**
Fatal Crashes (Fatalities)	1 (2)	0 (0)
Injury Crashes (Injuries)	8 (11)	13 (17)
Property Damage Only	19	25
Crash Type: # (%)		
Broadside (Left Turn and Thru)	11 (32.1%) [3 INJ, 3 Injured] [1 FAT, 2 Killed]	3 (7.9%) [1 INJ, 1 Injured]
Approach Turn	4 (10.5%) [1 INJ, 1 Injured]	13 (34.2%) [7 INJ, 9 Injured]
Head On	2 (7.1%) [1 INJ, 3 Injured]	0 (0%)
Sideswipe Opposite Direction	0 (0%)	0 (0%)
Crash Rate (Crashes Per Million Entering Vehicles, CPMEV)	0.31	0.39

Table 2 shows that crashes in general increased by about 36% at the intersection with Warren Ave between the before and after period. Total broadside crash numbers involving left turn and through movements decreased by about 72%, from 11 to 3, injury level crashes and the number of injuries both increased by 66% from 3 to 1. Fatal broadside crashes involving left turning or through movements were eliminated completely, with 1 in the before period and none in the after period. Crash records indicate that in the after period the 3 left turn and/or thru broadside crashes which occurred still involved eastbound and westbound at-fault vehicles.

Table 2 also indicates that a significant increase in the number of approach turn crashes occurring at Warren Ave has been observed between the before and after periods. Total approach turn crashes more than tripled between the before and after periods, from 4 to 13, with injury crashes increasing remarkably from 1 to 7, with the number of persons injured increasing from 1 to 9. **Figure 1** shows that in the after period 10 out of the 13 approach turn crashes involved northbound at-fault vehicles, with 9 out of 10 making left turns onto Warren Ave and 1 making a U-turn.

The project appears to have eliminated head-on crashes at the intersection with Warren Ave with no crashes recorded in the after period.

Figure 1 – Approach Turn Crashes at SH30 and Warren Ave At-Fault Driver Direction (2013-2017)

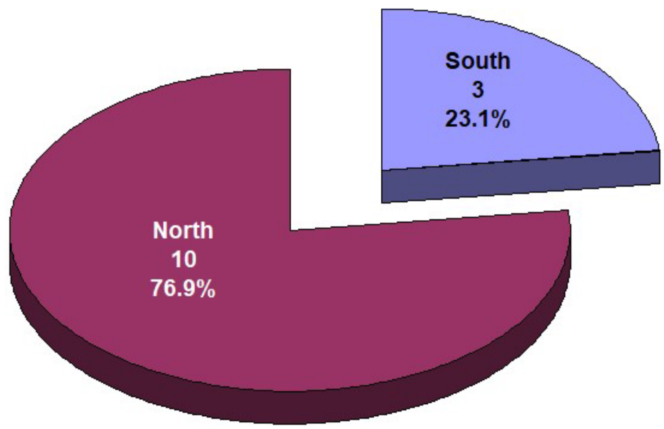


Table 3 – SH 30A (Havana St) and E Evans Ave (MP 4.51 – 4.55) - Results of Crash Analysis

	Before	After
Time Period:	1/1/2007 to 12/31/2011 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	44,800/5,000 (est.) vpd	46,200/6,000 (est.) vpd
Filters:	Intersection and Related Crashes	Intersection and Related Crashes
Total Crashes	**15**	**14**
Fatal Crashes (Fatalities)	0 (0)	0 (0)
Injury Crashes (Injuries)	3 (6)	4 (9)
Property Damage Only	12	10
Crash Type: # (%)		
Broadside (Left Turn and Thru)	2 (13.3%) [1 INJ, 3 Injured]	0 (0%)
Approach Turn	5 (33.3%) [1 INJ, 2 Injured]	2 (14.3%) [All PDO]
Head On	0 (0%)	0 (0%)
Sideswipe Opposite Direction	0 (0%)	0 (0%)
Crash Rate (CPMEV)	0.17	0.15

Table 3 shows overall crashes only reduced by 1. PDO crashes decreased by about 17%, however injury level crashes increased by 1 and the number of persons injured increased by 50% from 6 to 9. There were no fatal crashes in either the before or after period. The number of broadside crashes involving left turn and through movements were eliminated completely, with no crashes of this type seen in the after period. Approach turn crashes show a sizeable 60% reduction in crash numbers, with a 100% reduction in injury level crashes. Crash records indicate

that while all 5 approach turn crashes in the before period involved northbound at-fault vehicles, only 1 of the approach turn crashes in the after period involved an at-fault northbound vehicle.

The project appears to have been effective in removing broadside crashes involving left turns and through movements at the intersection with Evans Ave.

Table 4 – SH 30A (Havana St), Iliff Ave to Evans Ave (MP 4.36 – 4.55) - Results of Crash Analysis

	Before	**After**
Time Period:	1/1/2007 to 12/31/2011 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	44,800/5,000 (est.) vpd	46,200/5,000 (est.) vpd
Filters:	None	None
Total Crashes	**97**	**97**
Fatal Crashes (Fatalities)	1 (2)	0 (0)
Injury Crashes (Injuries)	26 (39)	35 (55)
Property Damage Only	70	62
Crash Type: # (%)		
Broadside (Left Turn and Thru)	16 (16.5%) [6 INJ, 8 Injured] [1 FAT, 2 Killed]	4 (4.1%) [2 INJ, 2 Injured]
Approach Turn	13 (13.4%) [2 INJ, 3 Injured]	17 (17.5%) [7 INJ, 9 Injured]
Head On	2 (2.1%) [1 INJ, 3 Injured]	0 (0%)
Sideswipe Opposite Direction	0 (0%)	0 (0%)

Overall, the project has achieved mixed results. While total crashes remained static, PDO crashes fell by about 11%, and fatal crashes have been removed. Injury level crashes on this corridor increased about 35%, with the number of injuries increasing 41%. The crash types which were targeted as part of the project were broadsides involving left turns and through movements, approach turns, head on and sideswipe same direction crashes.

Overall broadsides involving left turns and through movements have been reduced by 75%, with associated injury level crashes and persons injured reduced by about 66% and 75%, respectively. Fatal level broadside crashes involving left turns and through movements have been eliminated. Additionally, head-on collisions have been eliminated along the corridor.

Conversely, in the after period there is an observed increase in approach turn crashes, with total crashes increasing by about 31%. Remarkably, approach turn injury level crashes more than tripled and the number of injuries due to approach turn crashes tripled, from 3 to 9. There also appears to be a pattern of northbound at-fault approach turn crashes occurring at the intersection of SH 30 (Havana St) and the west leg of E Warren Ave.

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. An 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. However, SPF Analysis requires that the functions be calibrated specifically for the facility type and region being evaluated. At this time, these functions have not been derived for 6-lane urban arterials, or 6-lane 3-leg undivided unsignalized urban intersections in the State of Colorado, so SPF analysis cannot be provided for this project.

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 2** for all relevant crash types (broadsides involving left turns and through movements, approach turns, head-on and sideswipe opposite) that occurred on the segment. **Figure 2** shows the result of the Benefit/Cost calculation is a B/C ratio of **48.83.** This result strongly suggests that the project was justified from the cost-effectiveness standpoint, although results from the safety standpoint are mixed.

Table 5 – SH 30A (Havana Street), Iliff Avenue to Evans Avenue, (MP 4.29 – 4.55) – Benefit Cost Analysis

Colorado Department of Transportation
DiExSys™ Vision Zero Suite
Economic Analysis Report

06/17/2022
Job #: 20220617065929

Location: 30 A **Begin:** 4.36 **End:** 4.55 **From:** 01/01/2007 **To:** 12/31/2011

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors				Other Information	
PDO:	22		Weighted PDO:	5.40	11%	:CRF for PDO	Cost of PDO:	$ 11,100
INJ:	10	15 :Injured	Weighted INJ:	3.69	0%	:CRF for INJ	Cost of INJ:	$ 101,800
FAT:	1	2 :Killed	Weighted FAT:	0.49	100%	:CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	10%	:Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
	Cost:	$ 230,000					Service Life:	20
	From:	01/01/2007					Capital Recovery Factor:	0.080
	To:	12/31/2011	Days:	1826			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: 48.83 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Raised Medians Access Control (Broadsides LT&Thru, Approach Turns, Head-On & Sideswipe Opp)
Special Notes: Based on reduction in crashes from 2007-2011 to 2013-2017 (5yr periods surrounding construction)

Location #2, SH 30A Idaho Pl to Kentucky Ave

Problem Description: Broadside (left turn and thru) and approach turn crashes. SH 30A is a six-lane urban principal arterial between MP 5.68 and 5.98, with one major junction with Mississippi Avenue at MP 5.79 and 2 minor junctions with Arizona Pl and Tennessee Ave, and frequent business access driveways. As described in the Federal Hazard Elimination Program (FHEP) application for this project, the five-year crash history (2000 – 2004) showed that there was a total of 37 PDO and 26 Injury applicable crashes. Our data query in VZS revealed similar results with a total of 27 PDO and 18 Injury crashes with 26 people injured, including 22 broadsides (LT or thru), 15 approach turns, 1 head-on and 3 sideswipe opposite direction crashes.

Improvement Description: This portion of the project involved the installation of central raised medians along SH 30 (Havana St) between Mississippi Ave and Kentucky Ave, mile points 5.82-5.98 approximately, as well as raised median islands at Arizona Pl (access to The Gardens on Havana shopping area), and at 1155 S. Havana St (access to King Soopers shopping center), between MP 5.66 and MP 5.73 approximately. The project restricted all left turn movements from retail business accesses and from Tennessee Ave, as well as removing and removed thru movements at that intersection. Improvements for this location comprised about $570,000 of the project's total cost.

The FHEP application anticipated that a 90% reduction in relevant types of crashes (broadsides from left turns and through movements, approach turns, sideswipe opposite direction and head on) might be realized by the improvement. The expected benefit/cost ratio was estimated to be 7.89.

Summary and Findings

Traffic counts indicate that the average ADT on this portion of SH 30 increased from 36,130 vpd in the before period to 41,617 vpd in the after period, an increase of about 15%. There appears to have been successive significant development between 2009 and 2013 on the 'Gardens on Havana' retail site, which included the development of Arizona Pl into a through street connecting SH 30 (Havana St) and S Joliet Street to the east.

The safety analysis was made between MP 5.66 and MP 5.98 from the beginning of the median installation at Arizona Pl to the end of median installations just south of Kentucky Ave. Analysis excluded the Mississippi Ave intersection which underwent no changes as part of the project. The analysis on the face of it shows an increase in both the total number of crashes, and in the number of severe crashes. There were 68 total crashes on the segment during the five-year period before the improvements were made (2007 – 2011). Among the 68 crashes, 23 resulted in injuries and 1 resulted in a fatality. A total of 28 people were injured and 1 was killed. The remaining 44 crashes involved property damage only.

In the five years after construction (2013 – 2017), the number of crashes increased to 98, an increase of about 44%, which it must be noted was also accompanied by an increase of traffic volume of about 15%. The number of injury related crashes increased from 23 to 29 (about 26%) and there were no fatal crashes in the after period. The number of injured people increased by about 21% from 28 to 34. The remaining 69 crashes involved property damage only, an increase of almost 57%.

It is noted that other features of this project area have been altered including slight alterations to vehicle paths. Arizona Pl is now a through street, where previously it was not. The area to the southeast of Mississippi Ave has seen major retail development. It is likely that these alterations may have influenced the frequency and types of crashes that occurred during the after period.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records shows an increase in the number of crashes from 68 during the five-year period (2007 to 2011) before the improvements to 98 during the five-year after period (2013 to 2017) after improvements (see **Table 6)**. The number of serious crashes shows an increase from 23 in the before period to 29 in the after period:

- Before (2007 – 2011) – 1 fatal crash and 23 injury crashes with 1 killed and 28 injured
- After (2013 – 2017) – No fatal crashes and 29 injury crashes with 34 injured

There was an increasing trend in the volume of traffic on the corridor from the before period to the after period that we could determine from available sources, so that the conclusions that follow show a somewhat more pronounced degree of safety improvement.

Table 6– SH 30 (Havana St), (MP 5.66 – 5.98 Arizona Pl to Kentucky Ave) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2007 to 12/31/2011 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	36,130 vpd	41,617 vpd
Filters:	Intersection, intersection related, driveway access, non-intersection (MP 5.66-5.77, MP 5.82-5.98)	Intersection, intersection related, driveway access, non-intersection (MP 5.66-5.77, MP 5.82-5.98)
Total Crashes	**68**	**98**
Fatal Crashes (Fatalities)	1 (1)	0
Injury Crashes (Injuries)	23 (28)	29 (34)
Property Damage Only	44	69
Crash Type: # (%)		
Broadside (LT and Thru)	19 (27.9%) [9 INJ, 10 Injured]	5 (5.1%) [1 INJ, 1 Injured]
Approach Turn	5 (7.4%) [1 INJ, 2 Injured]	23 (23.5%) [9 INJ, 11 Injured]
Head On	0	0
Sideswipe Opposite Direction	0	0

Tables 6 through **10** following, show the changes in crash frequency and severity for the following locations between MP 5.66 and MP 5.98:

- Intersection of Arizona Place and driveway access to 1205 S Havana St (Chipotle),
- Intersection with driveway access to 1155 S Havana St (King Soopers)
- Intersection with Tennessee Ave and driveway access to 1001 S Havana St (Meridian Garden apartments) and

- The segment north of Mississippi Ave to Kentucky Avenue for non-intersection mainline only crashes.

Table 7– SH 30 (Havana St), (MP 5.66 – 5.70 Arizona Pl & Chipotle) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2007 to 12/31/2011 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	36,130/5,000(est.) vpd	41,617/10,000(est.) vpd
Filters:	Intersection, Intersection Related and Driveway Access Crashes	Intersection, Intersection Related and Driveway Access Crashes
Total Crashes	**4**	**13**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	2 (2)	4 (4)
Property Damage Only	2	9
Crash Type: # (%)		
Broadside (WBLT and Thru)	1 (14.3%) [1 INJ, 1 Injured]	0
Approach Turn	1 (14.3%) [PDO]	3 (23.1%) [2 INJ, 2 Injured]
Head On	0	0
Sideswipe Opposite Direction	0	0
Crash Rate (CPMEV)	0.05	0.14

Table 7 shows that the project was effective in reducing broadside crashes due to left turn and/or thru movements from westbound Arizona Pl. However, broadside crashes due to eastbound and southbound at-fault vehicles increased from zero in the before period to 3 and 1, respectively, in the after period, with all movements being left-turn movements. At the same time approach turn crashes tripled between periods, and all involved northbound and southbound left-turning vehicles at fault. As there were no head-on collisions or sideswipe opposite direction crashes in either the before or the after period, the project at Arizona Pl seems to have effectively only removed one targeted crash. The increase in approach turn crashes is likely at least partially attributable to the overall increase in traffic volume through the corridor which accompanied the commercial development in the area. However, had a raised central median been provided south of the intersection with Mississippi Avenue, as it was to the north, the problem may have been avoided.

Table 8 – SH 30 (Havana St), (MP 5.71 – 5.73 King Soopers Lot) - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2007 to 12/31/2011 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	36,130/5,000(est.) vpd	41,617/7,500(est.) vpd
Filters:	Intersection, Intersection Related and Driveway Access Crashes	Intersection, Intersection Related and Driveway Access Crashes
Total Crashes	**6**	**6**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	2 (2)	2 (3)
Property Damage Only	4	4
Crash Type: # (%)		
Broadside (EBLT)	2 (50%) [PDO]	1 (16%) [PDO]
Approach Turn	0	1 (16%) [1 INJ, 2 Injured]
Head On	0	0
Sideswipe Opposite Direction	0	0
Crash Rate (CPMEV)	0.08	0.07

Table 8 shows crash frequency remained stable at this intersection and while the number of injury crashes did not increase, the number of injuries did increase by 1. Moreover, it seems that targeted movements (eastbound left turns), continued to occur. There were no approach turn crashes in the before period but 1 crash with 2 people injured in the after period. The project has achieved at most a limited reduction in targeted crashes, i.e. those related to eastbound left turns. Moreover, the project itself may have increased the potential for approach turn crashes to occur due to northbound vehicles turning left into the lot. Provision of a central raised median similar to that provided north of Mississippi Ave as part of the project, may have made the improvements more effective and prevented approach turn crashes as well.

Table 9 – SH 30 (Havana St), (MP 5.90 – 5.94 Tennessee Ave) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2007 to 12/31/2011 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	36,130/4,000(est.) vpd	41,617/5,000(est.) vpd
Filters:	Intersection, Intersection Related and Driveway Access Crashes	Intersection, Intersection Related and Driveway Access Crashes
Total Crashes	**12**	**25**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	4 (5)	6 (7)
Property Damage Only	8	19
Crash Type: # (%)		
Broadside (WBLT & thru, EBLT & thru)	4 (33.3%) [2 INJ, 2 Injured]	0
Approach Turn	2 (16.7%) [1 INJ, 2 Injured]	16 (64%) [4 INJ, 5 Injured]
Head On	0	0
Sideswipe Opposite Direction	0	0
Crash Rate (CPMEV)	0.16	0.29

Table 9 shows that crash frequency more than doubled at the intersection between the before and after periods, while the number of severe crashes increased 50% and the number of injuries increased 40% from 5 to 7. The project appears to have been successful in removing instances of broadsides due to east or westbound left turns and through movements, with no crashes of these types recorded in the after period. However, the number of approach turn crashes at the intersection increased significantly between the before and after period by a factor of 8, while injury level approach turn crashes quadrupled and the number of people injured in approach turn crashes more than doubled. Of the 16 approach turn crashes occurring in the after period, 13 (about 81%) involved northbound left turns. **Figure 2** shows that traffic queueing may be a problem at the intersection with Mississippi Avenue downstream following both the retail development to the southeast and the increased traffic volume on the corridor in the after period. It's possible that northbound left turning vehicles are misjudging gaps in traffic, faced with 3 opposing lanes of traffic, queueing conditions may prevent a clear view across all lanes for turning vehicles.

The installation of the raised central median concentrated left turns in the vicinity of Tennessee Avenue rather than creating distribution of left turns along Havana. In this regard an increase in approach turn crashes would not have been unexpected, however the magnitude of the increase would not have been anticipated. Further access control at this location may be appropriate if the problem has not improved to date following the after period.

Figure 2 – Traffic Queues South of Tennessee Ave on SH 30 (June 2017)

Table 10 – SH 30 (Havana St), (MP 5.83 – 5.98 Mississippi Ave to Kentucky Ave) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2007 to 12/31/2011 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	36,130 vpd	41,617 vpd
Filters:	Non-Intersection	Non-Intersection
Total Crashes	**18**	**33**
Fatal Crashes (Fatalities)	1 (1)	0
Injury Crashes (Injuries)	5 (7)	10 (13)
Property Damage Only	12	23
Crash Type: # (%)		
Head On	0	0
Sideswipe Opposite Direction	0	0

Table 10 shows that between MP 5.83 and MP 5.98 where central medians were installed, there were no head-on or sideswipe opposite direction crashes in either the before or the after period. Crash records indicate however, that while there were zero fatalities recorded in the after period, the overall number of crashes increased by 83%. The number of injury level crashes doubled, and the number of injuries increased by about 86%, from 7 to 13. Crash records indicate that in both the before and after periods, the crash distribution shows rear end collisions and sideswipe same direction collisions were the dominant crash types. These crash types are generally seen where congestion is a problem. With records indicating these crashes predominantly occurred in the southbound direction, a capacity or progression problem may be present approaching Mississippi Avenue. It is unlikely the project itself caused the increase in crashes.

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. However, SPF Analysis requires that the functions be calibrated specifically for the facility type and region being evaluated. At this time, these functions have not been derived for 6-lane urban arterials, or 6-lane 3-leg undivided unsignalized urban intersections in the State of Colorado, so SPF analysis cannot be provided for this project.

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. However, because within the project limits as a whole the overall crash numbers increased, as did the number of approach turn crashes, the B/C analysis is based only on the reduction seen in broadside crashes due to relevant left turns and thru movements.

Overall, the project achieved mixed results, successfully reducing the number of broadsides due to left turn and thru movements, particularly those at the injury level, but failing to ameliorate approach turn crashes. There were no east-west approach turn crashes in the before period, but approach turns involving a north or southbound vehicle increased in the after period, particularly at the Meridian Gardens driveway access opposite Tennessee Ave. There were no head-on or sideswipe opposite direction crashes in either the before or after period where the medians are located. **Table 11,** which is based only on the reduction in broadside crashes due to left turns and thru movements, shows that the project was successful from the cost-effectiveness standpoint, however, given the rise in approach turn crashes it does not seem to have been effective from the safety standpoint.

Table 11 – SH 30A (Havana Street), Idaho to Kentucky Avenue, (MP 5.66 – 5.98) – Benefit Cost Analysis

Colorado Department of Transportation
DiExSys™ Vision Zero Suite
Economic Analysis Report

06/20/2022

Job #: 20220620085524

Location: 30 A **Begin:** 5.66 **End:**5.98 **From:**01/01/2007 **To:**12/31/2011

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	19		Weighted PDO:	4.67	60% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	9	10 :Injured	Weighted INJ:	2.46	90% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	69% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
	Cost:	$ 570,000				Service Life:	20
	From:	01/01/2007				Capital Recovery Factor:	0.080
	To:	12/31/2011	Days: 1826			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: 5.60 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Raised Medians Access Control (Broadsides Left-Turn & Thru Movements Only)

Special Notes: Based on reduction in crashes from 2007-2011 to 2013-2017 (5yr periods surrounding construction)

Location #3, SH 30A Virginia Ave

Problem Description: Broadside crashes due to westbound left turn and through movements. SH 30 at Virginia Ave is an urban 6-lane divided unsignalized 4-leg intersection.

Improvement Description: This portion of the project involved the installation of a median island and NO LEFT TURN sign on the east side of Virginia Ave. Application documents indicate that improvements for this location comprised about $100,000 of the project's total cost.

The FHEP application anticipated that a 90% reduction in relevant types of crashes (i.e., WB left turn and thru broadsides) might be realized by the improvement. The expected benefit/cost ratio was estimated to be 3.55.

Summary and Findings

We used MP 6.47 to 6.51 to assess the impacts at the intersection. This project was completed in 2012, so the after period is 2013-2017. The median island and regulatory sign which were installed as part of this project prohibited left turns from westbound Virginia Avenue but did not affect any other movements at the intersection (see **Figures 3-7**).

Figure 3 – SH 30 (Havana) and Virginia Ave., Aerial View Sept. 2011

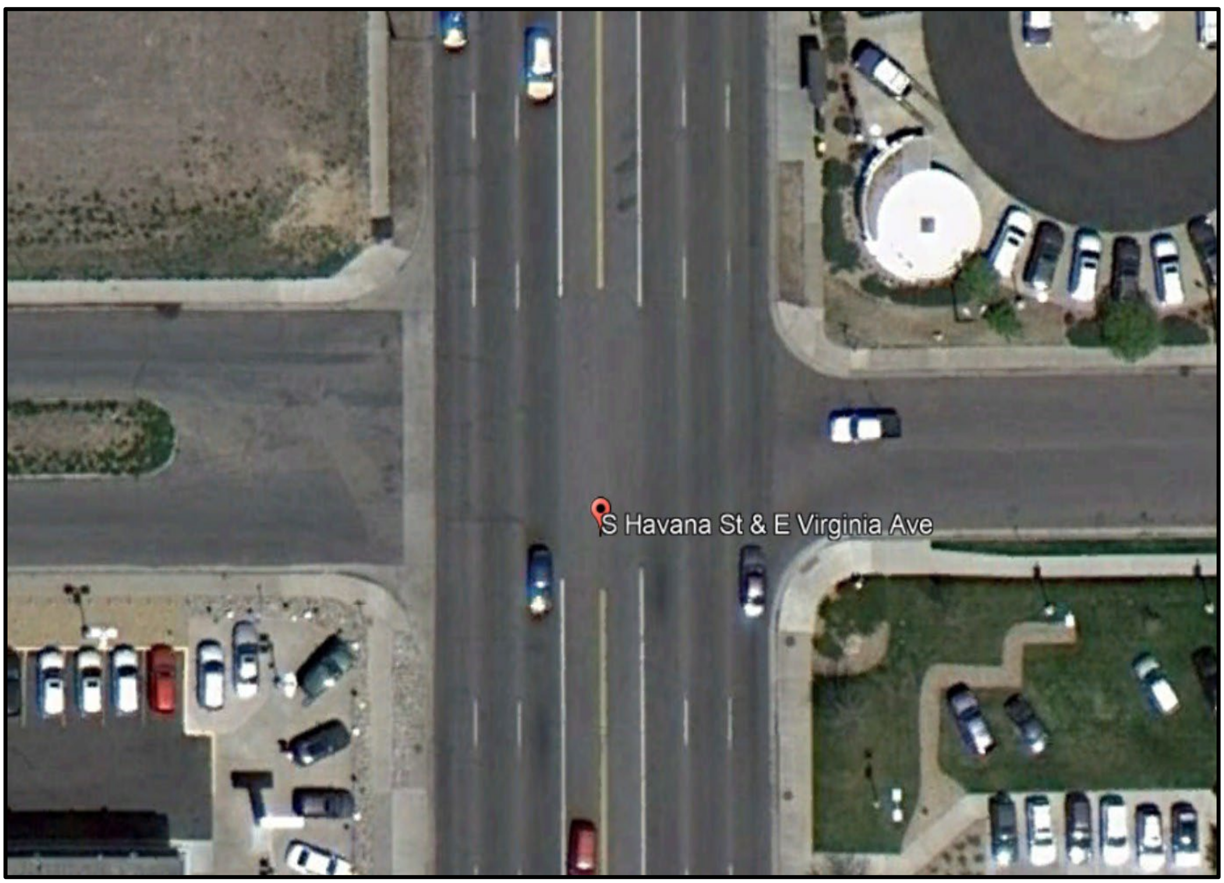


Figure 4 – SH 30 (Havana) and Virginia Ave., Aerial View Oct. 2012

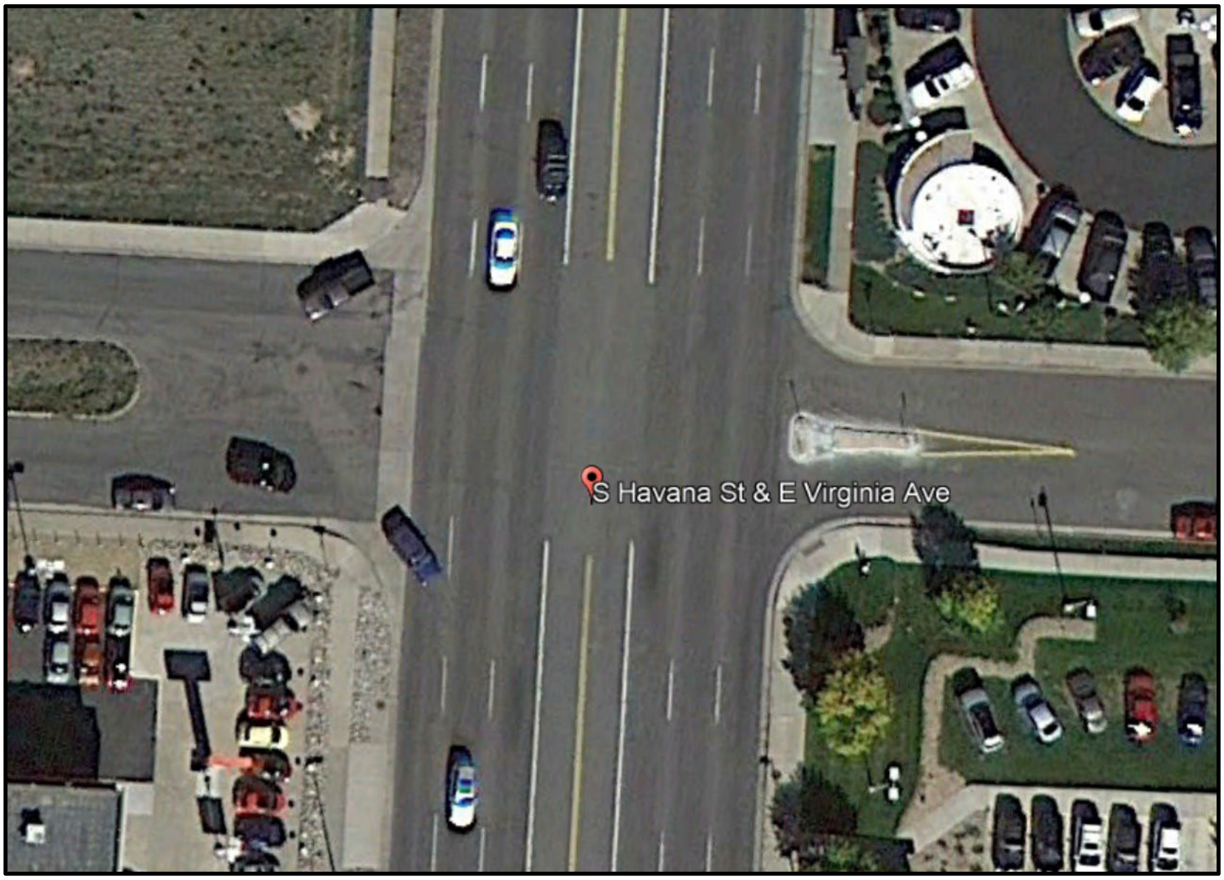


Figure 5 – View Facing West, Virginia Ave., Sept. 2011

Figure 6 – No Left Turn, Westbound Virginia Ave., Sept. 2014

However, additional improvements were made at the intersection during the after period following completion of this project. Sometime between October 2012 and October 2013 thru movements were prohibited from eastbound Virginia Avenue (**Figures 7** and **8**). Furthermore, re-striping which took place between late 2012 and late 2013 also prohibited left turns from Southbound SH 30 (Havana) onto eastbound Virginia Avenue (see **Figure 9**).

Figure 7 – View Facing East from Northbound Havana, Oct. 2012

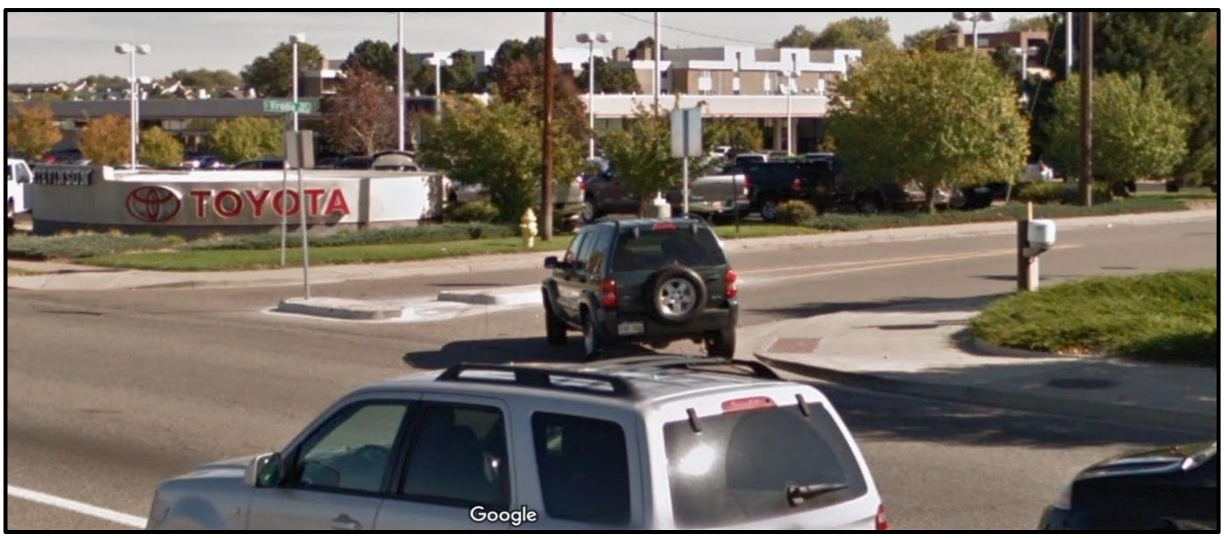


Figure 8 – View Facing East, Virginia Ave., Sept. 2014

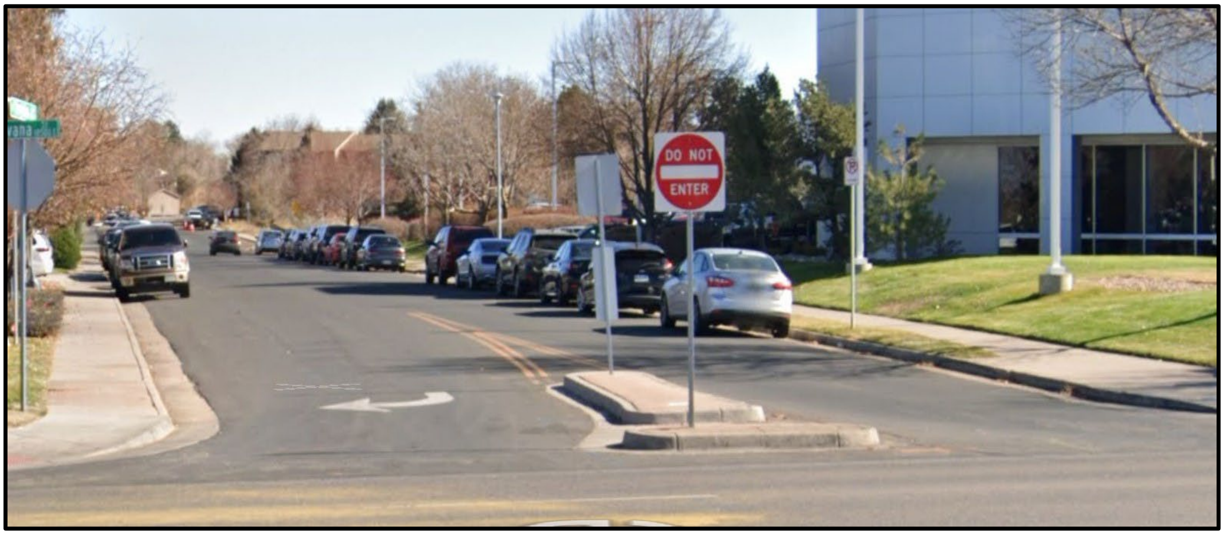
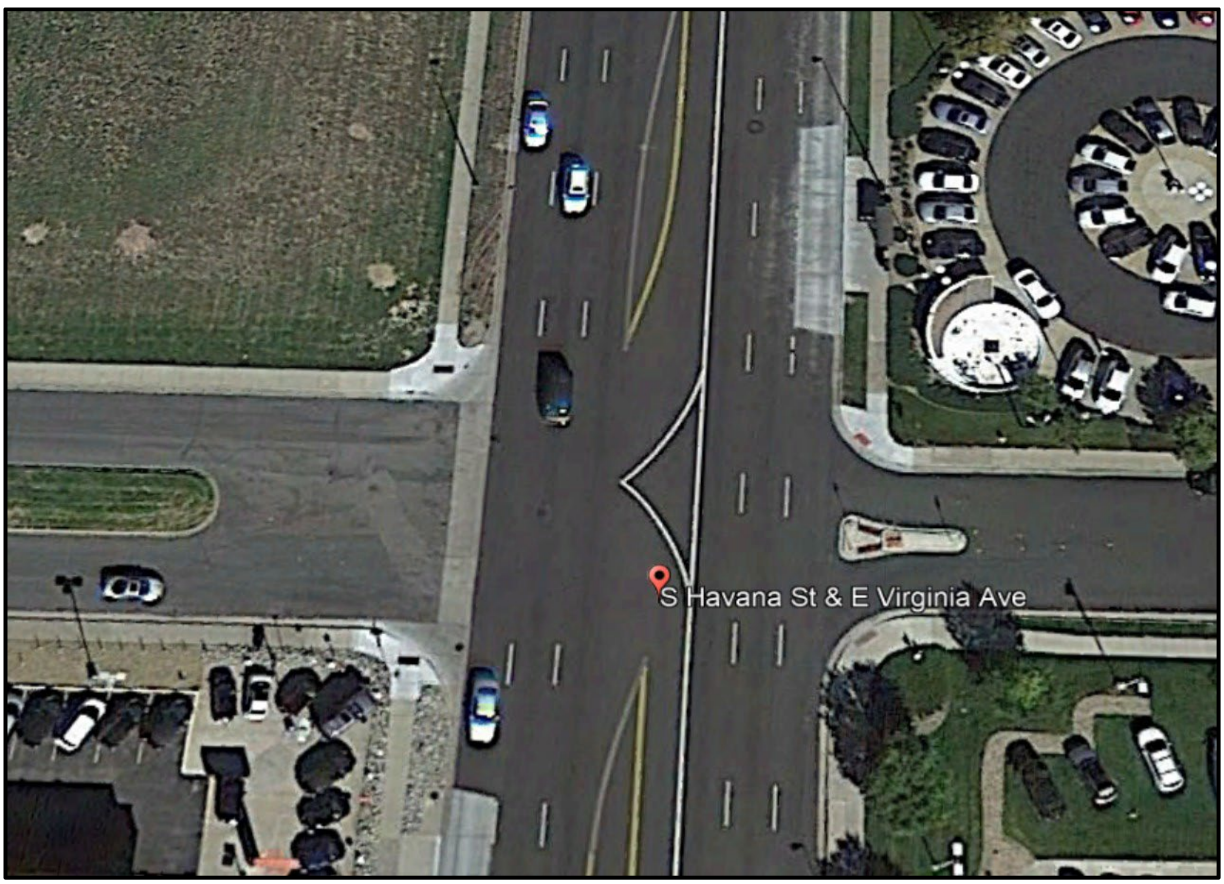


Figure 9 – SH 30 (Havana) and Virginia Ave., Aerial View, Oct. 2013



The analysis is therefore affected by the compounding improvements at the intersection. Improvements made after project completion may have resulted in an overall crash reduction at the intersection. However, crashes affected by this particular project were broadside crashes and approach turn crashes involving westbound left turning movements. Therefore, to assess any crash reduction in crashes related to these movements due to this project, analysis will focus only on broadside and approach turn crashes at the intersection which involved westbound left turning vehicles.

CDOT MS2 traffic counts indicate that the average ADT on this portion of SH 30 increased from 36,662 vpd in the before period to 41,646 in the after period. We estimated the ADT on Virginia Ave to be about 1,500 vpd in the before period and about 1,000 vpd in the after period.

The analysis of safety before and after the improvements were made on the eastern leg of Virginia Ave shows a reduction in both the total number of crashes involving westbound left turning vehicles (‘qualifying crashes’) and in the number of severe crashes involving westbound left turning vehicles. There were 7 total qualifying crashes in the five-year period before the improvements were made (2007 – 2011). Among the 5 crashes, 3 resulted in injuries with a total of 7 people injured. The remaining 4 crashes involved property damage only. There were no fatal crashes. All of the 7 crashes were Broadside crashes.

In the five years after construction (2013 – 2017), the number of qualifying crashes decreased to 3, a reduction of about 57%. The number of PDO crashes fell by 50% to 2 crashes. The number of injury related crashes decreased from 3 to 1 (66%) with 1 person injured (a decrease of 6 people or about 86%). There were no fatal crashes. All 3 crashes were Broadside crashes.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 6.47 to 6.51 shows a decrease in the qualifying number of crashes from 7 during the five-year period (2007 to 2011) before the improvements to 3 during the five-year after period (2013 to 2017) (see **Table 12**). The number of serious crashes shows a decrease from 3 in the before period to 1 in the after period:

- Before (2007 – 2011) – 0 fatal crashes and 3 injury crashes with 7 injured
- After (2013 – 2017) – 0 fatal crashes and 1 injury crashes with 1 injured

Table 12 – SH 30 at Virginia Avenue, (MP 6.47 – 6.51) - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2007 to 12/31/2011 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	36,662/1,500 (est.) vpd	41,646/1,000 (est.) vpd
Filters:	Intersection, Intersection Related Crashes and Driveway Access Westbound left turn at-fault	Intersection, Intersection Related Crashes and Driveway Access Westbound left turn at-fault
Total Crashes	**7**	**3**
Fatal Crashes (Fatalities)	0 (0)	0 (0)
Injury Crashes (Injuries)	3 (7)	1 (1)
Property Damage Only	4	2

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. An 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.

However, SPF Analysis requires that the functions be calibrated specifically for the facility type and region being evaluated. At this time, these functions have not been derived for urban 6-lane divided unsignalized 4-leg intersections in the State of Colorado, so SPF analysis cannot be provided for this location.

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Table 13** for the reduction seen in crashes involving westbound left turning at-fault vehicles between the before and the after period. **Table 13** shows the result of the Benefit/Cost calculation is a B/C ratio of **19.44.** This result strongly suggests that the project was justified from both the cost-effectiveness and the safety standpoints.

At the same time, the project is intended to operate whereby westbound left turn movements are prohibited and the crash records clearly indicate that illegal movements continue to occur in the after period with citations including failure to observe a traffic device. A more effective measure would be the installation of a raised central median which prevents westbound left turn and through movements while protecting eastbound and northbound left turns, such as filling in the currently striped area which delineates these turning movements with a concrete median. We estimate the reduction in qualifying crashes to be 90%.

Table 13 – SH 30A at Virginia Avenue, (MP 6.47 – 6.51) – Benefit Cost Analysis

Colorado Department of Transportation
DiExSys™ Vision Zero Suite
Economic Analysis Report

06/21/2022

Job #: 20220621084421

Location: 30 A **Begin:** 6.47 **End:** 6.51 **From:** 01/01/2007 **To:** 12/31/2011

Benefit Cost Ratio Calculations

Crashes				Projected Crashes and Reduction Factors				Other Information	
PDO:	4			Weighted PDO:	0.98	50%	:CRF for PDO	Cost of PDO:	$ 11,100
INJ:	3	7	:Injured	Weighted INJ:	1.72	86%	:CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0	:Killed	Weighted FAT:	0.00	0%	:CRF for FAT	Cost of FAT:	$ 1,820,600
				B/C Weighted Year Factor:	5.00	65%	:Weighted CRF	Interest Rate:	5%
								AADT Growth Factor:	2.0%
		Cost:	$ 100,000					Service Life:	20
		From:	01/01/2007					Capital Recovery Factor:	0.080
		To:	12/31/2011	Days:	1826			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: 19.44 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Prohibit Westbound Left Turns with Raised Median Island & Regulatory Sign. WBLT At-fault crashes
Special Notes: Based on reduction in crashes from 2007-2011 to 2013-2017 (5yr periods surrounding construction)

Location #4, SH 30A (6th Ave) Billings Street to Dillion Way (Sable Boulevard)

Problem Description: Broadside (left turn and thru) and approach turn crashes. SH 30A is a six-lane urban principal arterial with dedicated left turn lanes at this location and frequent business driveway accesses. As described in the Federal Hazard Elimination Program (FHEP) application for this project, the five-year crash history (2000 – 2004) showed that there was a total of 8 qualifying broadside and approach turn crashes, our data query in VZS revealed the same results. Crashes included 2 injury crashes, injuring a total of 4 people. Broadside (left turn and thru) and approach turn crashes made up 57% of all driveway access crashes.

Improvement Description: This portion of the project involved the installation of a raised central median on SH 30 (6th Ave) between Billings Street and Dillon Way (Sable Boulevard), MP 10.06 to MP 10.16. Application documents indicate that the improvements for this location comprised about $95,000 of the project's total cost.

The FHEP application anticipated that a 90% reduction in relevant types of crashes (i.e., northbound and southbound left turn and thru broadside crashes, and approach turn crashes). The expected benefit/cost ratio was estimated to be 4.62.

Summary and Findings

Traffic counts indicate that the average ADT on this portion of SH 30 did not change from the before period (2007-2011) to the after period (2013-2017), remaining around 34,390 vpd.

For this analysis we will consider only the relevant crash types, that is left-turn and thru broadsides and approach turns (Note: there were no head-on or sideswipe opposite direction collisions in either period). The analysis of safety before and after the improvements were made on this portion of the corridor shows a reduction in the total number of crashes. There were 2 total qualifying crashes on the segment during the five-year period before the improvements were made (2007 – 2011). Both crashes involved property damage only. There was 1 NBLT broadside and 1 WBLT approach turn crash.

In the five years after construction (2013 – 2017), the number of qualifying crashes decreased to zero.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after qualifying crash records from MP 10.06 to 10.16 shows a decrease in the number of crashes from 2 during the five-year period (2007 to 2011) before the improvements to zero during the five-year after period (2013 to 2017) (see **Table 14**). There were no serious crashes in either period.

- Before (2007 – 2011) – 0 fatal crashes, 0 injury crashes and 2 property damage only
- After (2013 – 2017) – 0 crashes

Table 14 – SH 30 (6th Ave), Billings St to Dillon Way (Sable Blvd) (MP 10.06 – 10.16) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2007 to 12/31/2011 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	34,390 vpd	34,390 vpd
Filters:	Non-Intersection and Driveway Access Crashes (Left turn and thru broadsides, approach turns)	Non-Intersection and Driveway Access Crashes (Left turn and thru broadsides, approach turns)
Total Crashes	**2**	**0**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	0	0
Property Damage Only	2	0

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. An 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.

However, SPF Analysis requires that the functions be calibrated specifically for the facility type and region being evaluated. At this time, these functions have not been derived for urban 6-lane principal arterials in the State of Colorado, so SPF analysis cannot be provided for this location.

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Table 15** for all targeted crashes in the segment. **Table 15** shows the result of the Benefit/Cost calculation is a B/C ratio of **0.79.** This result strongly suggests that the project was not justified from cost-effectiveness standpoint. It is, however, more difficult to say for certain if the safety benefits are attributable to project alone. It is notable that in the 2000-2004 period, which was considered as part of the original application, the problem with left turn and thru broadsides as well as approach turns seems to have been more significant. In that 2000-2004 period our VZS query shows there were:

- 5 NB at-fault broadsides, 3 involving left turns and 2 involving thru movements, which included 4 PDO crashes and 1 injury crash in which 1 person was injured,

- 3 WBLT at-fault approach turn crashes, which included 2 PDO crashes and 1 injury crash in which 3 people were injured.

The changes from the 2000-2004 period to the 2007-2011 period, pre-construction, are in themselves remarkable, with only 2 PDO crashes occurring in the latter, represents a reduction of total qualifying crashes by 75% and qualifying injury crashes by 100%. We don't know to what the decrease in broadsides and approach turns between 2000-2004 and 2007-2011 is attributable, however, whatever it may be, the central median project appears to have been successful in eradicating all targeted crashes.

Table 15 – SH 30A (MP 10.06 to 10.16) – Benefit Cost Analysis

Colorado Department of Transportation
DiExSys™ Vision Zero Suite
Economic Analysis Report

06/21/2022
Job #: 20220621094434

Location: 30 A **Begin:** 10.06 **End:** 10.16 **From:** 01/01/2007 **To:** 12/31/2011

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	2		Weighted PDO:	0.49	100% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	0	0 :Injured	Weighted INJ:	0.00	0% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	100% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
	Cost:	$ 95,000				Service Life:	20
	From:	01/01/2007				Capital Recovery Factor:	0.080
	To:	12/31/2011	Days: 1826			Annual Maintenance/Delay Cost:	$ 0

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

Type of Improvement: Central Raised Median to Restrict Movements (HO,Sideswipe Opp, Approach Turn and BS left turn &
Special Notes: Based on reduction in crashes from 2007-11 to 2013-17 (5yr periods surrounding construction)

Location #5, SH 83A (Leetsdale Dr) Quebec Street to Oneida Street

Problem Description: Broadside and approach turn crashes at the driveway access to the South Lowry Marketplace shopping center in the 7100 Block. SH 83 between Quebec Street and Oneida Street is a 6-lane divided urban arterial. It has driveway accesses to residential complexes on the north side and to commercial and retail developments, including a shopping plaza, on the south side.

Improvement Description: This portion of the project involved the installation of a raised central median beginning east of Oneida Street at approximately MP 74.94 and continuing to Quebec Street at approximately MP 75.05. Left turns and through movements were prohibited from the Lowry Marketplace shopping plaza on the south side and from the eastern driveway access point for the apartment complex in the 7200 Block on the north side, but not the western driveway access of the apartment complex. Also prohibited were westbound left turns into the plaza. Application documents indicate that improvements for this location comprised about $280,000 of the project's total cost.

The FHEP application anticipated that a 90% reduction in targeted crashes (i.e. left turn and thru broadside crashes, approach turns, head-on and sideswipe opposite direction crashes) might be realized by the improvement. The expected benefit/cost ratio was estimated to be 11.08.

Summary and Findings

We used MP 74.94 to 75.07 to assess the impacts on the segment. This project was started and completed in 2012, so the after period is 2013-2017. However, Google Street View imagery indicates that between October 2009 and October 2011, efforts were made to stop the pattern of westbound left turn approach turn crashes into the shopping plaza on the south side. **Figure 10** shows the presence of a DO NOT ENTER sign targeted at westbound traffic in October 2011, **Figure 11** shows the sign was not present in October 2009, the nearest previous date to which we have imagery for, while **Figure 12** shows the exit at the end of the after period in 2017. Combined with crash records however, we can tell that all approach turns on the segment during the before period were westbound left turn at-fault vehicles making turns into the shopping plaza, furthermore we can tell there were at least 4 or more such crashes each year in the before period, up to and including through 2010, except for 2011, in which there were no westbound left turn approach turn crashes. **Figure 13** shows that the pattern ceased in 2011. Considering this, it is difficult to attribute the conclusions which follow solely to the project, in regard to westbound at-fault approach turn crashes at the shopping plaza.

Figure 10 - Access to Shopping Plaza 7100 BLK Leetsdale Dr, Facing South, October 2011

Figure 11 - Access to Shopping Plaza 7100 BLK Leetsdale Dr, Facing South, October 2009

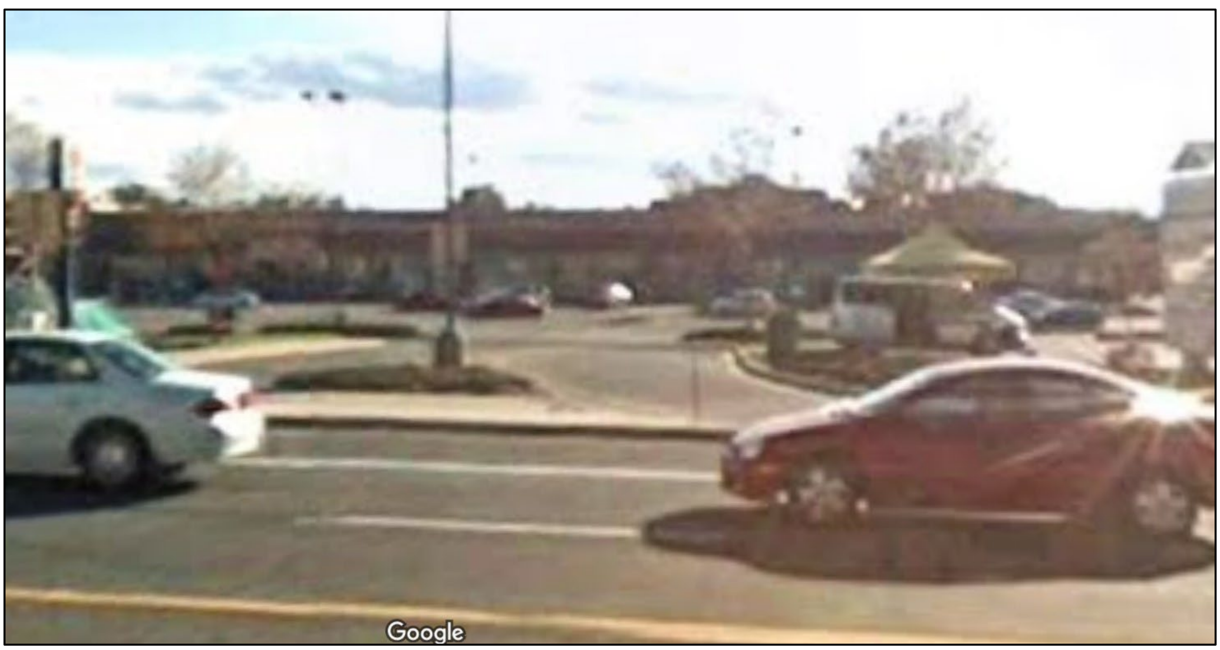
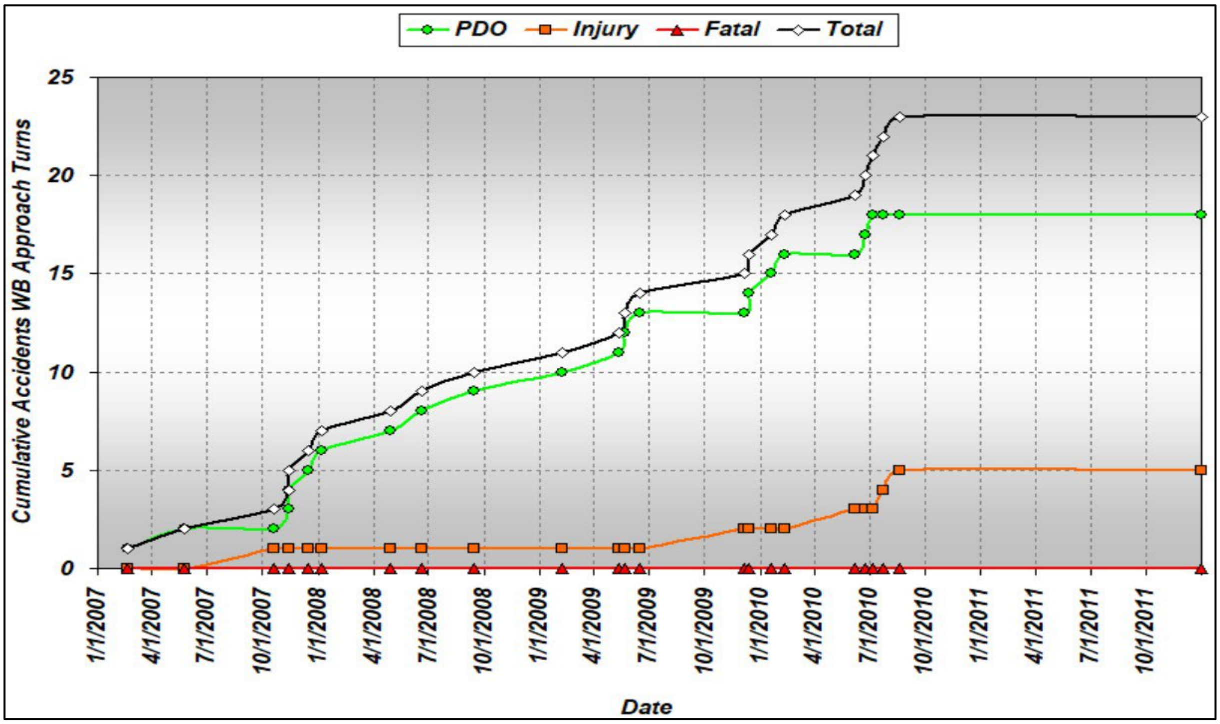


Figure 12 - Access to Shopping Plaza 7100 BLK Leetsdale Dr, Facing South, May 2017

Figure 13 - Westbound At-Fault Approach Turn Crashes 2007-2011



We will consider only relevant crash types for the analysis, those are broadside crashes that occurred involving left turn and thru movements, approach turn crashes, head-on and sideswipe opposite direction crashes. CORIS traffic counts indicate that the average ADT on this portion of SH 83 decreased from 47,000 vpd in the before period to 41,400 vpd in the after period.

The analysis of safety before and after the improvements were made on this segment of SH83 shows a reduction in both the total number of crashes and in the number of severe crashes. There were 92 total non-intersection and driveway access crashes during the five-year period before the improvements were made (2007 – 2011) (1 additional sideswipe opposite direction crash which was miscoded from the intersection with Parker Road was removed). Among the 92 crashes, 24 resulted in injuries with a total of 31 people injured. There was 1 fatality with 1 person killed (pedestrian). The remaining 67 crashes involved property damage only. Two of the crashes (about 2%) were broadsides involving left turns. There were 23 (about 25%) approach turn crashes, all of which involved at-fault westbound vehicles turning left into the shopping plaza. There were no sideswipe opposite direction crashes or head-on collisions. Proportionally, these crash types represent about 27% of all crashes and about 29% of all injury crashes.

In the five years after construction (2013 – 2017), the total number of non-intersection and driveway access crashes decreased to 45 (3 additional were miscoded from the Walgreen’s Driveway on Parker Road to the east), a reduction of about 51%. The number of injury related crashes decreased 50% from 24 to 12, with 15 people injured (a decrease of 16 people or about 52%). The number of fatalities remained static at 1 fatality and 1 person killed (pedestrian). The remaining 32 crashes in the after period involved property damage only, a reduction of about 52%. There was 1 crash of the targeted crash types in the after period, a broadside crash which occurred approximately 275 feet west of the intersection of Quebec and Leetsdale, involving a southbound left turning vehicle conflicting with a westbound thru vehicle. **Figure 14** shows that the raised median includes an unraised segment adjacent to the eastern driveway access for the apartment complex on the north side in the 7200 Block. Signs facing eastbound and westbound mainline traffic indicate turns are restricted to emergency and authorized vehicles only. The view from the driveway access facing south shows that permitted movements from this position are more ambiguous. An effective measure would be the erection of a NO THRU MOVEMENT sign (MUTCD R3-27) on the exit of the driveway access.

Figure 14 – View South from Eastern Driveway Access to 7200 BLK on SH 83 (Leetsdale), Oct. 2014

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 74.94 to 75.07 shows a decrease in the targeted crashes from 25 during the five-year period (2007 to 2011) before the improvements to 1 during the five-year after period (2013 to 2017) (see **Table 16**). The number of serious crashes shows a decrease from 7 in the before period to 1 in the after period:

- Before (2007 – 2011) – 0 fatal crashes and 7 injury crashes with 11 injured
- After (2013 – 2017) – 0 fatal crashes and 1 injury crash with 1 injured

Table 16 – SH 83 (Leetsdale Dr) Quebec St to Oneida St, (MP 74.94 – 75.07) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2007 to 12/31/2011 (5 yr.)	1/1/2013 to 12/31/2017 (5 yr.)
AADT	47,000 vpd	41,400 vpd
Filters:	Non-Intersection and Driveway Access Crashes	Non-Intersection and Driveway Access Crashes
Total Crashes	**92**	**45**
Fatal Crashes (Fatalities)	1 (1)	1 (1)
Injury Crashes (Injuries)	24 (31)	12 (15)
Property Damage Only	67	32
Crash Type: # (%)		
Broadside (LT and Thru)	2 (2.2%) [2 INJ, 3 Injured]	1 (2.2%) [1 INJ, 1 Injured]
Approach Turn	23 (25%) [5 INJ, 8 Injured]	0
Head On	0	0
Sideswipe Opposite Direction	0	0
Crash Rate (CPMMVT)	8.25	4.58

The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. An 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.

However, SPF Analysis requires that the functions be calibrated specifically for the facility type and region being evaluated. At this time, these functions have not been derived for urban 6-lane principal arterials or urban 6-lane undivided unsignalized 3-leg intersections in the State of Colorado, so SPF analysis cannot be provided for this location.

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Table 17** for the reduction seen in all targeted crashes at the location. **Table 17** shows the result of the Benefit/Cost calculation is a B/C ratio of **13.33.** This result strongly suggests that the project was justified from both the cost-effectiveness and safety standpoint.

However, as outlined above, due to the DO NOT ENTER sign which was erected, likely sometime in late 2010 to early 2011, for westbound left turning traffic at the shopping plaza, it is not possible to say for certain that the median project alone caused the reduction in approach turn crashes. It appears the sign was a useful, low-cost short-term countermeasure. When the westbound left turn approach turns at the shopping plaza are removed, we see a reduction of 50% in other targeted crash types, with the number of left turn and thru broadsides being reduced from 2 in the before period to 1 in the after period. This indicates a 50% reduction in crashes and **Table 18** shows that the project was still effective from the safety standpoint and justified from the cost-effectiveness standpoint.

Table 17 – SH 83A (Leetsdale Dr) Quebec St to Oneida St, (MP 74.94 – 75.07) – Benefit Cost Analysis

Colorado Department of Transportation
DiExSys™ Vision Zero Suite
Economic Analysis Report

06/22/2022
Job #: 20220622045321

Location: 83 A **Begin:** 74.94 **End:** 75.07 **From:** 01/01/2007 **To:** 12/31/2011

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	18		Weighted PDO:	4.42	100% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	7	11 :Injured	Weighted INJ:	2.70	91% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	97% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 280,000
From: 01/01/2007
To: 12/31/2011 Days: 1826

Benefit Cost Ratio: 13.33 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Central Raised Concrete Median to Restrict Movements (LT&Thru Broadsides, App. Turns, HO & SSO)
Special Notes: Based on reduction in crashes from 2007-11 to 2013-17 (5yr periods surrounding construction)

Table 18 – SH 83A (Leetsdale Dr) Quebec St to Oneida St, (MP 74.94 – 75.07) – Benefit Cost Analysis with Approach Turns at 7100 BLK Removed

Colorado Department of Transportation
DiExSys™ Vision Zero Suite
Economic Analysis Report

06/22/2022

Job #: 20220622045321

Location: 83 A **Begin:** 74.94 **End:** 75.07 **From:** 01/01/2007 **To:** 12/31/2011

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors				Other Information	
PDO:	0		Weighted PDO:	0.00	0%	:CRF for PDO	Cost of PDO:	$ 11,100
INJ:	2	3 :Injured	Weighted INJ:	0.74	66%	:CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0%	:CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	66%	:Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
	Cost:	$ 280,000					Service Life:	20
	From:	01/01/2007					Capital Recovery Factor:	0.080
	To:	12/31/2011	Days:	1826			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: 2.20 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Central Raised Concrete Median to Restrict Movements (LT&Thru Broadsides Only)

Special Notes: Based on reduction in crashes from 2007-11 to 2013-17 (5yr periods surrounding construction)

Project Information

Project Name: US 6 & I-70B Intersection Improvements

Project Description: Mast Arm Replacement and Signal Upgrades

CDOT Region: 3 | Project Def: 17999 | County: Mesa

Location: US 6 & I-70B | Mile Points: N/A | Length: N/A

Schedule: | Work Start Date: Oct 2011 | Work End Date: Jan 2012

Problem Description:

No problem description was provided for the original HSIP funding application for the intersection improvement project.

Improvement Description:

The project area is the intersection of United States Highway (US) 6 with Interstate (I-) 70B in Mesa County, Colorado.

US 6 & I-70B in Mesa County, Colorado

The project involved replacing the signal mast arm in Mesa County, Colorado. The cost of construction was $806,765.60.

US 6 – Facing East – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements at the intersection of US 6 with I-70B show a significant decrease in the total number and severity of crashes. A comparison of rear end types before and after the improvements were made showed that there was a decrease in affected crashes.

The total number of crashes decreased from 85 to 23, and Injuries + Fatalities (severe crashes) decreased from 22 to 7. The number injuries decreased from 30 to 10. The AADT decreased by approximately 15% in the after period on I-70B and increased by 11% on US 6.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 15 years for this project was 7.18:1. The result is an improvement that was justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 decrease of variability in crashes as ADT decreases. LOSS reflects how a segment of roadway or intersection is performing in regard to its expected crash frequency or severity at a specific level of ADT.

Study intersections were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at the intersection of US 6 with I-70B shows an approximate 73% decrease in the number of crashes from the five-year before period (2006-2010) to the five-year after period (2013-2017). The number of severe (fatal and injury) crashes decreased by approximately 68%.

- Before Period: 22 severe crashes, 30 injured
- After Period: 7 severe crashes, 10 injured

The crash rate for all crashes at this intersection decreased by 73% between the before period and after period.

- Before Period: 16.57 crashes per million vehicle miles traveled
- After Period: 5.33 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses

		Before	After
Time Period:		01/01/2006 – 12/31/2010 (5 yr)	01/01/2013 – 12/31/2017 (5 yr)
AADT	I-70B	25,024	21,367
	US 6	14,390	15,991
Crash Filters:		Intersection Related	
Total Crashes:		**85**	**23**
Fatal Crashes (Fatalities):		0(0)	0 (0)
Injury Crashes (Injuries):		22 (30)	7 (10)
PDO Crashes:		63	16

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for the intersection of US 6 & I-70B reflect a decrease in the crash record for this project. The intersection is LOSS I for total frequency of crashes in the after period and LOSS IV in the before period. The intersection is LOSS I for the severity of crashes in the after period, and LOSS III in the before period.

It should be noted that SPF methodology is usually applied to segments that are a minimum of one mile in length and the crashes per mile per year for the study segment is likely inaccurate for an intersection.

Figure 1. SPF For Total Crashes

Before: 2006–2010 After: 2013–2017

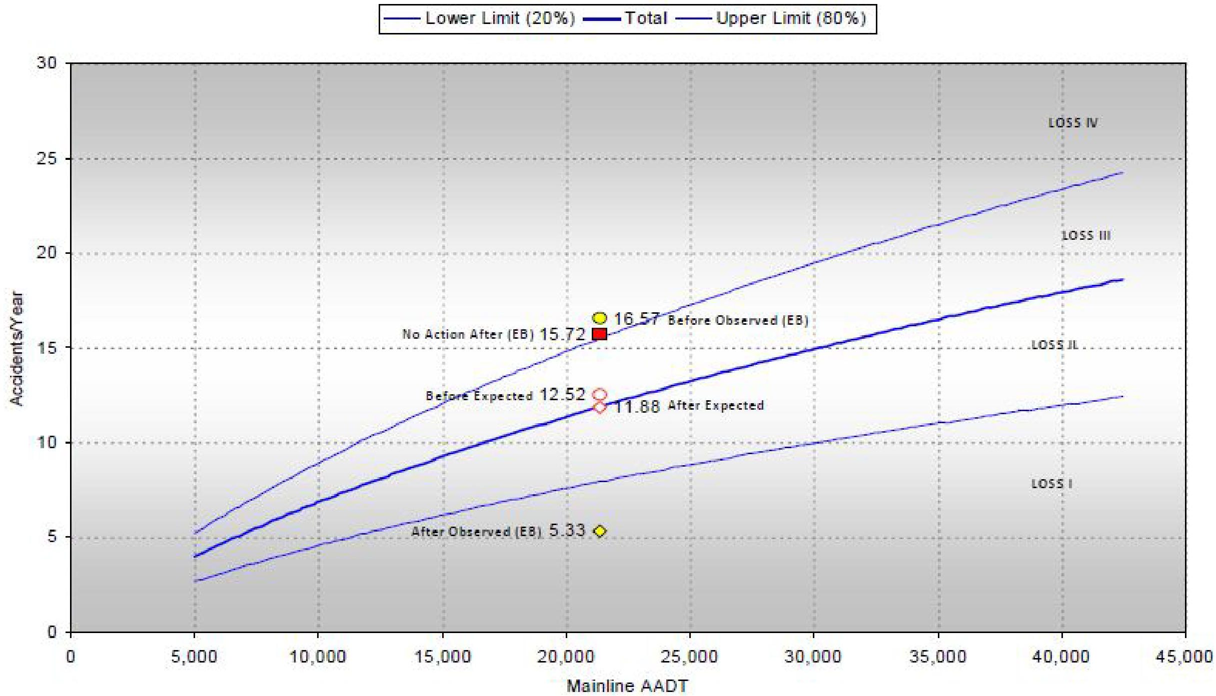


Figure 2. SPF For Severe Crashes

Before: 2006–2010 After: 2013–2017

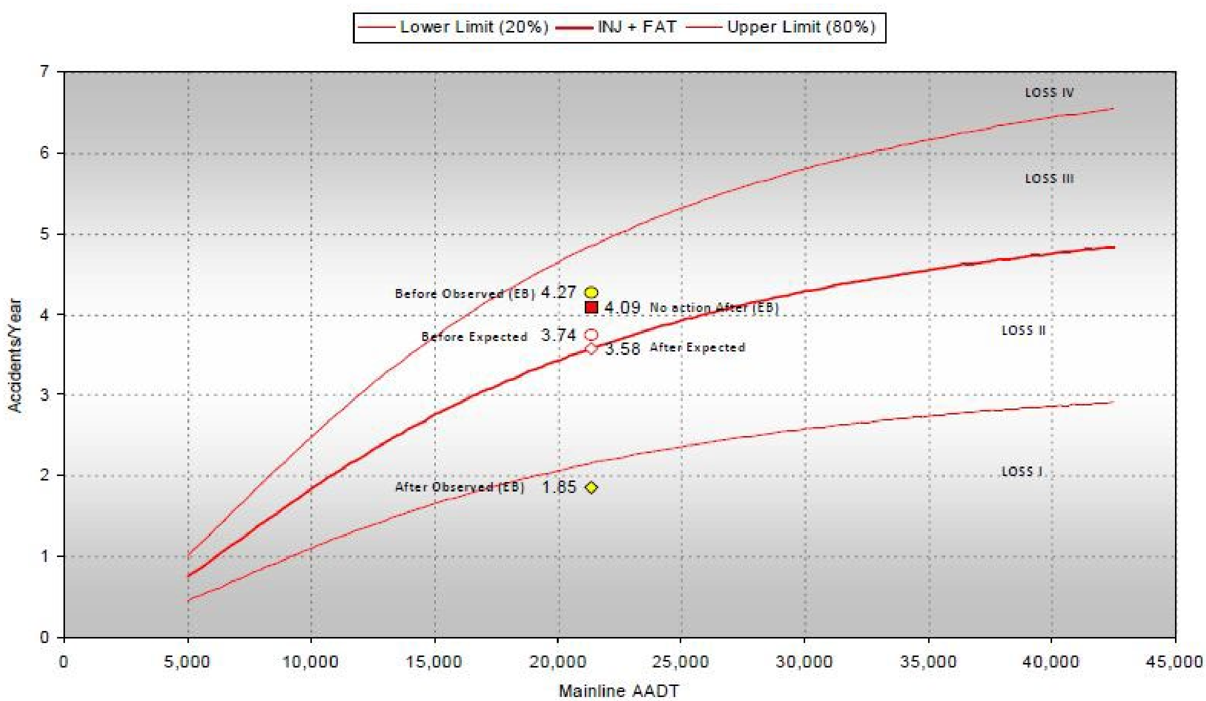


Table 2 provides a summary of the crashes per year (CPY) for the study intersection along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)
Total Crashes			
LOSS	LOSS IV	LOSS I	LOSS IV
CPYPM	16.57	5.33	15.72
Expected CPYPM	12.52	11.88	11.88
Proportion of Mean	1.32	0.45	1.32
Severe (Injury & Fatal) Crashes			
LOSS	LOSS III	LOSS I	LOSS III
CPYPM	4.27	1.85	4.09
Expected CPYPM	3.74	3.58	3.58
Proportion of Mean	1.14	0.52	1.14

Crash Type Analyses

A more detailed review of the before and after crash record shows the rear end types that were most affected by the roadway improvements. **Table 3** shows a comparison of the targeted crashes.

The No-Build After crashes were estimated using the change in traffic volumes on US 6 between the before and after period, as found in **Table 1** (approximately 15% decrease).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2006 – 12/31/2010 (5 yr)	01/01/2013 – 12/31/2017 (5 yr)	01/01/2013 – 12/31/2017 (5 yr)
Total Crashes	**85**	**23**	**81**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	22 (30)	7 (10)	21 (29)
PDO	63	16	60
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 65% / 73%	--
Rear End Crashes	38	7	36
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	13 (16)	4 (7)	12 (15)
PDO	25	3	24
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 53% / 87%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of 7.18 was ultimately realized** and is largely attributed to significant decrease in number of total and severe crashes. This outcome displays that this safety improvement project was justified.

Following the installation of mast arms for signal mounting, crash data suggests a decrease in the targeted crashes. The resulting B/C analysis would also suggest an effective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: Accident History for All Locations **From:** 01/01/2013 **To:** 12/31/2017

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	60		Weighted PDO:	13.92	73% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	21	29 :Injured	Weighted INJ:	6.73	65% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	70% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	15
	Cost:	$ 806,765				Capital Recovery Factor:	0.096
	From:	01/01/2007				Annual Maintenance/Delay Cost:	$ 0
	To:	12/31/2011	Days:	1826			

Benefit Cost Ratio: 7.18 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: US 6/F Road & I-70 Business Mast Arm Upgrades

Special Notes: All Intersection Related Crashes

Project Information

Project Name: Garrison Street & Ralston Road Intersection Improvements

Project Description: Left Turn Alignment and Signal Improvements

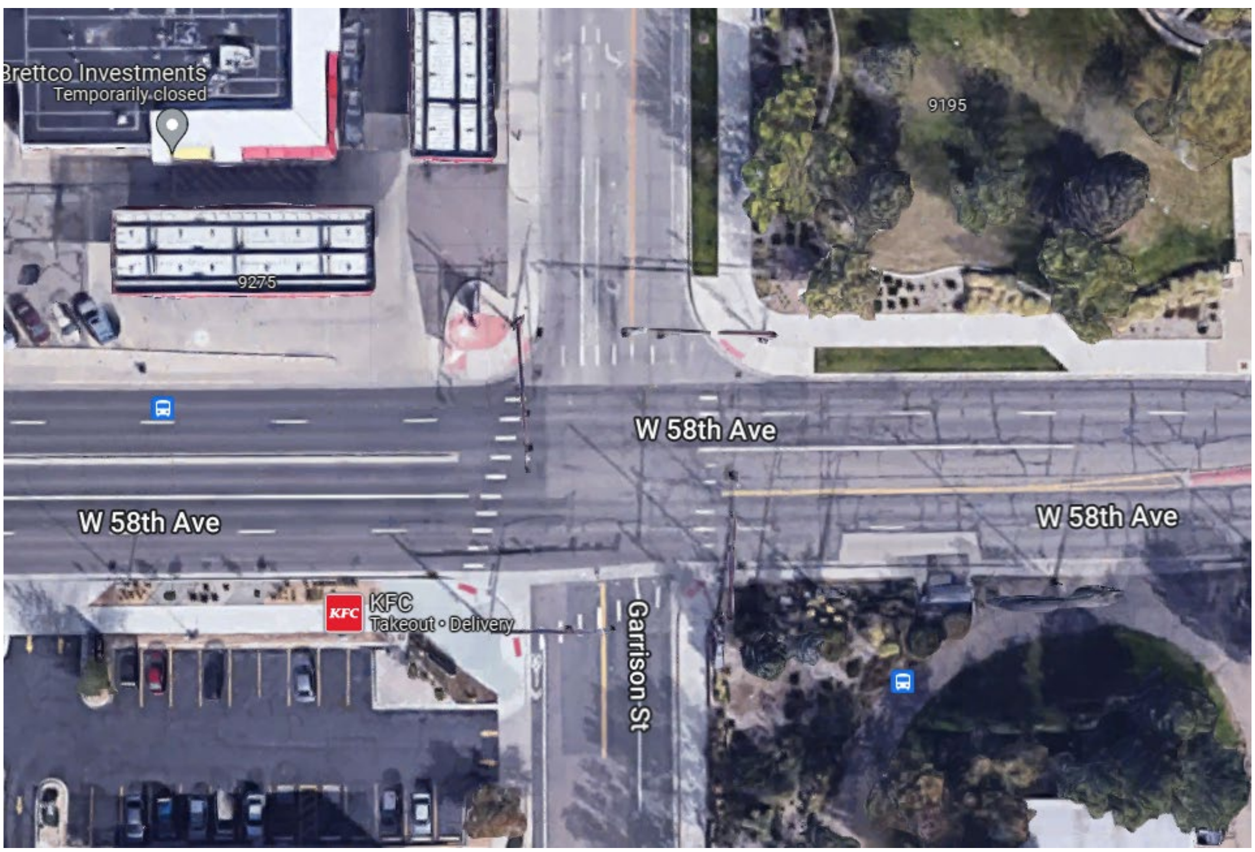
CDOT Region:	1	Project Def:	18001	County:	Jefferson
Location:	Garrison Street & Ralston Road	Mile Points:	N/A	Length:	N/A
Schedule:		Work Start Date:	Mar 2012	Work End Date:	March 2013

Problem Description:

No problem description was provided for the original HSIP funding application for the intersection improvement project.

Improvement Description:

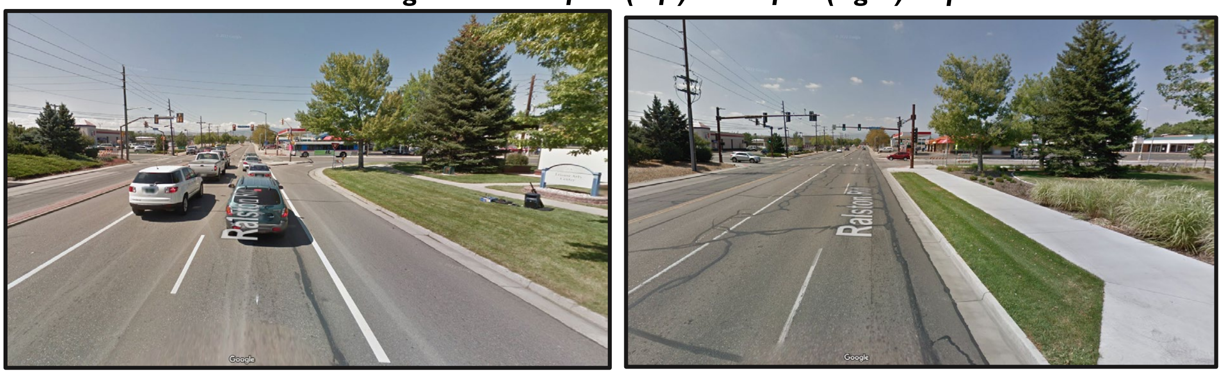
The project area is the intersection of Garrison Street with Ralston Road in Jefferson County, Colorado.



Garrison Street & Ralston Road in Jefferson County, Colorado

The project involved realigning the left turn lanes and other signal improvements in Jefferson County, Colorado. The cost of construction was $224,118,91.

Garrison St – Facing South – Before (left) and After (right) improvements



Ralston Rd – Facing West – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements at the intersection of Garrison Street with Ralston Road show a significant decrease in the total number and severity of crashes.

The total number of crashes decreased from 38 to 35, and Injuries + Fatalities (severe crashes) decreased from 10 to 5. The number injuries decreased from 13 to 5. The AADT decreased by approximately 22% in the after period on Garrison Street and increased by 25% on Ralston Road.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 10 years for this project was 5.48:1. The result is an improvement that was justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 decrease of variability in crashes as ADT decreases. LOSS reflects how a segment of roadway or intersection is performing in regard to its expected crash frequency or severity at a specific level of ADT.

Study intersections were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at the intersection of Garrison Street with Ralston Road shows an approximate 8% decrease in the number of crashes from the five-year before period (2007-2011) to the five-year after period (2014-2018). The number of severe (fatal and injury) crashes decreased by approximately 49%.

- Before Period: 10 severe crashes, 13 injured
- After Period: 5 severe crashes, 5 injured

The crash rate for all crashes at this intersection decreased by 8% between the before period and after period.

- Before Period: 7.05 crashes per million vehicle miles traveled
- After Period: 6.59 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses

		Before	After
Time Period:		01/01/2007 – 12/31/2011 (5 yr)	01/01/2014 – 12/31/2018 (5 yr)
AADT	Ralston Road	17,998	22,424
	Garrison Street	4,182	3,270
Crash Filters:		Intersection Related	
Total Crashes:		**38**	**35**
Fatal Crashes (Fatalities):		0(0)	0 (0)
Injury Crashes (Injuries):		10 (13)	5 (5)
PDO Crashes:		28	30

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for the intersection of Garrison Street and Ralston Road reflect a decrease in the crash record for this project. The intersection is LOSS IV for total frequency of crashes in both the before and after periods. The intersection is LOSS II for the severity of crashes in the after period, and LOSS III in the before period.

It should be noted that SPF methodology is usually applied to segments that are a minimum of one mile in length and the crashes per mile per year for the study segment is likely inaccurate for an intersection.

Figure 1. SPF For Total Crashes

Before: 2007–2011 After: 2014–2018

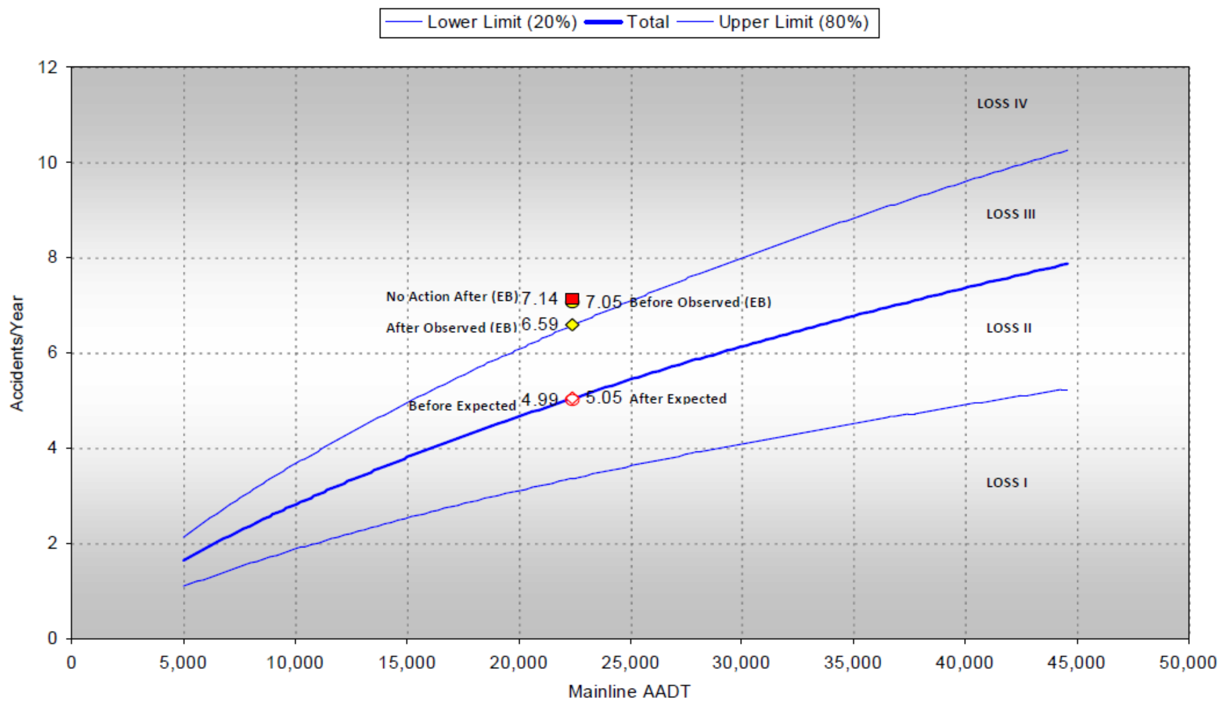


Figure 2. SPF For Severe Crashes

Before: 2007–2011 After: 2014–2018

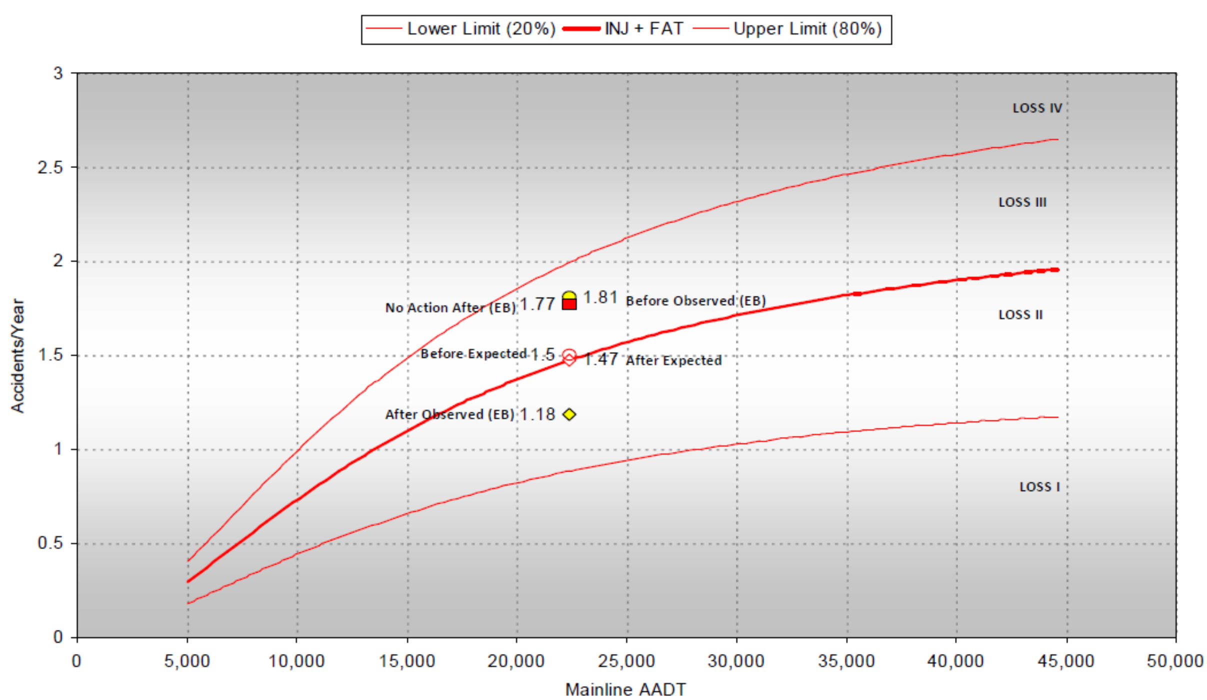


Table 2 provides a summary of the crashes per year (CPY) for the study intersection along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)
Total Crashes			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPYPM	7.05	6.59	7.14
Expected CPYPM	4.99	5.05	5.05
Proportion of Mean	1.41	1.31	1.41
Severe (Injury & Fatal) Crashes			
LOSS	LOSS III	LOSS II	LOSS III
CPYPM	1.81	1.18	1.77
Expected CPYPM	1.50	1.47	1.47
Proportion of Mean	1.21	0.8	1.21

Crash Type Analyses

A more detailed review of the before and after crash record shows the broadside crash types that were most affected by the roadway improvements. **Table 3** shows a comparison of the targeted crashes.

The No-Build After crashes were estimated using the change in traffic volumes on Ralston Road between the before and after period, as found in **Table 1** (approximately 25% increase).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2007 – 12/31/2011 (5 yr)	01/01/2014 – 12/31/2018 (5 yr)	01/01/2014 – 12/31/2018 (5 yr)
Total Crashes	**38**	**35**	**38**
Fatal (Fatalities)	0(0)	0 (0)	0(0)
Injury (Injuries)	10 (13)	5 (5)	10 (13)
PDO	28	30	28
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 61% / -6%	--
Broadside Crashes	6	6	6
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	0 (0)	0 (0)	0 (0)
PDO	6	6	6
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 0% / 0%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of 5.48 was ultimately realized** and is largely attributed to significant decrease in number of total and severe crashes. This outcome displays that this safety improvement project was justified.

Following the realignment of left turn lanes and other signal improvements, crash data suggests a decrease in the targeted crashes. The resulting B/C analysis would also suggest an effective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: Accident History for All Locations **From:**01/01/2014 **To:**12/31/2018

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors				Other Information	
PDO:	28		Weighted PDO:	6.15	-6%	:CRF for PDO	Cost of PDO:	$ 11,100
INJ:	10	13 :Injured	Weighted INJ:	2.85	61%	:CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0%	:CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	11%	:Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
	Cost:	$ 244,119					Service Life:	10
	From:	01/01/2007					Capital Recovery Factor:	0.129
	To:	12/31/2011	Days:	1826			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: 5.48 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Garrison Street & Ralston Road Left Turn Alignment and Signal Improvements
Special Notes: All Intersection Related Crashes

Project Information

Project Name:	I-25 MP 124.0 - 127.0 Wild Animal Fencing				
Project Description:	Wild Animal Fencing				
CDOT Region: 2	Project Def:	18075	County:	El Paso	
Location: I-25A	Mile Points:	124.0 – 127.0	Length:	3 Miles	
Schedule:	Work Start Date:	11/23/2011	Work End Date:	06/25/2012	

Problem Description:

No problem description was provided for the original HSIP funding application for the intersection improvement project.

Improvement Description:

The project area includes the segment of Interstate (I-) 25 between Mile Points (MP) 124.0 and 127.0 in El Paso County, Colorado. This segment had a high number of wild animal crashes.

I-25 in El Paso County, Colorado

The project involved installing wildlife fencing. The cost of construction was $1,181,226.10.

I-25 – Southbound – Before (Left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements along I-25 shows a decrease in the total number of crashes. A comparison of wild animal crash types before and after the improvements were made showed that there was a decrease in total wild animal crashes.

The total number of crashes reduced from 30 to 2 and Injuries + Fatalities (severe crashes) decreased from 3 to 0. The number of injuries decreased from 3 to 0. The AADT increased by approximately 17% in the after period.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 10 years for this project was 2.20:1. The result is an improvement that was justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – I-25

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records along I-25 in the project area shows an approximate 93% decrease in the total number of crashes from the five-year before period (2006-2010) to the five-year after period (2013-2017). The number of severe (fatal and injury) crashes decreased by 100%.

- Before Period: 3 severe crashes, 3 injured
- After Period: 0 severe crashes, 0 injured

The crash rate for all crashes along this corridor decreased by 93% between the before period and after period.

- Before Period: 3.09 crashes per million vehicle miles traveled
- After Period: 1.64 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses – I-25

		Before	After
Time Period:		01/01/2006 – 12/31/2010 (5 yr)	01/01/2013 – 12/31/2017 (5 yr)
AADT	I-25	34,323	40,277
Crash Filters:		Wild Animal	
Total Crashes:		**30**	**2**
Fatal Crashes (Fatalities):		0 (0)	0 (0)
Injury Crashes (Injuries):		3(3)	0(0)
PDO Crashes:		27	2

Safety Performance Functions

SPF plots for total crashes (**Figure 1**) show a decrease in the crash record for this project. Severe (injury and fatal) crashes (**Figure 2**) for I-25 in the project area reflect a decrease in the crash record. The intersection is LOSS I for both total frequency of crashes and severe frequency of crashes in both the before and after periods.

Figure 1. SPF For Total Crashes

Before: 2006–2010 After: 2013–2017

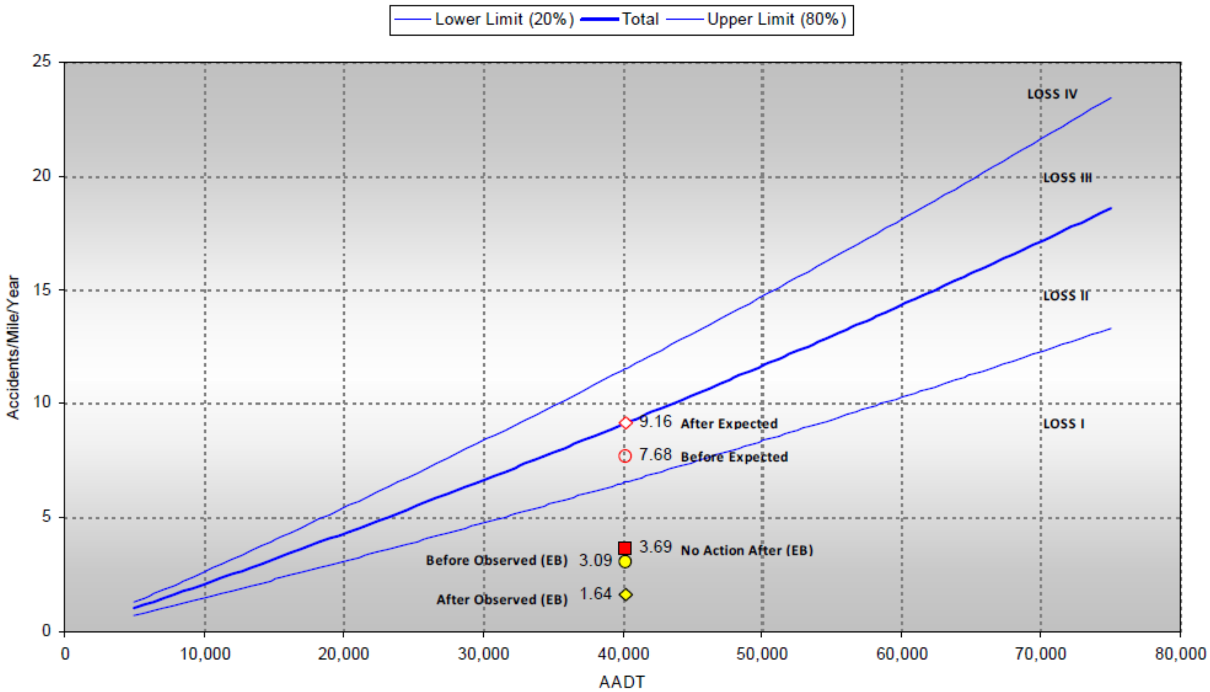


Figure 2. SPF For Severe Crashes

Before: 2006–2010 After: 2013–2017

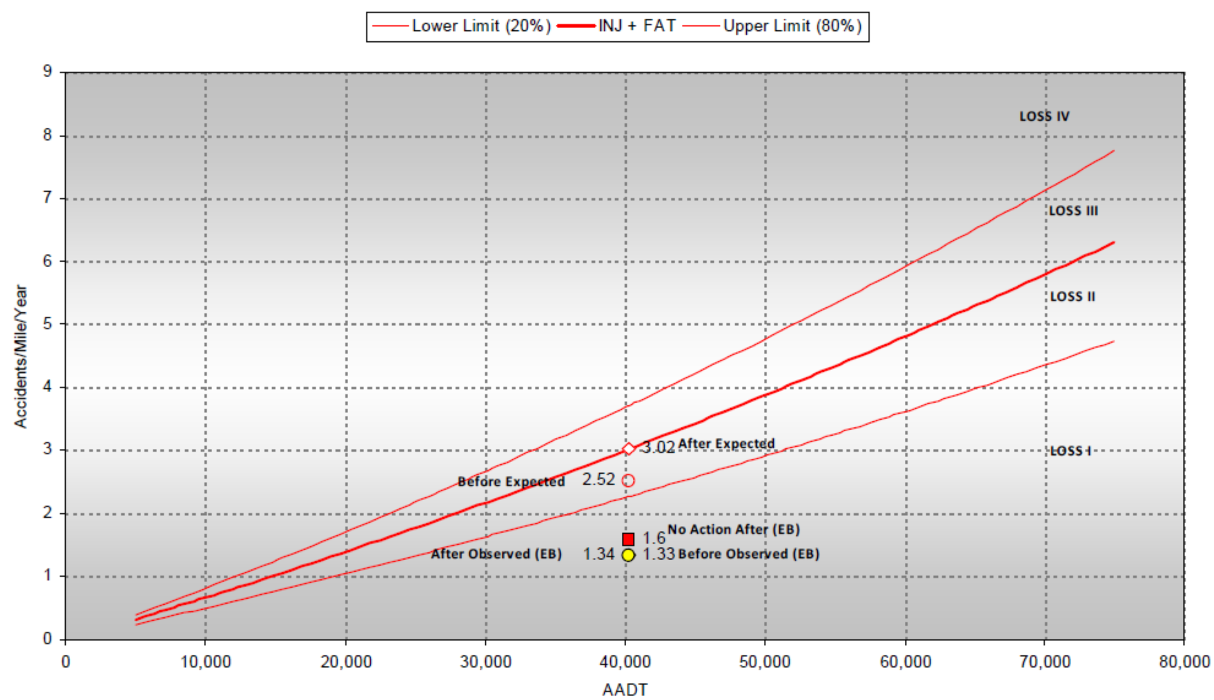


Table 2 provides a summary of the crashes per year (CPY) for I-25 along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Flat and Rolling 4-Lane Divided Freeways (2016)	Rural Flat and Rolling 4-Lane Divided Freeways (2016)	Rural Flat and Rolling 4-Lane Divided Freeways (2016)
Total Crashes			
LOSS	LOSS I	LOSS I	LOSS I
CPYPM	3.09	1.64	3.69
Expected CPYPM	7.68	9.16	9.16
Proportion of Mean	0.40	0.18	0.40
Severe (Injury & Fatal) Crashes			
LOSS	LOSS I	LOSS I	LOSS I
CPYPM	1.33	1.34	1.60
Expected CPYPM	2.52	3.02	3.02
Proportion of Mean	0.53	0.44	0.53

Crash Type Analyses

A more detailed review of the before and after crash record shows the wild animal crash types that were most affected by the roadway improvements. **Table 3** shows a comparison of the total, fatal and injury crashes.

The No-Build After crashes were estimated using the change in traffic volumes on I-25 between the before and after period, as found in **Table 1** (approximately 17% increase).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2006 – 12/31/2010 (5 yr)	01/01/2013 – 12/31/2017 (5 yr)	01/01/2013 – 12/31/2017 (5 yr)
Total Crashes	**30**	**2**	**39**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	3(3)	0(0)	4(4)
PDO	27	2	35
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 100% / 93%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of 2.20 was ultimately realized** and is largely attributed to the decrease in all crash types. This outcome displays that this safety improvement project was justified.

Following implementation of a wild animal crossing, crash data suggests a decrease in the targeted crashes, and the Resulting B/C analysis would also suggest an effective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: 25 B **Begin:** 124.00 **End:** 127.00 **From:** 01/01/2006 **To:** 12/31/2010

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	35		Weighted PDO:	8.12	94% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	7	7 :Injured	Weighted INJ:	1.62	100% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	95% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	15

Cost:	$ 1,181,226	Capital Recovery Factor:	0.096
From:	01/01/2006		
To:	12/31/2010	Days: 1826	Annual Maintenance/Delay Cost: $ 0

Benefit Cost Ratio: 2.20 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: I-25 MP 124-127 - Wild Life Crossing

Special Notes: Wild ANimal Crashes

Project Information

Project Name: SH 45 & WCR 96 Intersection Improvements

Project Description: Add a westbound right turn acceleration lane and a southbound left turn lane

CDOT Region: 2		Project Def:	18080	County:	Pueblo
Location:	SH 45 & SH 96	Mile Points:	N/A	Length:	N/A
Schedule:		Work Start Date:	Dec 2012	Work End Date:	Sept 2013

Problem Description:

No problem description was provided for the original HSIP funding application for the intersection improvement project.

Improvement Description:

The project area is the intersection of State Highway (SH) 45 with SH 96 in Pueblo County, Colorado. This intersection experiences high volumes of approaching and sideswipe crashes.

SH 45 & SH 96 in Pueblo County, Colorado

The project involved adding left turn lanes on SH 392 in Weld County, Colorado. The cost of construction was $2,332,671.12.


Pueblo Blvd – Facing East – Before (left) and After (right) improvements


Thatcher Ave – Facing South – Before (left) and After (right) Improvements

Summary & Findings

The analysis of safety conditions before and after improvements at the intersection of SH 45 with SH 96 show a significant increase in the total number and severity of crashes. A comparison of rear end, approach turn, and overtaking turn types before and after the improvements were made showed that there was an increase in affected crashes.

The total number of crashes increased from 79 to 78, and Injuries + Fatalities (severe crashes) remained constant at 27. The number injuries decreased from 41 to 40. The AADT increased by approximately 7.8% in the after period on SH 45 and 3.4% on SH 96.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 20 years for this project was 0.47:1. The result is an improvement that was not justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at the intersection of SH 45 with SH 96 shows an approximate 1% decrease in the number of crashes from the five-year before period (2007-2011) to the five-year after period (2014-2018). The number of severe (fatal and injury) crashes remained constant.

- Before Period: 27 severe crashes, 41 injured
- After Period: 27 severe crashes, 40 injured

The crash rate for all crashes at this intersection increased by 1% between the before period and after period.

- Before Period: 15.46 crashes per million vehicle miles traveled
- After Period: 15.37 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses

		Before	After
Time Period:		01/01/2007 – 12/31/2011 (5 yr)	01/01/2014 – 12/31/2018 (5 yr)
AADT	SH 45	26,027	28,058
	SH 96	13,215	13,667
Crash Filters:		Intersection Related	
Total Crashes:		**79**	**78**
Fatal Crashes (Fatalities):		0 (0)	0 (0)
Injury Crashes (Injuries):		27 (41)	27 (40)
PDO Crashes:		52	51

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for the intersection of SH 392 & WCR 35 reflect an increase in the crash record for this project. The intersection is LOSS III for total frequency of crashes in the before and after periods. The intersection is LOSS III for the severity of crashes in the before and after periods.

It should be noted that SPF methodology is usually applied to segments that are a minimum of one mile in length and the crashes per mile per year for the study segment is likely inaccurate for an intersection.

Figure 1. SPF For Total Crashes

Before: 2007–2011 After: 2014–2018

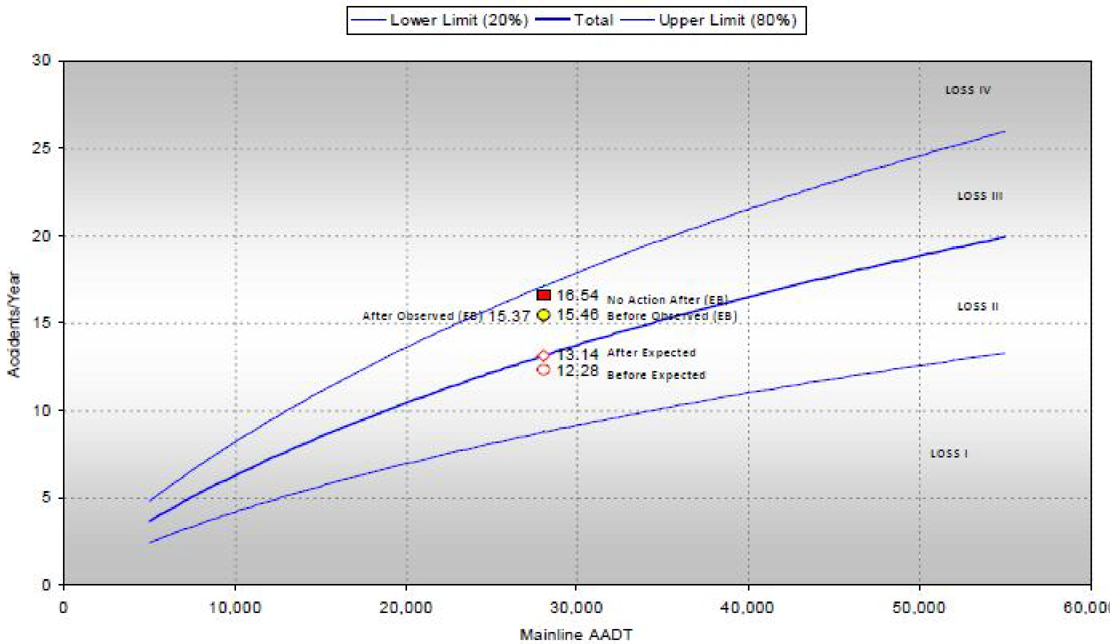


Figure 2. SPF For Severe Crashes

Before: 2007–2011 After: 2014–2018

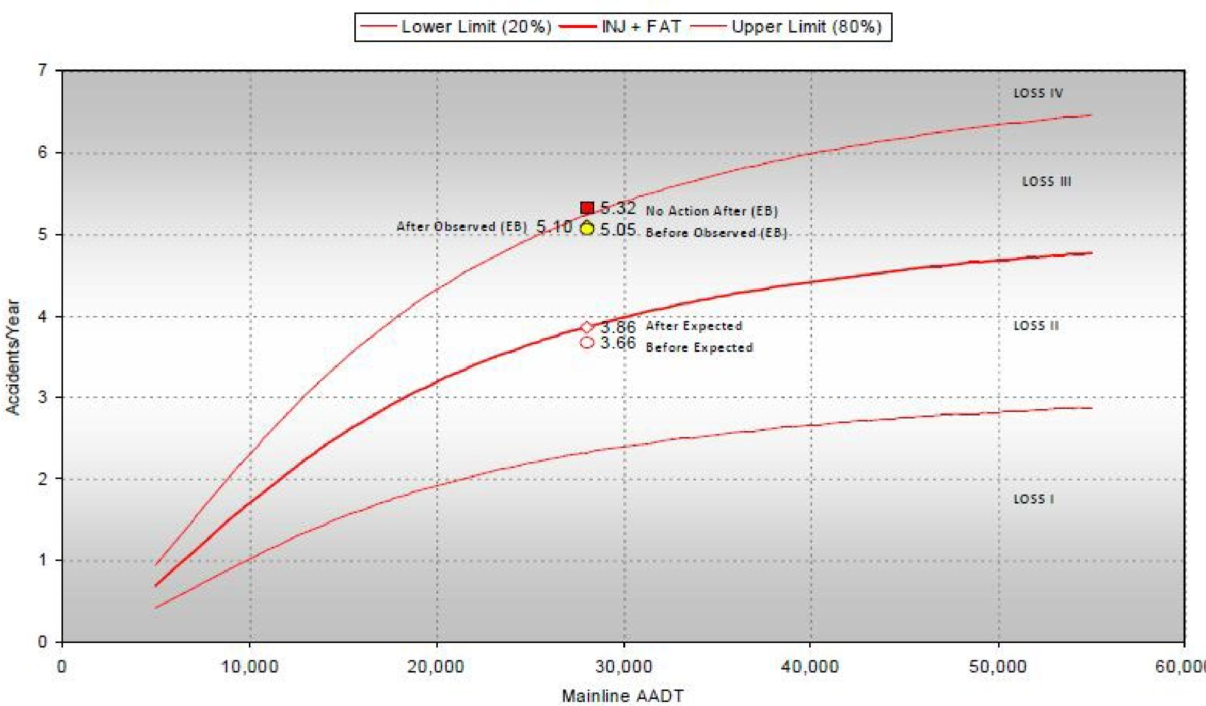


Table 2 provides a summary of the crashes per year (CPY) for the study intersection along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)
Total Crashes			
LOSS	LOSS III	LOSS III	LOSS III
CPYPM	15.46	15.37	16.54
Expected CPYPM	12.28	13.14	13.14
Proportion of Mean	1.26	1.17	1.26
Severe (Injury & Fatal) Crashes			
LOSS	LOSS III	LOSS III	LOSS IV
CPYPM	5.05	5.10	5.32
Expected CPYPM	3.66	3.86	3.86
Proportion of Mean	1.38	1.32	1.38

Crash Type Analyses

A more detailed review of the before and after crash record for all intersection related crashes was conducted. **Table 3** shows a comparison of the total, fatal, and injury crashes.

The No-Build After crashes were estimated using the change in traffic volumes on SH 45 between the before and after period, as found in **Table 1** (approximately 7.8% increase).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2007 – 12/31/2011 (5 yr)	01/01/2014 – 12/31/2018 (5 yr)	01/01/2014 – 12/31/2018 (5 yr)
Total Crashes	**79**	**78**	**84**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	27 (41)	27 (40)	28 (43)
PDO	52	51	56
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 7% / 8%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of 0.47 was ultimately realized** and is largely attributed to significant increase in number of total and severe crashes. This outcome displays that this safety improvement project was not justified.

Following the addition of a westbound right turn acceleration lane and dual southbound left turn lanes, crash data suggests an increase in the targeted crashes. The resulting B/C analysis would also suggest an ineffective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: Accident History for All Locations **From:**01/01/2014 **To:**12/31/2018

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	56		Weighted PDO:	13.76	8% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	28	43 :Injured	Weighted INJ:	10.56	7% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	7% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 2,332,672
From: 01/01/2007
To: 12/31/2011 Days: 1826

Benefit Cost Ratio: 0.47 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SH 45 & SH 96 Intersection Improvements
Special Notes: All Intersection Related Crashes

Project Information

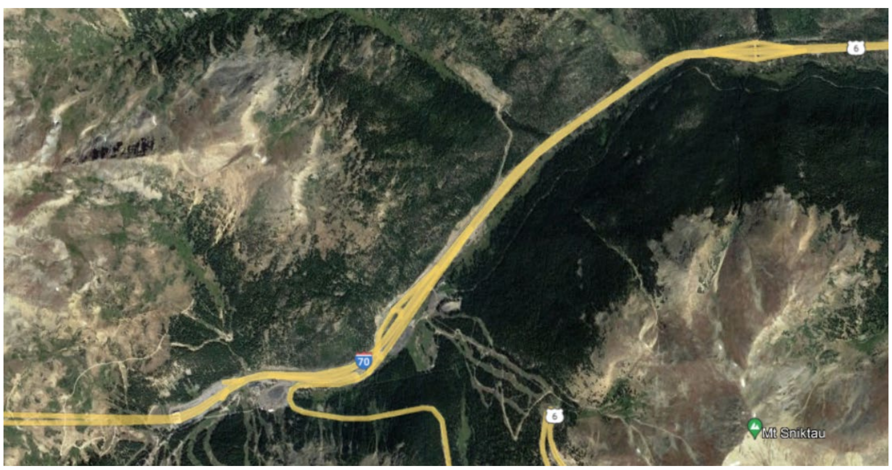
Project Name:	I-70 MP 215 – 217.75 Variable Message Signing				
Project Description:	Variable Message Signing (VMS)				
CDOT Region: 1	Project Def:	18139	County:	Clear Creek	
Location: I-70 A	Mile Points:	215-217.75	Length:	2.75 Miles	
Schedule:	Work Start Date:	Aug 2011	Work End Date:	Apr 2015	

Problem Description:

No problem description was provided for the original HSIP funding application for the intersection improvement project.

Improvement Description:

The project area includes the segment of I-70 between Mile Points (MP) 215.0 and 217.75 in Clear Creek County, Colorado.



I-70 in Summit County, Colorado

The project involved installation of Variable Message Signing (VMS) over approximately 2.75 miles of I-70. The cost of construction was $976,250.69.

I-70 – Eastbound – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements along I-70 shows a significant decrease in the total number and severity of crashes. An analysis of eastbound mainline crashes showed that both the total and severity of effected crashes decreased in the after period.

The total number of crashes decreased from 131 to 115; however, Injuries + Fatalities (severe crashes) increased from 29 to 31. The number of injuries increased from 52 to 58. There were no fatalities. The AADT increased by approximately 20% in the after period.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 10 years for this project was 0.87:1. The result is an improvement that was not justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 decrease of variability in crashes as ADT decreases. LOSS reflects how a segment of roadway or intersection is performing in regard to its expected crash frequency or severity at a specific level of ADT.

Study intersections were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – I-70

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records along I-70 in the project area shows an approximate 12% decrease in the total number of crashes from the four-year before period (2007-2010) to the four-year after period (2016-2019). The number of severe (fatal and injury) crashes increased by approximately 7%.

- Before Period: 29 severe crashes, 52 injured
- After Period: 31 severe crashes, 58 injured

The crash rate for all crashes along this corridor decreased by 12% between the before period and after period.

- Before Period: 11.8 crashes per million vehicle miles traveled
- After Period: 10.63 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses – I-70A

		Before	After
Time Period:		01/01/2007 – 12/31/2010 (4 yr)	01/01/2016 – 12/31/2019 (4 yr)
AADT	I-70	29,425	35,401
Crash Filters:		EB, Mainline, Non-Intersection	
Total Crashes:		**131**	**115**
Fatal Crashes (Fatalities):		0 (0)	0 (0)
Injury Crashes (Injuries):		29 (52)	31 (58)
PDO Crashes:		102	84

Safety Performance Functions

SPF plots for total crashes (**Figure 1**) for I-70 in the project area reflect a decrease in the crash record for this project. SPF plots for severe (injury and fatal) crashes (**Figure 2**) reflect a decrease as well. The intersection is LOSS II for total and severe frequency of crashes in the before period, LOSS II for the total frequency of crashes in the after period, and LOSS III for the severe frequency of crashes in the after period.

Figure 1. SPF For Total Crashes

Before: 2007–2010 After: 2016–2019

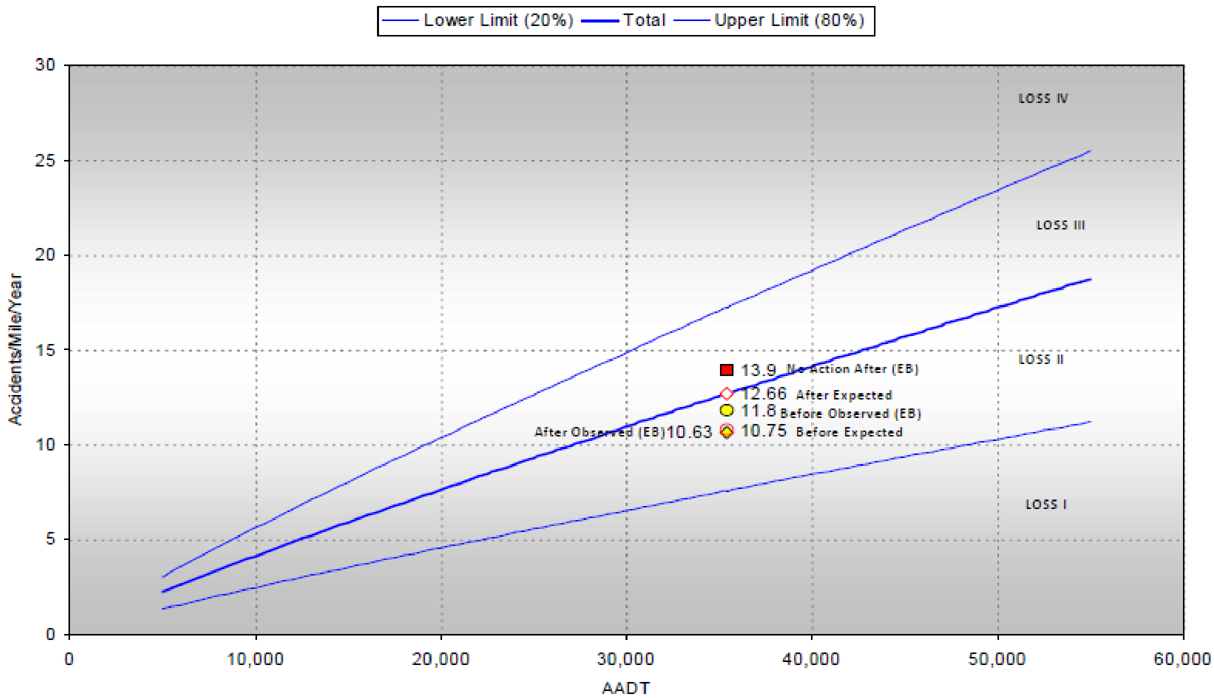


Figure 2. SPF For Severe Crashes

Before: 2007–2010 After: 2016–2019

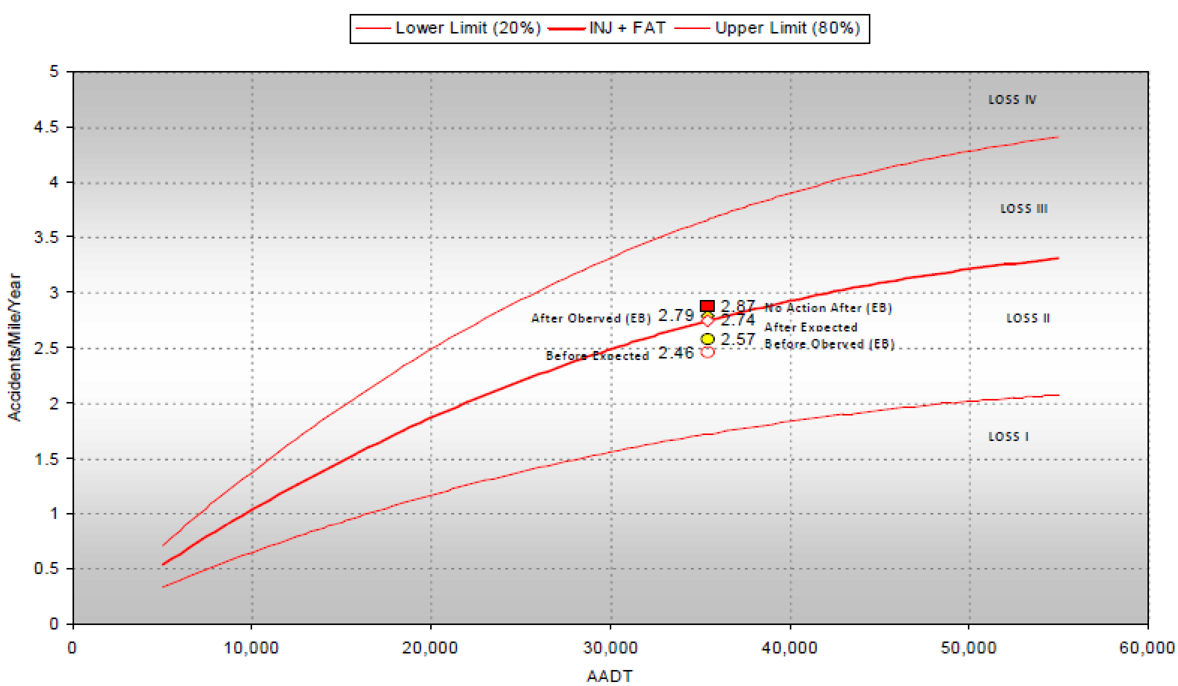


Table 2 provides a summary of the crashes per year (CPY) for I-70 along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Mountainous 4-Lane Divided Freeways (2016)	Rural Mountainous 4-Lane Divided Freeways (2016)	Rural Mountainous 4-Lane Divided Freeways (2016)
Total Crashes			
LOSS	LOSS II	LOSS II	LOSS III
CPYPM	11.8	10.63	13.9
Expected CPYPM	10.75	12.66	12.66
Proportion of Mean	1.10	0.84	1.10
Severe (Injury & Fatal) Crashes			
LOSS	LOSS II	LOSS III	LOSS III
CPYPM	2.57	2.79	2.87
Expected CPYPM	2.46	2.74	2.74
Proportion of Mean	1.05	1.02	1.05

Crash Type Analyses

Table 3 shows a comparison of the total, fatal and injury crashes.

The No-Build After crashes were estimated using the change in traffic volumes on I-70 between the before and after period, as found in **Table 1** (approximately 20% increase).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2007 – 12/31/2010 (4 yr)	01/01/2016 – 12/31/2019 (4 yr)	01/01/2016 – 12/31/2019 (4 yr)
Total Crashes	**131**	**115**	**154**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	29 (52)	31 (58)	32 (58)
PDO	102	84	120
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 0% / 30%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of 0.87 was ultimately realized** and is largely attributed to a slight decrease in PDO crashes. This outcome displays that this safety improvement project was not justified.

Following implementation of variable message signing, crash data suggests a decrease in the targeted crashes; however, the resulting B/C analysis would suggest an ineffective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: 70 A **Begin:** 215.00 **End:** 217.75 **From:** 01/01/2016 **To:** 12/31/2019

Benefit Cost Ratio Calculations

Crashes				Projected Crashes and Reduction Factors			Other Information	
PDO:	120			Weighted PDO:	32.93	30% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	32	58	:Injured	Weighted INJ:	15.91	0% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0	:Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
				B/C Weighted Year Factor:	4.00	23% :Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
							Service Life:	10
	Cost:	$ 976,251					Capital Recovery Factor:	0.129
	From:	01/01/2007						
	To:	12/31/2011		Days:	1461		Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: **0.87** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: I-70 MP 215-217.75

Special Notes: EB Direction Mainline Crashes

Project Information

Project Name: SH 172 & CR 513 Intersection Improvements

Project Description: Intersection Improvements

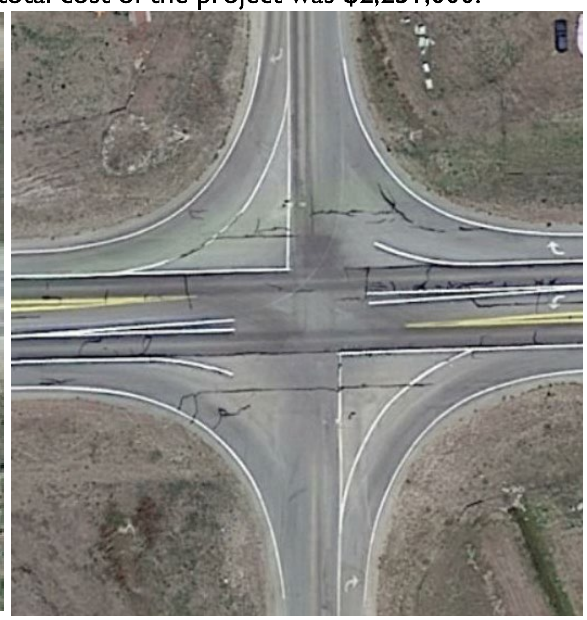
CDOT Region:	5	Project Def:	18237	County:	La Plata
Location:	SH 172	Mile Points:	16.58	Length:	17.09
Schedule:		Work Start Date:	Jan 2014	Work End Date:	Dec 2014

Problem Description:

No problem description was provided in the original HSIP application.

Improvement Description:

Align offset county roads along SH 172 at CR 513. The total cost of the project was $2,251,000.

SH 172 & CR 513 before (left) and after (right) in La Plata County, Colorado

SH 172 – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements along the segment shows a total decrease in the total number of crashes. The rate of total crashes decreased by 100%, and the number of severe crashes decreased by 100%.

The total number of crashes decreased from 5 to 0, and Injuries + Fatalities (severe crashes) decreased from 2 to 0. The number of injuries decreased from 5 to 0. The number of fatalities decreased from 1 to 0. The AADT increased by approximately 2.3% in the after period.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 20 years for this project was 3.21:1. The result is an improvement that was justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – SH 172 at CR 513

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at the intersection of SH 172 with CR 513 show a decrease in the number of crashes from the five-year before period (2009-2013) to the five-year after period (2015-2019). The number of severe (fatal and injury) crashes also decreased.

- Before Period: 2 severe crashes, 5 injured, 1 killed
- After Period: 0 severe crashes, 0 injured, 0 killed

The crash rate for all crashes at this intersection decreased by 100% between the before period and after period.

- Before Period: 1.12 crashes per million entering vehicles
- After Period: 0.22 crashes per million entering vehicles

Table 1. Results of Overall Crash Analyses

		Before	After
Time Period:		01/01/2009 – 12/31/2013 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)
AADT	SH 172	8,864	9,072
Crash Filters:		None	
Total Crashes:		**5**	**0**
Fatal Crashes (Fatalities):		1 (1)	0 (0)
Injury Crashes (Injuries):		1 (5)	0 (0)
PDO Crashes:		3	0

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) reflect a decrease in the crash record for this project. The segment is LOSS II for total and severe frequency of crashes in the before period, and LOSS I for severe and total frequency of crashes in the after period.

Figure 1. SPF For Total Crashes

SH 172 0.85 – 1.6MP
Before: 2009–2013 After: 2015–2019

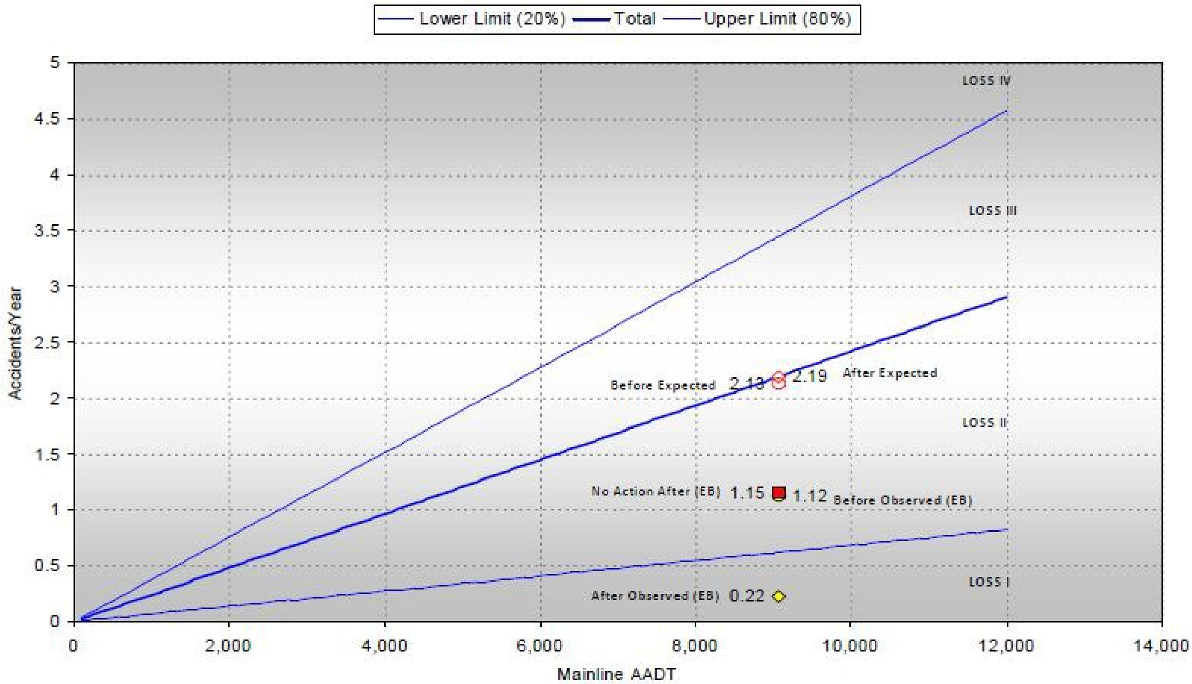


Figure 2. SPF For Severe Crashes – Before

Alameda Avenue & Depew Street
Before: 2009–2013 After: 2012–2016

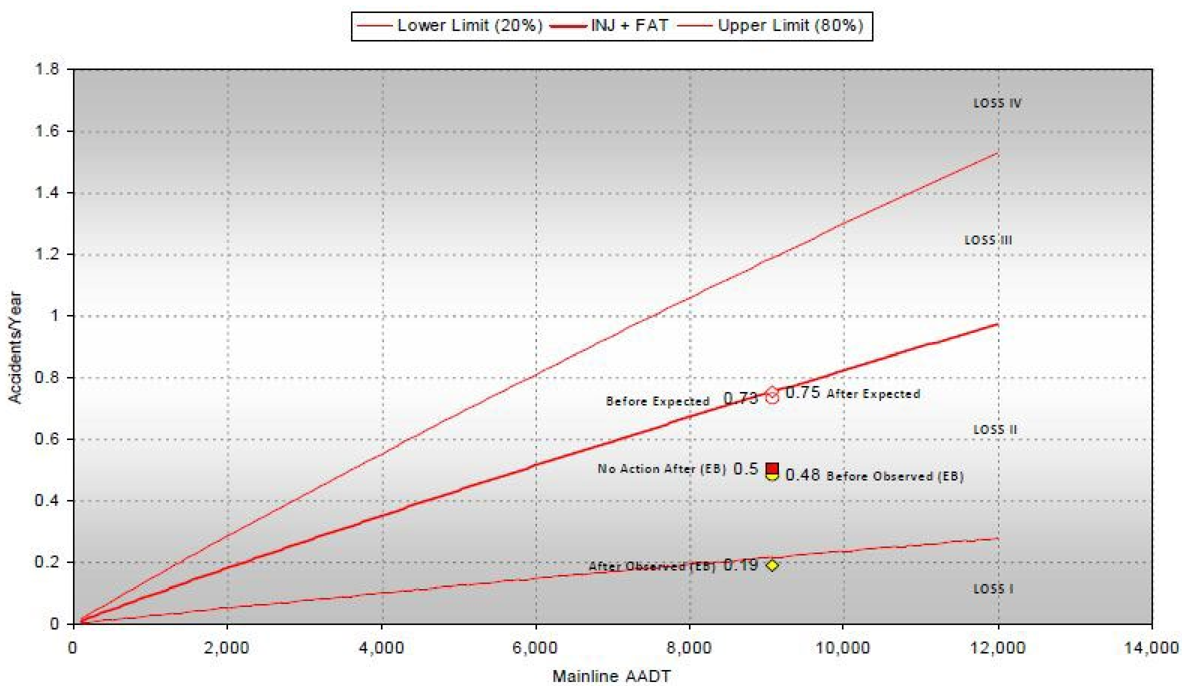


Table 2 provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)
Total Crashes			
LOSS	LOSS II	LOSS I	LOSS II
CPY	1.12	0.22	1.15
Mean CPY	2.13	2.19	2.19
Proportion of Mean	0.53	0.10	0.53
Severe (Injury & Fatal) Crashes			
LOSS	LOSS II	LOSS I	LOSS II
CPY	0.48	0.19	0.50
Mean CPY	0.73	0.75	0.75
Proportion of Mean	0.66	0.25	0.66

Crash Type Analyses

A more detailed review of the before and after crash record shows the crash types that were most affected by the improvements including intersection related crashes. **Table 3** shows a comparison of the targeted crashes.

The No-Build After crashes were estimated using the change in traffic volumes on SH 172 between the before and after period, as found in **Table 1** (approximately 2.3% increase).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2009 – 12/31/2013 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)
Total Crashes	**5**	**0**	**5**
Fatal (Fatalities)	1 (1)	0 (0)	1 (1)
Injury (Injuries)	1 (5)	0 (0)	1 (5)
PDO	3	0	3
% Reduction in Total (Fatal/Injury/PDO)	--	100% / 100% / 100%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 3.21 was ultimately realized** and is largely attributed to a complete reduction in PDO, injury and fatal crash types.

Following the previously mentioned improvements, crash data suggests a complete reduction in the targeted crashes. The resulting B/C analysis would suggest an effective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: 172 A **Begin:** 16.58 **End:**17.09 **From:**01/01/2015 **To:**12/31/2019

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	3		Weighted PDO:	0.74	100% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	1	5 :Injured	Weighted INJ:	1.23	100% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	1	1 :Killed	Weighted FAT:	0.25	100% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	100% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
Cost:	$ 2,251,000					Capital Recovery Factor:	0.080
From:	01/01/2009					Annual Maintenance/Delay Cost:	$ 0
To:	12/31/2013		Days:	1826			

Benefit Cost Ratio: **3.21** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SH 172 & County Road 513 - Intersection Safety Improvements

Special Notes: Intersection Related Crashes

Project Information

Project Name: SH 82 & Valley Road/JW Drive Intersection Improvements

Project Description: Install raised median, pork chops, and acceleration lane

CDOT Region:	3	Project Def:	18264A	County:	Eagle
Location:	SH 82 & Valley Rd	Mile Points:	MP 18.00-18.05	Length:	N/A
Schedule:		Work Start Date:	2012	Work End Date:	2013

Problem Description:

A high number of broadside crashes were noted at this intersection.

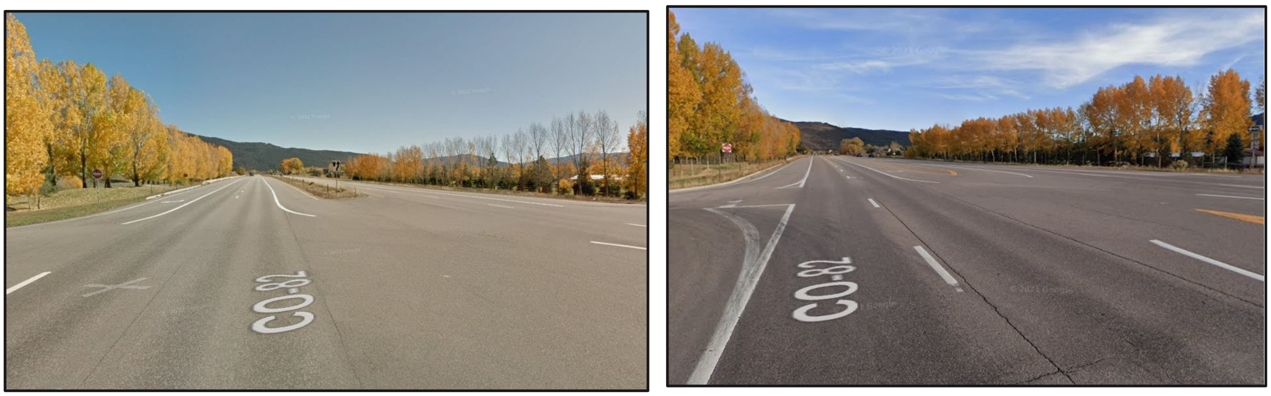
Improvement Description:

The project area is the intersection of SH 82 with Valley Road/JW Drive in Eagle, CO.

SH 82 & Valley Road

The project involved installation of raised medians, striping pork chop islands, and adding acceleration lanes for minor street turning movements. The cost of construction was $750,000.

SH 82 & Valley Rd – Westbound – Before (left) and After (right) improvements



SH 82 & Valley Rd – Eastbound – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements at this intersection shows a slight increase in the total number and severity of crashes. A comparison of all intersection related crashes before and after the improvements were made showed that there was a slight increase in all targeted crashes.

The total number of crashes increased from 7 to 9, and Injuries + Fatalities (severe crashes) decreased from 8 to 6. The average AADT decreased by approximately 17% in the after period.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 20 years for this project was -0.12:1. The result is an improvement that was not justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections and/or segments were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections/segments in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – SH 82 & Valley Rd/JW Dr

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at SH 82 & Valley Road in the project area shows an approximate 80% increase in the total number of crashes from the five-year before period (2008-2012) to the five-year after period (2014-2018). The number of severe (fatal and injury) crashes stayed constant.

- Before Period: 4 severe crashes, 8 injured
- After Period: 3 severe crashes, 6 injured

The total crashes along this corridor increased by 80% between the before period and after period.

- Before Period: 7 total crashes
- After Period: 9 total crashes

Table 1. Results of Overall Crash Analyses – SH 82 & Valley Rd/JW Dr

	Before	After
Time Period:	01/01/2008 – 12/31/2012 (5 yr)	01/01/2014 – 12/31/2018 (5 yr)
Crash Filters:		
Total Crashes:	**7**	**9**
Fatal Crashes (Fatalities):	0 (0)	0 (0)
Injury Crashes (Injuries):	4 (8)	3 (6)
PDO Crashes:	3	6
Reduction (Fatalities/Injuries/PDO)	--	0% / 0% / -200%

Safety Performance Functions

SPF plots for total crashes (**Figure 1**) reflect an increase in the crash record for this project; however, the SPF plot for severe crashes (**Figure 2**) for the intersection of SH 82 with JW/Valley Road reflect an decrease in the crash record. The intersection is LOSS II for total frequency of crashes in the before and after periods. The intersection is LOSS III for the severity of crashes in the before period and LOSS II in the after period.

It should be noted that SPF methodology is usually applied to segments that are a minimum of one mile in length and the crashes per mile per year for the study segment is likely inaccurate for an intersection.

Figure 1. SPF For Total Crashes

Before: 2008–2012 After: 2014–2018

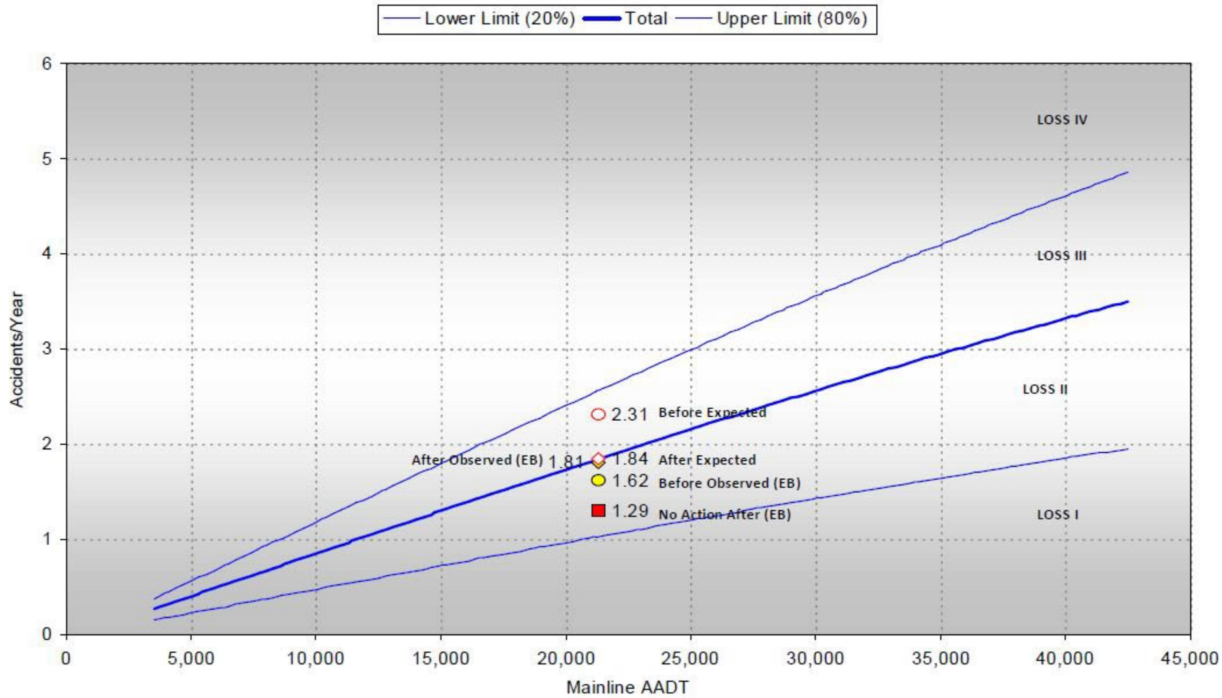


Figure 2. SPF For Severe Crashes

Before: 2008–201 After: 2014–2018

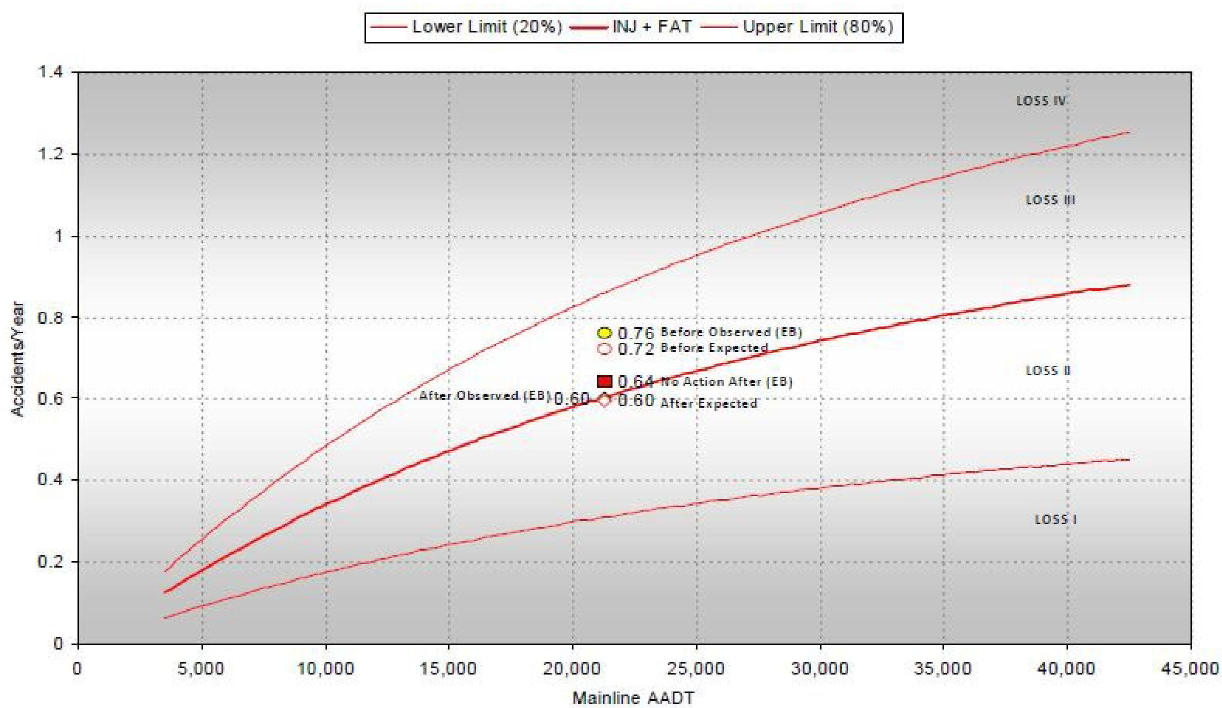


Table 2 provides a summary of the crashes per year (CPY) for the study intersection along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Urban 4-Lane Divided Unsignalized 4-leg Intersection (2018)	Urban 4-Lane Divided Unsignalized 4-leg Intersection (2018)	Urban 4-Lane Divided Unsignalized 4-leg Intersection (2018)
Total Crashes			
LOSS	LOSS II	LOSS II	LOSS II
CPYPM	1.62	1.81	1.29
Expected CPYPM	2.31	1.84	1.84
Proportion of Mean	0.70	0.98	0.70
Severe (Injury & Fatal) Crashes			
LOSS	LOSS III	LOSS II	LOSS III
CPYPM	0.76	0.6	0.64
Expected CPYPM	0.72	0.60	0.60
Proportion of Mean	1.06	1.00	1.06

Crash Type Analyses

A more detailed review of the before and after crash record shows the broadside types that were most affected by the roadway improvements. **Table 3** shows a comparison of the targeted crashes.

The No-Build After crashes were estimated using the change in traffic volumes on SH 82 between the before and after period, as found in **Table 1** (approximately 17% decrease).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2008 – 12/31/2012 (5 yr)	01/01/2014 – 12/31/2018 (5 yr)	01/01/2014 – 12/31/2018 (5 yr)
Total Crashes	**7**	**9**	**5**
Fatal (Fatalities)	0 (0)	0 (0)	0(0)
Injury (Injuries)	4 (8)	3 (6)	3 (6)
PDO	3	6	2
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 0% / -200%	--
Broadside Crashes	3	3	3
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	2 (4)	2 (4)	2 (4)
PDO	1	1	1
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 0% / 0%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of -0.12 was ultimately realized** and is largely attributed to significant increases in PDO and injury crashes. This outcome displays that this safety improvement project was not justified.

Following implementation of raised medians, striped pork chop islands, and acceleration lanes crash data suggests an increase in the targeted crashes. The Resulting B/C analysis would also suggest an ineffective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: Accident History for All Locations **From:**01/01/2014 **To:**12/31/2018

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	2		Weighted PDO:	0.49	-200% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	3	6 :Injured	Weighted INJ:	1.47	0% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	-39% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 750,000
From: 01/01/2008
To: 12/31/2012 Days: 1827

Benefit Cost Ratio: **-0.12** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SH 82 & JW/Valley Road
Special Notes: Intersecton Related Crashes

Project Information

Project Name: SH 82 MP 15.95 - 22.05 Wild Animal Fencing

Project Description: Wild Animal Fencing

CDOT Region:	3	Project Def:	18264B	County:	Garfield, eagle, & Pitkin
Location:	SH 82	Mile Points:	15.95 – 22.05	Length:	6.1 Miles
Schedule:		Work Start Date:	2012	Work End Date:	2013

Problem Description:

This segment had a high number of wild animal crashes.

Improvement Description:

The project area includes the segment of State Highway (SH) 82 between Mile Points (MP) 15.95 and 22.05 in Garfield, Eagle, & Pitkin Counties, Colorado.

SH 82 MP 15.95 – 22.05 in Colorado

The project involved installing wildlife fencing. The cost of construction was $1,800,000.

SH 82 – Southbound – Before (Left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements along SH 82 shows a decrease in the total number of crashes. A comparison of wild animal crash types before and after the improvements were made showed that there was a decrease in total wild animal crashes.

The total number of crashes reduced from 102 to 52 and Injuries + Fatalities (severe crashes) decreased from 3 to 1. The number of injuries decreased from 3 to 1. The AADT decreased by approximately 17% in the after period.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 15 years for this project was 0.70:1. The result is an improvement that was not justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

The corridor was examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar corridors in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – SH 82

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records along SH 82 in the project area shows an approximate 49% decrease in the total number of crashes from the five-year before period (2008-2012) to the five-year after period (2014-2018). The number of severe (fatal and injury) crashes decreased by 67%.

- Before Period: 3 severe crashes, 3 injured
- After Period: 1 severe crashes, 1 injured

The crash rate for all crashes along this corridor decreased by 49% between the before period and after period.

- Before Period: 3.65 crashes per million vehicle miles traveled
- After Period: 2.25 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses – SH 82

		Before	After
Time Period:		01/01/2008 – 12/31/2012 (5 yr)	01/01/2014 – 12/31/2018 (5 yr)
AADT	SH 82	25700	21275
Crash Filters:		Wild Animal	
Total Crashes:		**102**	**52**
Fatal Crashes (Fatalities):		0 (0)	0 (0)
Injury Crashes (Injuries):		3 (3)	1 (1)
PDO Crashes:		99	51

Safety Performance Functions

SPF plots for total crashes (**Figure 1**) show a decrease in the crash record for this project. Severe (injury and fatal) crashes (**Figure 2**) for SH 82 in the project area reflect a decrease in the crash record. The intersection is LOSS II for total frequency of crashes in the before period and LOSS I for total frequency of crashes in the after period. The severe frequency of crashes is LOSS I in both the before and after periods.

Figure 1. SPF For Total Crashes

Before: 2008–2012 After: 2014–2018

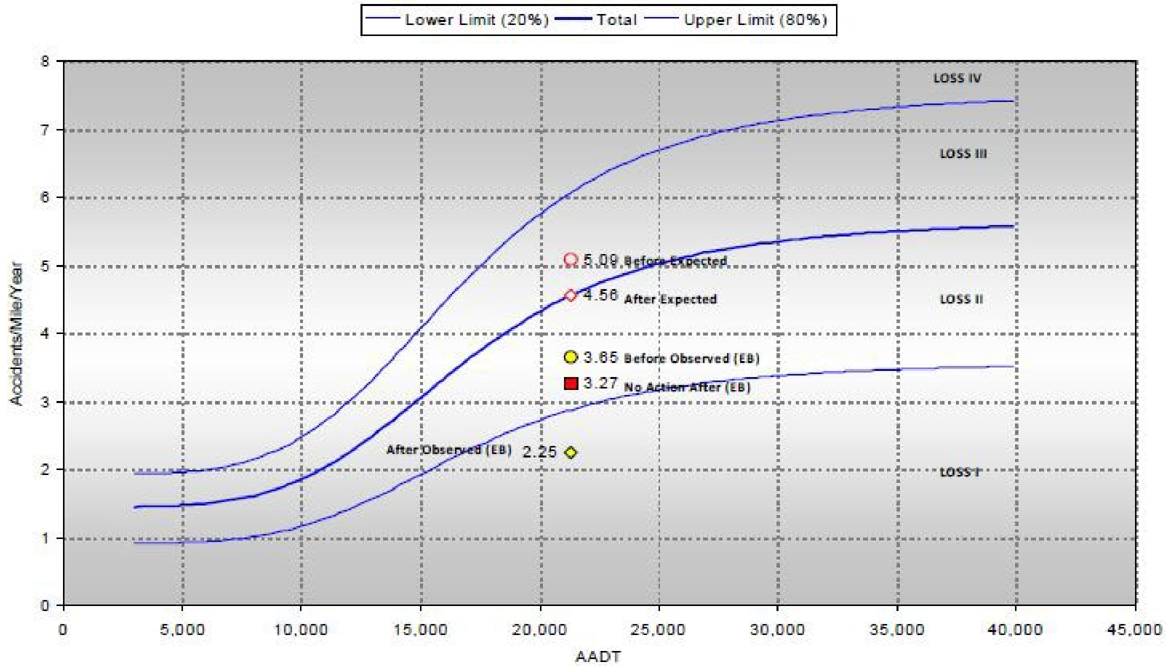


Figure 2. SPF For Severe Crashes

Before: 2008–2012 After: 2014–2018

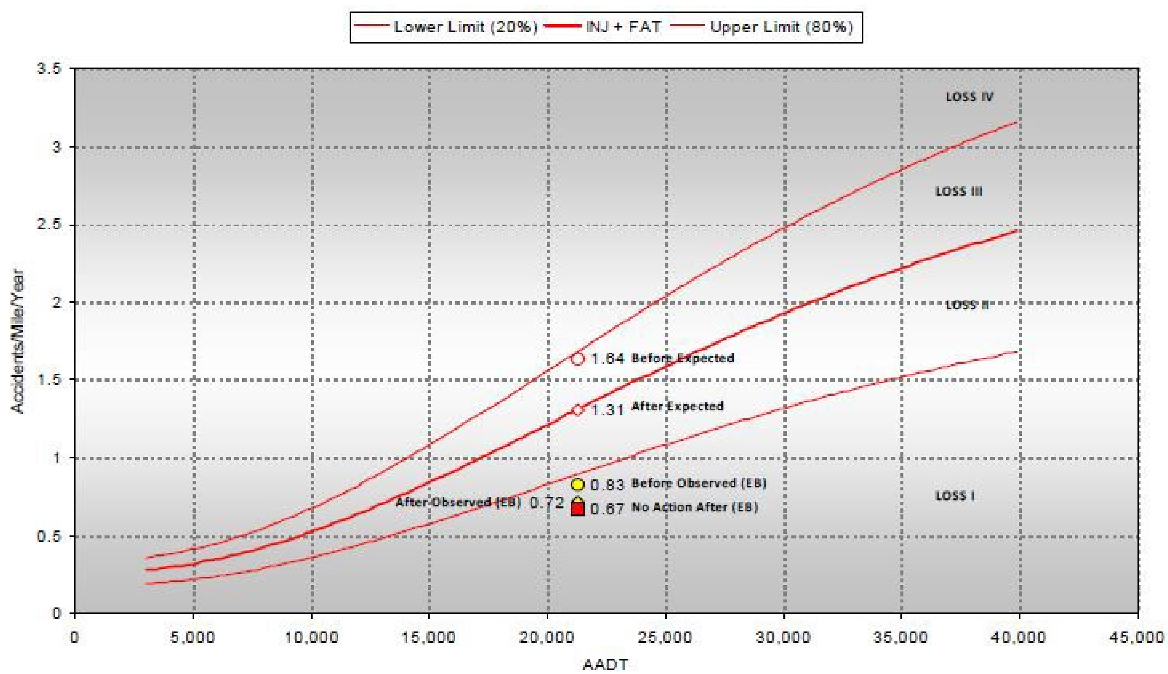


Table 2 provides a summary of the crashes per year (CPY) for SH 82 along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Flat and Rolling 4-Lane Divided Highways (2016)	Rural Flat and Rolling 4-Lane Divided Highways (2016)	Rural Flat and Rolling 4-Lane Divided Highways (2016)
Total Crashes			
LOSS	LOSS II	LOSS I	LOSS II
CPYPM	3.65	2.25	3.27
Expected CPYPM	5.09	4.56	4.56
Proportion of Mean	0.72	0.49	0.72
Severe (Injury & Fatal) Crashes			
LOSS	LOSS I	LOSS I	LOSS I
CPYPM	0.83	0.72	0.67
Expected CPYPM	1.64	1.31	1.31
Proportion of Mean	0.51	0.55	0.51

Crash Type Analyses

A more detailed review of the before and after crash record shows the wild animal crash types that were most affected by the roadway improvements. **Table 3** shows a comparison of the total, fatal and injury crashes.

The No-Build After crashes were estimated using the change in traffic volumes on SH 82 between the before and after period, as found in **Table 1** (approximately 17% decrease).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2008 – 12/31/2012 (5 yr)	01/01/2014 – 12/31/2018 (5 yr)	01/01/2014 – 12/31/2018 (5 yr)
Total Crashes	**102**	**52**	**90**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	3 (3)	1 (1)	2 (2)
PDO	99	51	88
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 54% / 42%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of 0.70 was ultimately realized** and is largely attributed to the decrease in all crash types, but a large cost. This outcome displays that this safety improvement project was not justified.

Following implementation of wild animal fencing, crash data suggests a decrease in the targeted crashes, but the resulting B/C analysis would suggest an ineffective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: 82 A **Begin:** 15.95 **End:**22.05 **From:**01/01/2008 **To:**12/31/2012

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	88		Weighted PDO:	20.41	42% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	2	2 :Injured	Weighted INJ:	0.46	54% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	42% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	15
						Capital Recovery Factor:	0.096
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 1,800,000
From: 01/01/2008
To: 12/31/2012 Days: 1827

Benefit Cost Ratio: 0.70 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SH 82 MP 15.95-22.05
Special Notes: Wildlife Crashes

Project Information

Project Name:		US 24 Rumble Strip Installation			
Project Description:		Installation of Centerline Rumble Strips			
CDOT Region:	5	Project Def:	18415	County:	Chaffee
Location:	US 24	Mile Points:	213.54	End Mile Point:	226.5
Schedule:		Work Start Date:	May 2011	Work End Date:	July 2011

Problem Description:

No problem description was provided for the original HSIP funding application for the intersection improvement project.

Improvement Description:

Centerline rumble strips were added along US 24 between mile points 213.54 and 226.5. The total cost of the project was $101,540.85.

US 24 213.54 – 226.5 MP in Chaffee County, Colorado

US 24 – Facing North – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements along the segment shows a large increase in the total number of crashes throughout the segment; however, targeted crashes of off-road left crashes resulted in a significant decrease in severe crashes. Off road left crashes decreased by 10%, and the number of severe crashes decreased by 27%.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four specific levels of safety.

- **LOSS I:** Indicates low potential for crash reduction
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- **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 or severity at a specific level of ADT.

Study intersections and/or segments were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections/segments in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – US 24 213.54 – 226.5 MP

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records along the 213.54– 226.5 MP segment on US 24 show a decrease in the number of crashes from the five-year before period (2006-2010) to the five-year after period (2012-2016). The number of severe (fatal and injury) crashes also decreased.

- Before Period: 22 severe crashes, 31 injured, 4 fatalities
- After Period: 16 severe crashes, 26 injured, 2 fatalities

The crash rate for all crashes at this intersection increased by 8% between the before period and after period.

- Before Period: 0.74 crashes per million entering vehicles
- After Period: 0.76 crashes per million entering vehicles

Table 1. Results of Overall Crash Analyses

		Before	After
Time Period:		01/01/2006 – 12/31/2010 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)
AADT	US 24	3,288	4,204
Crash Filters:		Head On, Sideswipe Opposite, Off Left/Median	
Total Crashes:		**39**	**36**
	Fatal Crashes (Fatalities):	3 (4)	2 (2)
	Injury Crashes (Injuries):	19 (31)	14 (26)
	PDO Crashes:	18	20

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) reflect a decrease in the crash record for this project. The segment is LOSS II for total frequency of crashes in the before and after periods and LOSS III for the severe frequency of crashes in the before and after periods.

Figure 1. SPF For Total Crashes

US 24 213.54 – 226.5 MP
Before: 2006–2010 After: 2012–2016

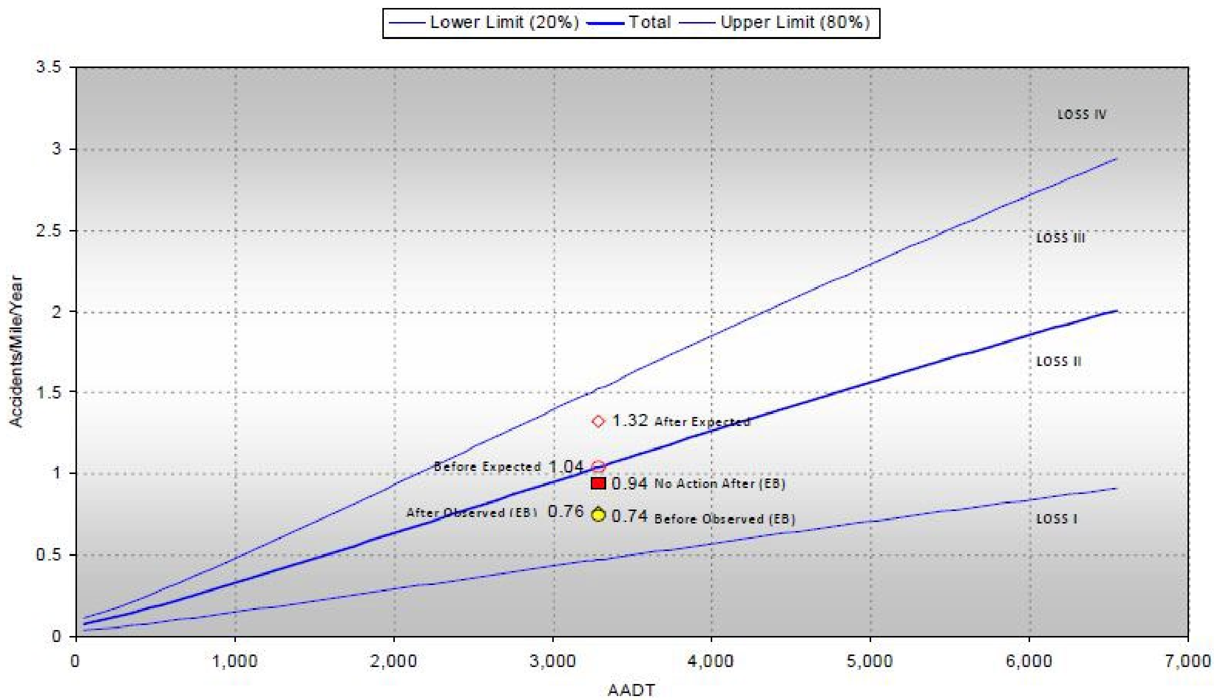


Figure 2. SPF For Severe Crashes – Before

US 24 213.54 – 226.5 MP
Before: 2006–2010 After: 2012–2016

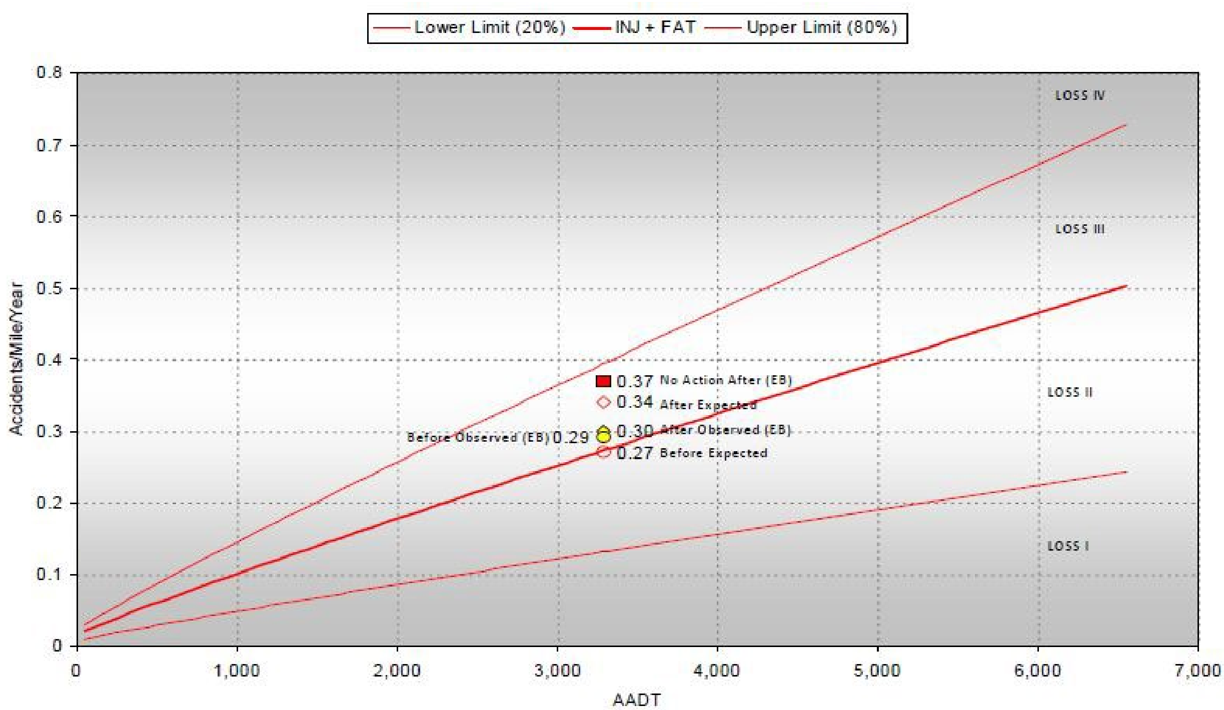


Table 2 provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)
Total Crashes			
LOSS	LOSS II	LOSS II	LOSS II
CPY	0.74	0.76	0.94
Mean CPY	1.04	1.32	1.32
Proportion of Mean	0.71	0.58	0.71
Severe (Injury & Fatal) Crashes			
LOSS	LOSS II	LOSS II	LOSS III
CPY	0.29	0.3	0.37
Mean CPY	0.27	0.34	0.34
Proportion of Mean	1.07	0.88	1.07

Crash Type Analyses

A more detailed review of the before and after crash record shows head on, sideswipe opposite, and all off left crash types that were most affected by the improvements. **Table 3** shows a comparison of the affected crashes.

The No-Build After crashes were estimated using the change in traffic volumes on US 24 between the before and after period, as found in **Table 1** (approximately 28% increase).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2006 – 12/31/2010 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)
Total Crashes	**39**	**36**	**52**
Fatal (Fatalities)	3 (4)	2 (2)	4 (5)
Injury (Injuries)	19 (31)	14 (26)	23 (38)
PDO	18	20	24
% Reduction in Total (Fatal/Injury/PDO)	--	60% / 32% / -17%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 111.08 was ultimately realized** and is largely attributed to a significant decrease in all crash types.

Following the previously mentioned improvements, crash data suggests a reduction in the targeted crashes. The resulting B/C analysis would suggest an effective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: 24 A **Begin:** 213.54 **End:** 226.50 **From:** 01/01/2012 **To:** 12/31/2016

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors				Other Information	
PDO:	24		Weighted PDO:	5.27	-17%	:CRF for PDO	Cost of PDO:	$ 11,100
INJ:	23	38 :Injured	Weighted INJ:	8.34	32%	:CRF for INJ	Cost of INJ:	$ 101,800
FAT:	4	5 :Killed	Weighted FAT:	1.10	60%	:CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	11%	:Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
							Service Life:	10
							Capital Recovery Factor:	0.129
							Annual Maintenance/Delay Cost:	$ 0

Cost:	$ 101,540
From:	01/01/2006
To:	12/31/2010
Days:	1826

Benefit Cost Ratio: **111.08** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SH 24 - Centerline Rumble Strips

Special Notes: Off Road Left, Head On, Sideswipe Opposite Crashes

Project Information

Project Name: Signal Improvements at Various Locations

Project Description: Flashing Yellow Arrow Upgrades & Signal Timing

CDOT Region: 5 Project Def: 18460 County: La Plata

Location:

US 160 & SH172	US 160 & CR 210	US 550 & 22nd St
US 160 & Three Springs Rd	US 160 & Santa Rita Dr	US 550 & 24th St
US 160 & US 550 West	US 550 & College Dr	US 550 & 25th St
US 160 & River Rd	US 550 & 9th St	US 550 & 27th St
US 160 & Dominguez Dr	US 550 & 17th St	US 550 & 32nd St
US 160 & Sawyer Dr	US 550 & US 160 East	US 550 & Animas View Dr

Schedule: Work Start Date: 2011 Work End Date: 2011

Problem Description:

The study intersections were evaluated based on approach turn type crashes.

Improvement Description:

The project area includes 18 intersection locations along US 160 and US 550 in Durango, CO.

Study Intersections in Durango, Colorado

The project involved replacing solid green balls with flashing yellow arrows and retiming signals. The cost of construction was $607,651.

US 160 & River Rd – Northbound Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements at the study intersections along US 160 & US 550 show a significant increase in the total number and severity of crashes. A comparison of approach turn types before and after the improvements were made showed that there was an increase in affected crashes.

The total number of crashes increased from 62 to 78, and Injuries + Fatalities (severe crashes) increased from 25 to 40. The number injuries increased from 46 to 68; however, the fatalities decreased from 1 to 0. The likelihood of an injury becoming a fatality is somewhat arbitrary and is not necessarily a reflection of the improvements. The AADT increased by approximately 5% in the after period on US 160 / US 550/ Main Avenue.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 20 years for this project was 7.73:1. The result is an improvement that was not justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at the study intersections along US 160 & US 550 shows an approximate 29% increase in the number of crashes from the five-year before period (2006-2010) to the five-year after period (2012-2016). The number of severe (fatal and injury) crashes increased by approximately 54%.

- Before Period: 26 severe crashes, 46 injured, 1 fatality
- After Period: 40 severe crashes, 68 injured, 0 fatalities

The crash rate for all crashes at this intersection increased by 29% between the before period and after period.

- Before Period: 11.73 crashes per million vehicle miles traveled
- After Period: 14.58 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses

		Before	After
Time Period:		01/01/2006 – 12/31/2010 (5 yr)	01/01/2012 – 12/31/2016 (5 yr)
AADT	Major	29,155	30,564
	Minor	2,752	4,031
Crash Filters:		Approach Turn	
Total Crashes:		**63**	**78**
Fatal Crashes (Fatalities):		1 (1)	0 (0)
Injury Crashes (Injuries):		25 (46)	40 (68)
PDO Crashes:		37	40

Safety Performance Functions – 3 Leg Intersections

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for the study intersections along US 160 & US 550 reflect an increase in the crash record for this project. The intersection is LOSS I for total frequency of crashes in the before and after periods, LOSS I for severe frequency of crashes in the before period, LOSS II for severe frequency of crashes in the after period.

It should be noted that SPF methodology is usually applied to segments that are a minimum of one mile in length and the crashes per mile per year for the study segment is likely inaccurate for an intersection.

Figure 1. SPF For Total Crashes

Before: 2006–2010 After: 2012–2016

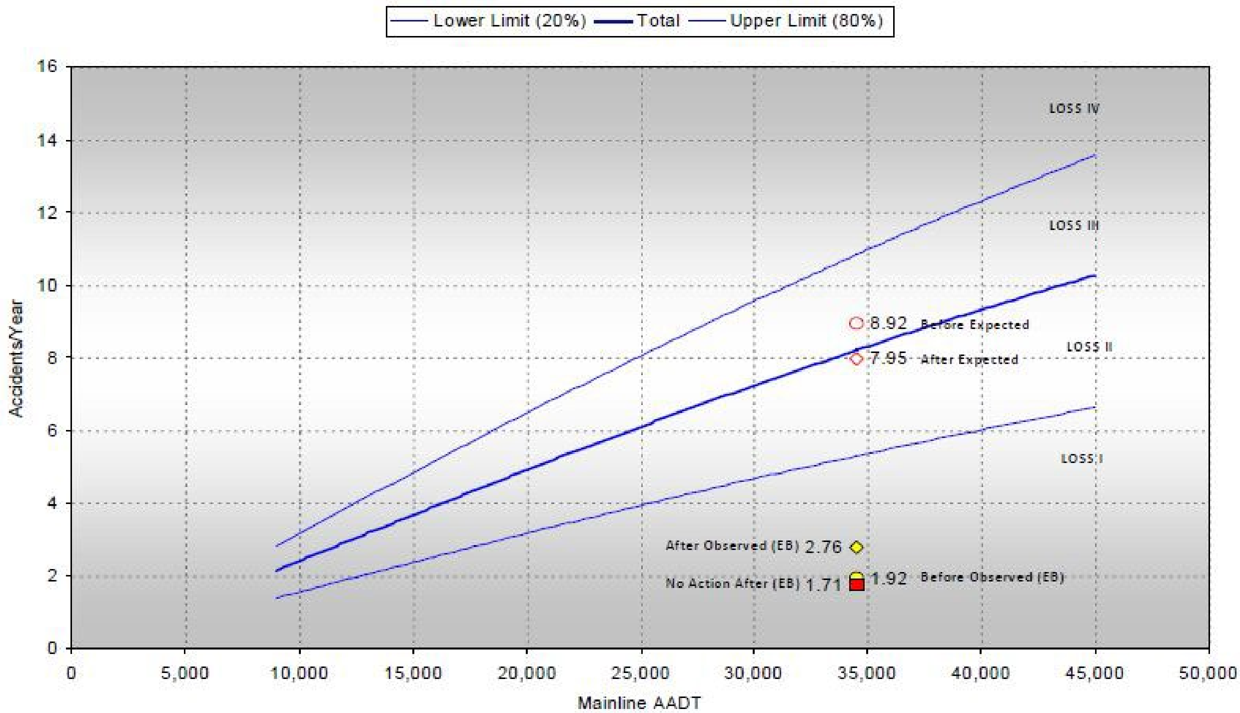


Figure 2. SPF For Severe Crashes

Before: 2006–2010 After: 2012–2016

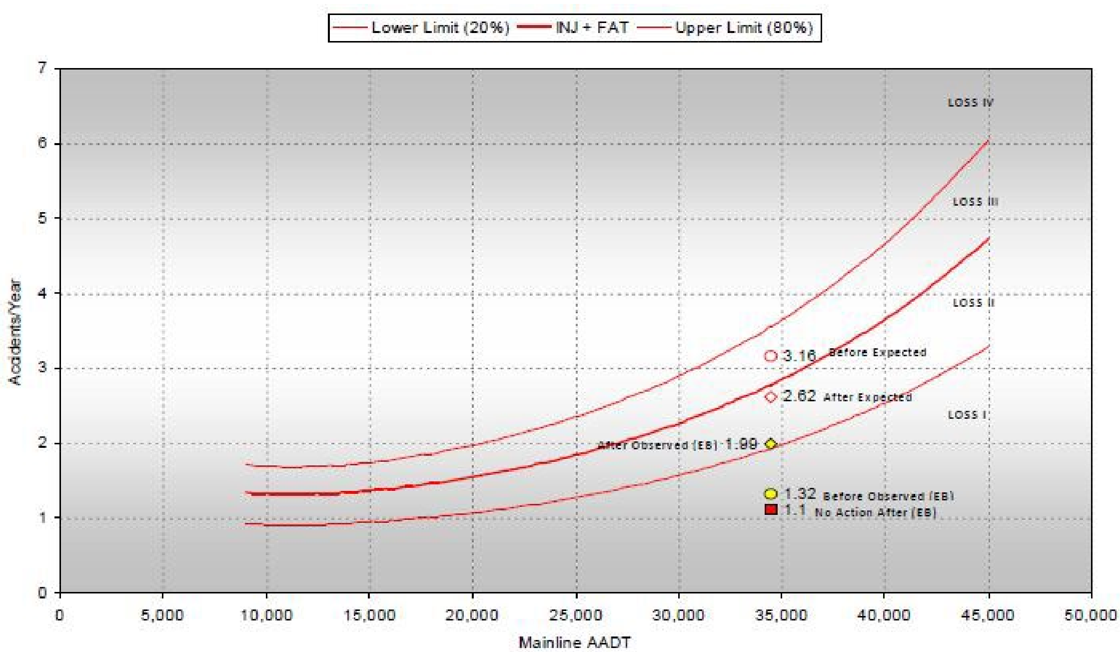


Table 2 provides a summary of the crashes per year (CPY) for the study intersection along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Urban 4-Lane Divided Signalized 3-leg Intersection (2018)	Urban 4-Lane Divided Signalized 3-leg Intersection (2018)	Urban 4-Lane Divided Signalized 3-leg Intersection (2018)
Total Crashes			
LOSS	LOSS I	LOSS I	LOSS I
CPYPM	1.92	2.76	1.71
Expected CPYPM	8.92	7.95	7.95
Proportion of Mean	0.22	0.35	0.22
Severe (Injury & Fatal) Crashes			
LOSS	LOSS I	LOSS II	LOSS I
CPYPM	1.32	1.99	1.10
Expected CPYPM	3.16	2.62	2.62
Proportion of Mean	0.42	0.76	0.42

Safety Performance Functions – 4 Leg Intersections

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for the study intersections along US 160 & US 550 reflect an increase in the crash record for this project. The intersection is LOSS III for total frequency of crashes in the before period and LOSS IV in the after period. The intersection is LOSS IV for the severity of crashes in both the before and after periods.

It should be noted that SPF methodology is usually applied to segments that are a minimum of one mile in length and the crashes per mile per year for the study segment is likely inaccurate for an intersection.

Figure 3. SPF For Total Crashes

Before: 2006–2010 After: 2012–2016

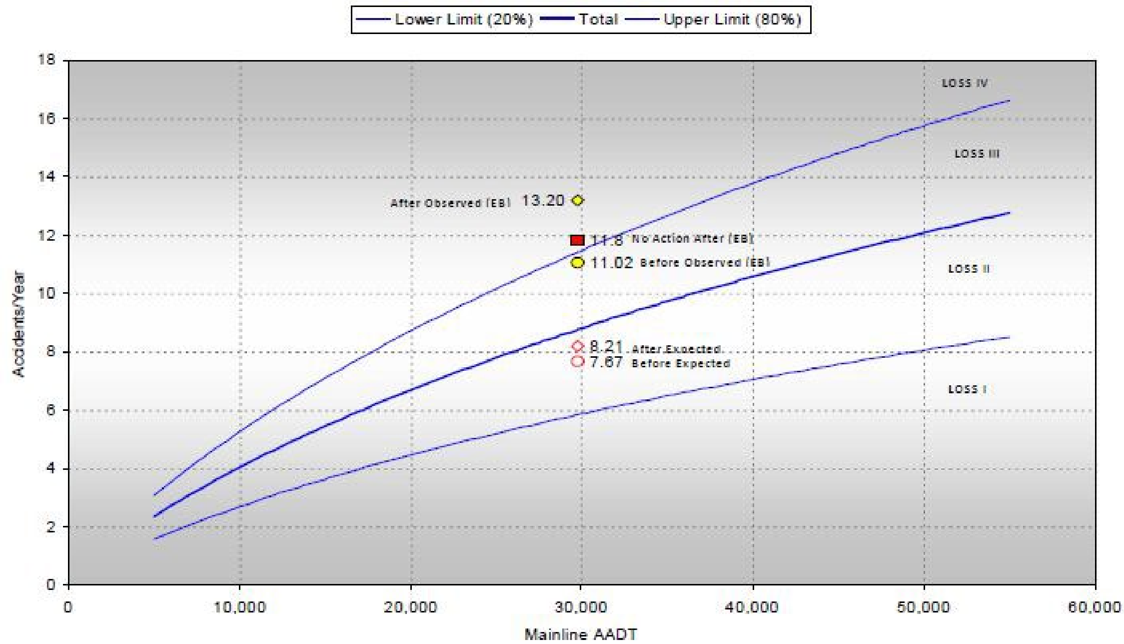


Figure 4. SPF For Severe Crashes

Before: 2006–2010 After: 2012–2016

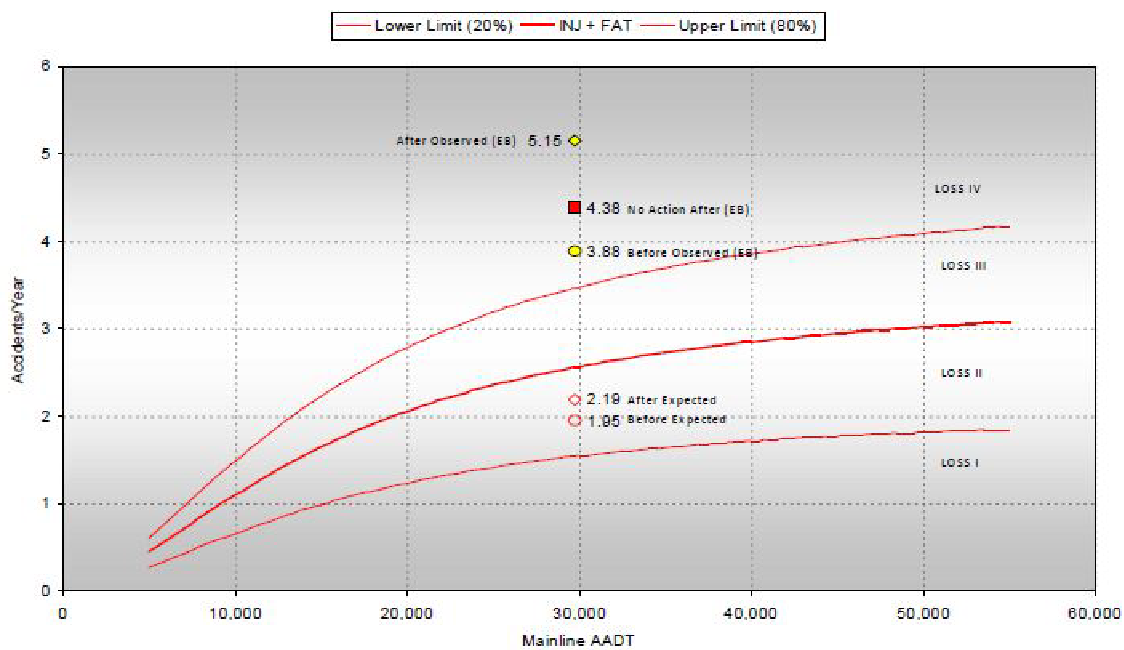


Table 2 provides a summary of the crashes per year (CPY) for the study intersection along with a comparison with the mean (expected) CPY for the before and after periods.

Table 3. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)
Total Crashes			
LOSS	LOSS III	LOSS IV	LOSS IV
CPYPM	11.02	13.20	11.80
Expected CPYPM	7.67	8.21	8.21
Proportion of Mean	1.44	1.61	1.44
Severe (Injury & Fatal) Crashes			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPYPM	3.88	5.15	4.38
Expected CPYPM	1.95	2.19	2.19
Proportion of Mean	1.99	2.35	1.99

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of -2.32 was ultimately realized** and is largely attributed to significant increase in number of total and severe crashes. This outcome displays that this safety improvement project was not justified.

Following the installation of flashing yellow arrows instead of solid green balls, crash data suggests an increase in the targeted crashes. The resulting B/C analysis would also suggest an ineffective safety project.

Figure 5. Benefit-Cost Analysis Summary

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	37		Weighted PDO:	9.09	-8% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	25	46 :Injured	Weighted INJ:	11.30	-48% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	1	1 :Killed	Weighted FAT:	0.25	100% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	-22% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
	Cost:	$ 607,651				Service Life:	20
	From:	01/01/2006				Capital Recovery Factor:	0.080
	To:	12/31/2010	Days:	1826		Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: -2.32 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: 18 Intersections along US 160 & US 550 & Main Avenue

Special Notes: Approach Turn Type Crashes

Project Information

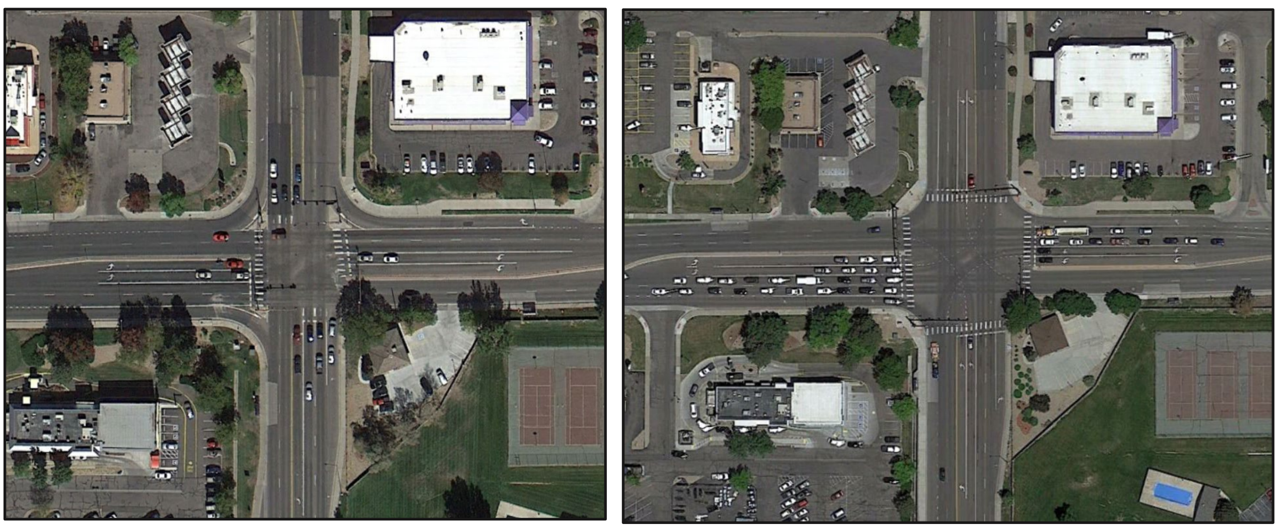
Project Name:	120th Ave & Colorado Blvd Intersection Improvements		
Project Description:	Added northbound and southbound left turn lanes and intersection realignment		
CDOT Region: 1	Project Def: 18544	County: Adams	
Location: 120th Ave & Colorado Blvd	Mile Points: N/A	Length: N/A	
Schedule:	Work Start Date: 2013	Work End Date: 2014	

Problem Description:

No problem description was provided for the original HSIP funding application for the intersection improvement project.

Improvement Description:

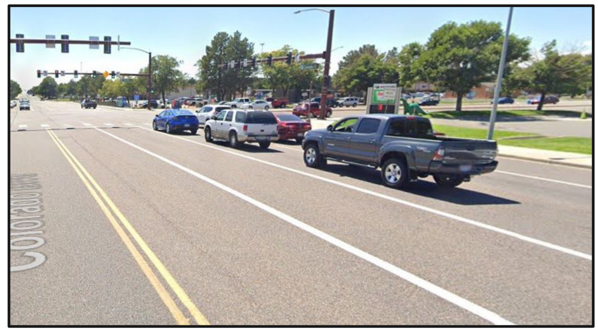
The project area is the intersection of 120th Avenue with Colorado Boulevard in Adams County, Colorado. This intersection experiences high volumes of approaching, rear end, and sideswipe same side crashes.



120th Ave & Colorado Blvd – Before (left) and After (right) Improvements

The project involved adding dual left turn lanes on Colorado Boulevard in Adams County, Colorado. The cost of construction was $1,938,387.


Colorado Blvd – Facing North – Before (left) and After (right) improvements



Colorado Blvd – Facing South – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements at the intersection of 120th Avenue with Colorado Boulevard show an increase in the total number of crashes. Severe crashes reduced slightly. A comparison of rear end, approach turn, and sideswipe same types before and after the improvements were made showed that there was an increase in affected crashes.

The total number of crashes increased from 76 to 79, and Injuries + Fatalities (severe crashes) stayed constant at 19; however, the number of injuries decreased from 29 to 27. The AADT increased by approximately 3% in the after period on 120th Avenue.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 10 years for this project was 0.19:1. The result is an improvement that was not justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at the intersection of 120th Ave with Colorado Blvd shows an approximate 2% increase in the number of crashes from the five-year before period (2008-2012) to the five-year after period (2015-2019). The number of severe (fatal and injury) crashes stayed constant.

- Before Period: 19 severe crashes, 29 injured
- After Period: 19 severe crashes, 27 injured

The crash rate for all crashes at this intersection increased by 2% between the before period and after period.

- Before Period: 15.47 crashes per million vehicle miles traveled
- After Period: 16.05 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses

		Before	After
Time Period:		01/01/2008 – 12/31/2012 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)
AADT	120th Ave	33,629	34,611
	Colorado Blvd	22,896	22,875
Crash Filters:		Intersection Related	
Total Crashes:		**76**	**79**
Fatal Crashes (Fatalities):		0 (0)	0 (0)
Injury Crashes (Injuries):		19 (29)	19 (27)
PDO Crashes:		57	60

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for the intersection of 120th Ave with Colorado Blvd reflect an increase in the crash record for this project. The intersection is LOSS II for total and severe frequency of crashes in the before period and after period.

It should be noted that SPF methodology is usually applied to segments that are a minimum of one mile in length and the crashes per mile per year for the study segment is likely inaccurate for an intersection.

Figure 1. SPF For Total Crashes

Before: 2008–2012 After: 2015–2019

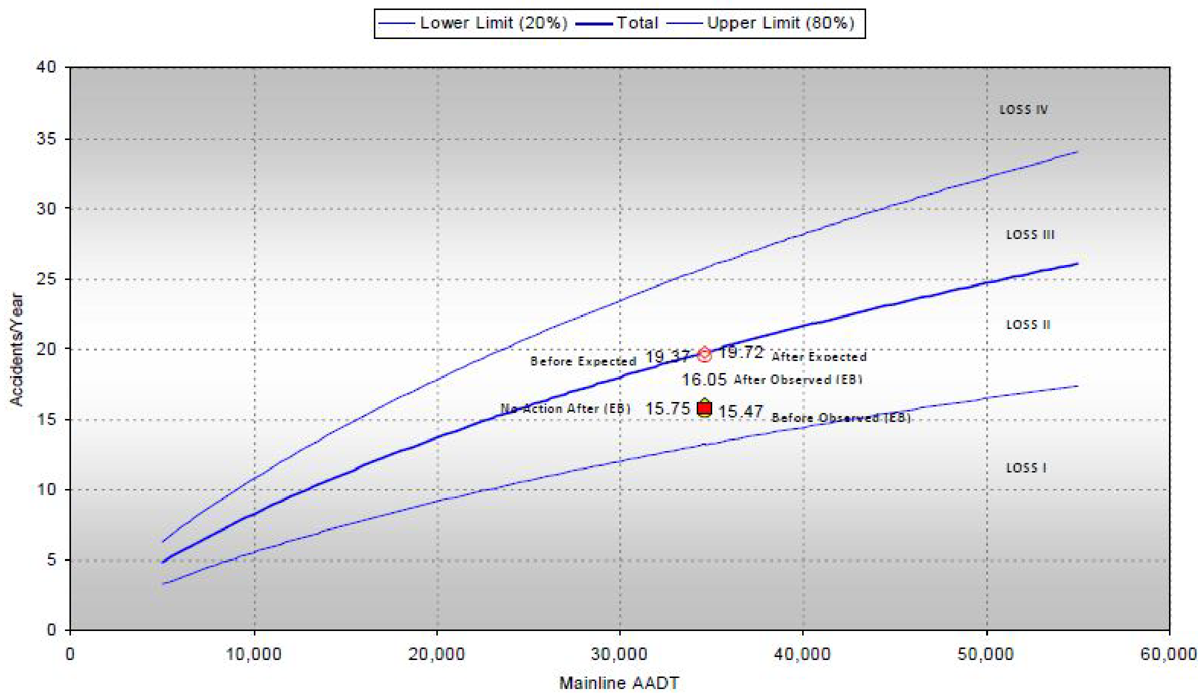


Figure 2. SPF For Severe Crashes

Before: 2008–2012 After: 2015–2019

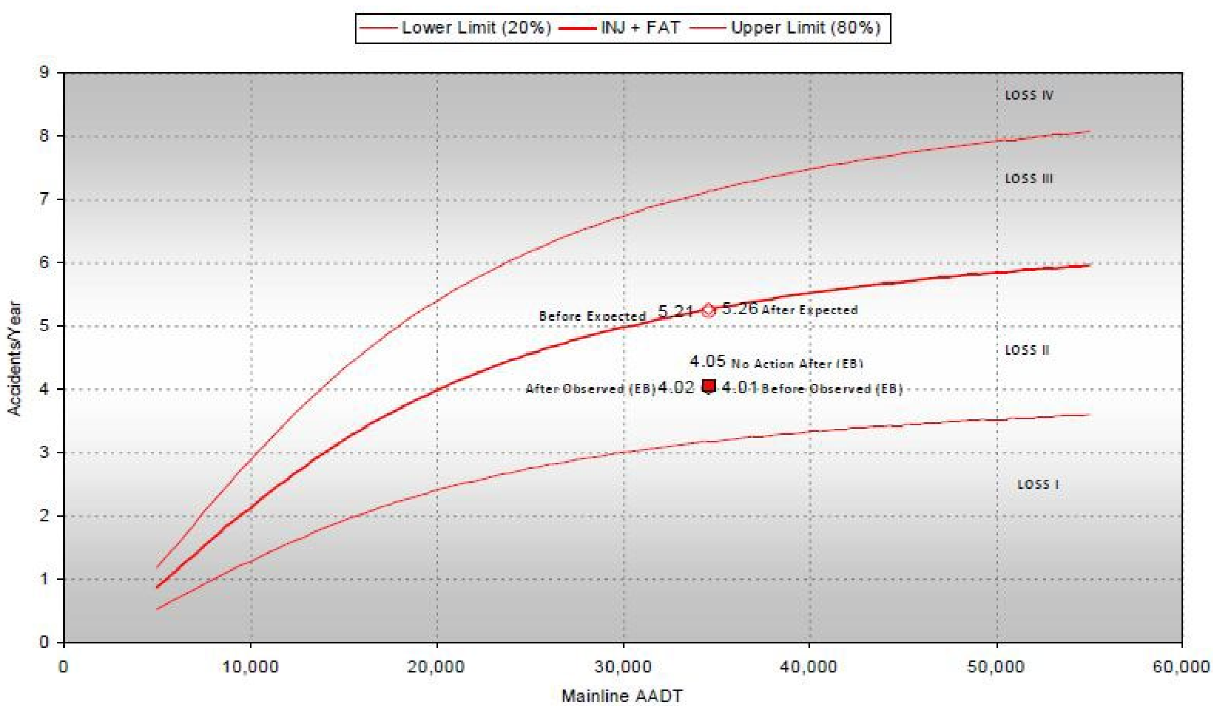


Table 2 provides a summary of the crashes per year (CPY) for the study intersection along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)	Urban 4-Lane Divided Signalized 4-leg Intersection (2018)
Total Crashes			
LOSS	LOSS II	LOSS II	LOSS II
CPYPM	15.47	16.05	15.75
Expected CPYPM	19.37	19.72	19.72
Proportion of Mean	0.80	0.81	0.80
Severe (Injury & Fatal) Crashes			
LOSS	LOSS II	LOSS II	LOSS II
CPYPM	4.01	4.02	4.05
Expected CPYPM	5.21	5.26	5.26
Proportion of Mean	0.77	0.76	0.77

Crash Type Analyses

A more detailed review of the before and after crash record shows the sideswipe same, approach turn, and rear end crash types that were most affected by the roadway improvements. **Table 3** shows a comparison of the total, fatal, and injury crashes.

The No-Build After crashes were estimated using the change in traffic volumes on 120th Avenue between the before and after period, as found in **Table 1** (approximately 3% increase).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2008 – 12/31/2012 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)
Total Crashes	**76**	**79**	**77**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	19 (29)	19 (27)	19 (29)
PDO	57	60	58
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 0% / -3%	--
Approach Turn, Rear End, & Sideswipe Same	**76**	**79**	77
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	19 (29)	19 (27)	19(29)
PDO	57	60	58
% Reduction in Total (Fatal/Injury/PDO)	--	0% / 0% / -3%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of 0.19 was ultimately realized** and is largely attributed to an increase in PDO crashes. This outcome displays that this safety improvement project was not justified.

Following the addition of a northbound and southbound dual left turn lanes and intersection realignment, crash data suggests an increase in the targeted crashes. The resulting B/C analysis would also suggest an ineffective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: 24 A **Begin:** 213.54 **End:** 226.50 **From:** 01/01/2015 **To:** 12/31/2019

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	58		Weighted PDO:	12.73	-3% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	19	29 :Injured	Weighted INJ:	6.37	8% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	-0% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
	Cost:	$ 1,938,387				Service Life:	10
	From:	01/01/2008				Capital Recovery Factor:	0.129
	To:	12/31/2012	Days:	1827		Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: **0.19** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Colorado Blvd & 120th Avenue

Special Notes: Intersection Related Crashes

Project Information

Project Name: US 50 Rumble Strip Installation

Project Description: Installation of Median and Shoulder Rumble Strips

CDOT Region:	2	Project Def:	18561	County:	Pueblo & Otero
Location:	US 50	Mile Points:	318-359	Length:	41 mi
Schedule:		Work Start Date:	2013	Work End Date:	2013

Problem Description:

No problem description was provided for the original HSIP funding application for the intersection improvement project.

Improvement Description:

Median and shoulder rumble strips were added along US 50 between mile points 318 and 359. The total cost of the project was $621,957.

US 50 318-359 MP in Pueblo & Otero Counties, Colorado

US 50 – Facing North – Before (left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements along the segment shows a decrease in both total and severity of targeted crashes throughout the segment.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections and/or segments were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections/segments in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – US 50 318 – 359 MP

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records along the 318 – 359 MP segment on US 50 show a decrease in the number of crashes from the five-year before period (2007-2011) to the five-year after period (2013-2017). The number of severe (fatal and injury) crashes also decreased.

- Before Period: 69 severe crashes, 87 injured, 9 fatalities
- After Period: 50 severe crashes, 65 injured, 1 fatalities

The crash rate for all crashes at this intersection decreased by 23% between the before period and after period.

- Before Period: 0.91 crashes per million entering vehicles
- After Period: 0.81 crashes per million entering vehicles

Table 1. Results of Overall Crash Analyses

		Before	After
Time Period:		01/01/2007 – 12/31/2011 (5 yr)	01/01/2013 – 12/31/2017 (5 yr)
AADT	US 50	3,525	3,745
Crash Filters:		Run off road, head on, & sideswipe opposite	
Total Crashes:		**168**	**137**
	Fatal Crashes (Fatalities):	7 (9)	1 (1)
	Injury Crashes (Injuries):	62 (87)	49 (65)
	PDO Crashes:	99	87

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) reflect a decrease in the crash record for this project. The segment is LOSS II for total frequency of crashes in the before and after periods, LOSS III for severe frequency of crashes in the before period, and LOSS II for severe frequency of crashes in the after period.

Figure 1. SPF For Total Crashes

US 50 318 – 359 MP
Before: 2007–2011 After: 2013–2017

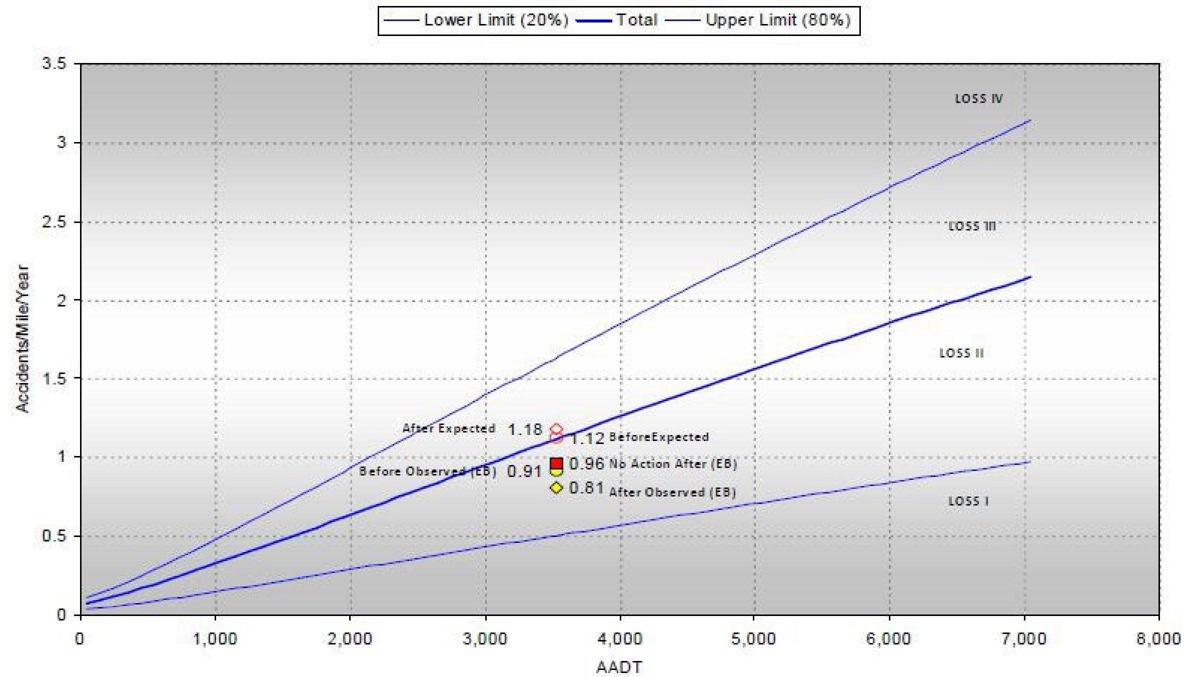


Figure 2. SPF For Severe Crashes – Before

US 50 318 – 359 MP
Before: 2007–2011 After: 2013–2017

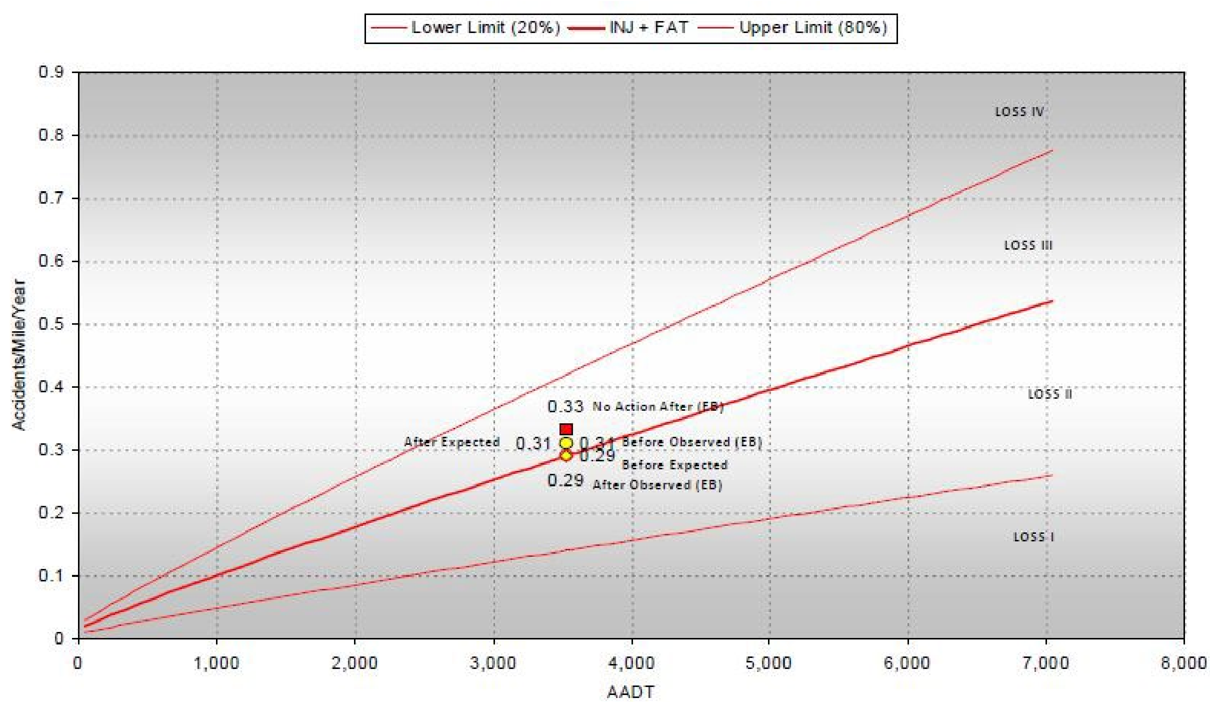


Table 2 provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)	Rural Flat and Rolling 2-Lane Undivided Highways (2016)
Total Crashes			
LOSS	LOSS II	LOSS II	LOSS II
CPY	0.91	0.81	0.96
Mean CPY	1.12	1.18	1.18
Proportion of Mean	0.81	0.69	0.81
Severe (Injury & Fatal) Crashes			
LOSS	LOSS III	LOSS II	LOSS III
CPY	0.31	0.29	0.33
Mean CPY	0.29	0.31	0.31
Proportion of Mean	1.07	0.94	1.07

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 52.85 was ultimately realized** and is largely attributed to a significant decrease in all crash types.

Following the previously mentioned improvements, crash data suggests a reduction in the targeted crashes. The resulting B/C analysis would suggest an effective safety project.

Figure 3. Benefit-Cost Analysis Summary

Location: 50 B **Begin:** 318.00 **End:**359.00 **From:**01/01/2013 **To:**12/31/2017

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	105		Weighted PDO:	23.05	17% :CRF for PDO	Cost of PDO:	$ 11,100
INJ:	66	92 :Injured	Weighted INJ:	20.19	30% :CRF for INJ	Cost of INJ:	$ 101,800
FAT:	7	10 :Killed	Weighted FAT:	2.20	90% :CRF for FAT	Cost of FAT:	$ 1,820,600
			B/C Weighted Year Factor:	5.00	24% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	10
						Capital Recovery Factor:	0.129
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 621,957
From: 01/01/2007
To: 12/31/2011 Days: 1826

Benefit Cost Ratio: 52.85 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SH 50 MP 318 - 359
Special Notes: Head-On, Sideswipe Opposite, Off Road Crashes

Project Information

Project Name:	SH 83 & Walker Road Intersection Improvements				
Project Description:	Geometric improvements and intersection lighting				
CDOT Region: 2	Project Def:	18783	County:	El Paso	
Location: SH 83 & Walker Rd	Mile Points:	28.00 to 28.28	Length:	N/A	
Schedule:	Work Start Date:	2013	Work End Date:	2015	

Problem Description:

A high number of broadside crashes were noted at this intersection.

Improvement Description:

The project area is the intersection of SH 83 with Walker Road in El Paso, CO.

SH 83 & Walker Road before (left) and after (right) improvements

The project involved geometric changes including channelizing islands along with lighting. The cost of construction was $730,602.

SH 83 & Walker Rd – northbound – Before (left) and After (right) improvements

Summary & Findings

Improvements to SH 83 and Walker Road/Hwy 105 intersection in response to high number of broadside crashes. The analysis of safety conditions before and after improvements at this intersection shows a significant increase in the total number and severity of crashes. A comparison of all intersection related crashes before and after the improvements were made showed that there was a significant increase in all targeted crashes.

The total number of intersection crashes increased from 7 to 27, and Injuries + Fatalities (severe crashes) increased from 5 to 22. The number of injuries increased from 7 to 41; there were no fatalities in either period. The average AADT increased by approximately 28% in the after period.

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 20 years for this project was –12.34:1. Broadside crashes are overrepresented in both the before and after periods. Approach turn crashes are overrepresented in the after period only. The result is an improvement that was not effective from the safety improvement and cost effectiveness standpoints.

Before (2010-2012) & After (2015-2017) Crash Summary

Crashes

	PDO	Injury	Fatal	Inj+Fat	Total
Before:	2	5	0	5	7
After:	5	22	0	22	27
Difference:	3	17	0	17	20

Injuries and Fatalities

	Injured (Poss/Minor)	Injured (Moderate)	Injured (Incapacitating)	Total Injured	Killed
Before:	3	2	0	7	0
After:	9	8	5	41	0
Difference:	6	6	5	34	0

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections and/or segments were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections/segments in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – SH 83 & Walker Rd

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at SH 83 & Walker Road in the project area shows an approximate 313% increase in the total number of crashes from the five-year before period (2010-2012) to the five-year after period (2015-2017). The number of severe (fatal and injury) crashes increased by approximately 400%.

- Before Period: 5 severe crashes, 7 injured, 0 fatalities
- After Period: 25 severe crashes, 47 injured, 1 fatalities

The total crashes along this corridor increased by 313% between the before period and after period.

- Before Period: 8 total crashes
- After Period: 33 total crashes

Table 1. Results of Overall Crash Analyses – SH 83 & Walker Rd

	Before	After
Time Period:	01/01/2010 – 12/31/2012 (3 yr.)	01/01/2015 – 06/30/2017 (3 yr.)
Crash Filters:	Intersection Related	
Total Crashes:	**7**	**27**
Fatal Crashes (Fatalities):	0 (0)	0 (0)
Injury Crashes (Injuries):	5 (7)	22 (41)
PDO Crashes:	2	5

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for the intersection of SH 83 with Walker Road reflect an increase in the crash record for this project. The intersection is LOSS IV for the severity of crashes as well as total frequency of crashes in both the before and after periods.

It should be noted that SPF methodology is usually applied to segments that are a minimum of one mile in length and the crashes per mile per year for the study segment is likely inaccurate for an intersection.

Figure 1. SPF For Total Crashes

Rural 2-Lane Divided Unsignalized 4-Leg Intersections (2018)

Before: 2010–2012 After: 2015–2017

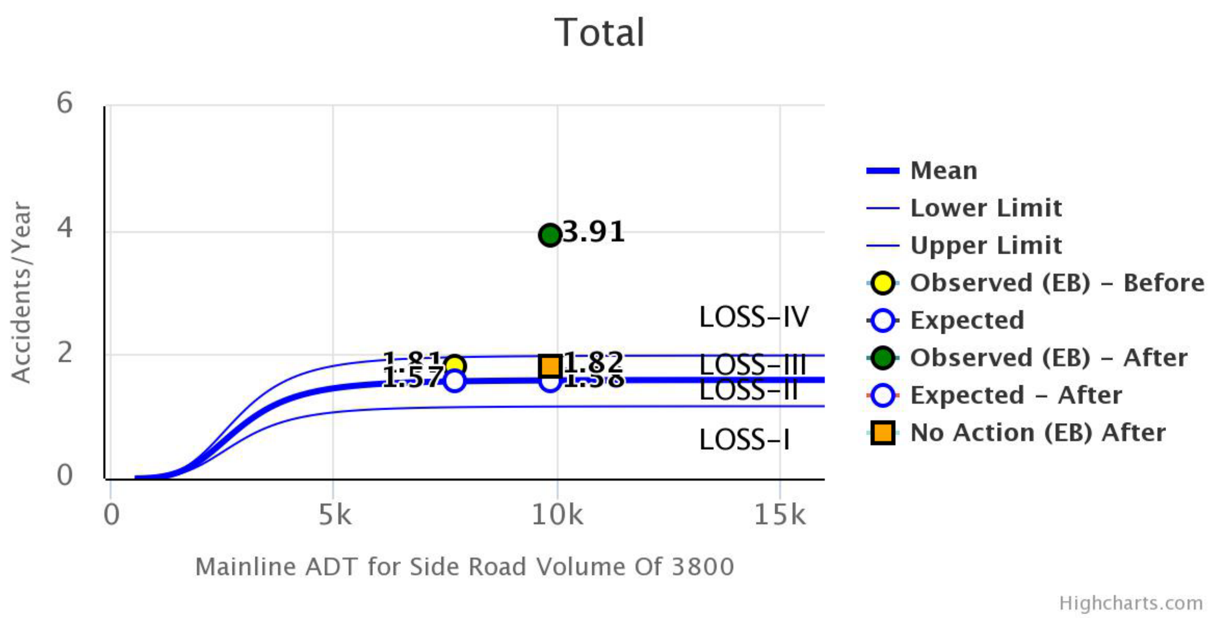


Figure 2. SPF For Severe Crashes

Rural 2-Lane Divided Unsignalized 4-Leg Intersections (2018)

Before: 2010–2012 After: 2015–2017

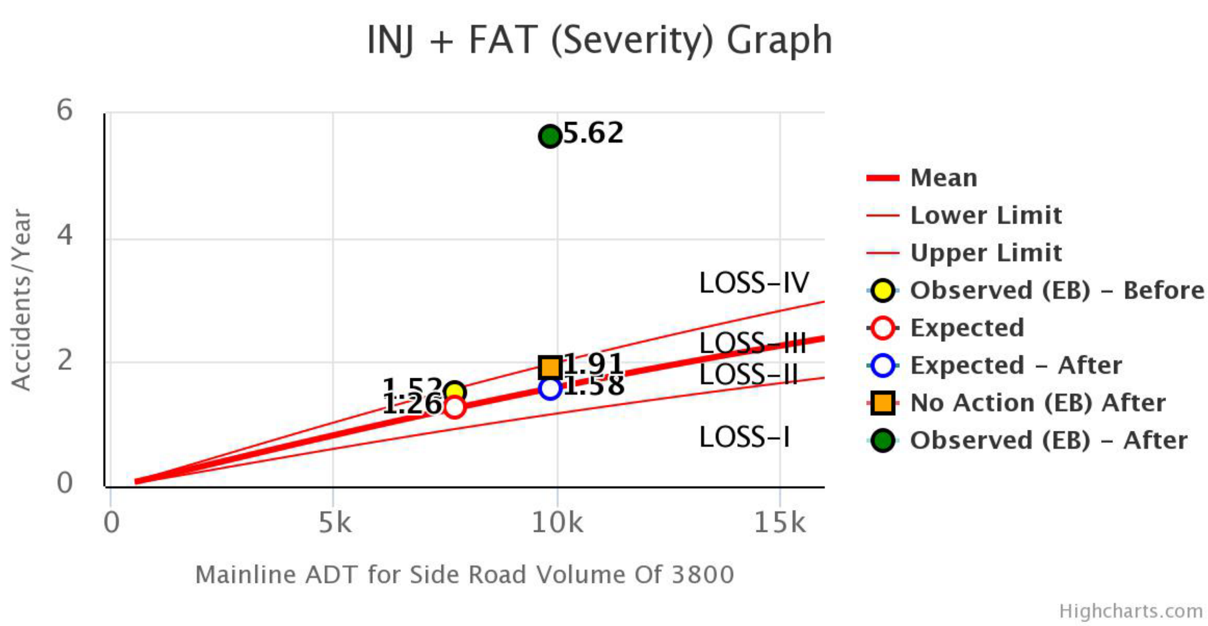


Table 2 provides a summary of the crashes per year (CPY) for the study intersection along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural 2-Lane Divided Unsignalized 4-leg Intersection (2018)		
Total Crashes			
LOSS	LOSS III	LOSS IV	LOSS III
CPY	1.81	3.91	1.82
Expected CPY	1.57	1.58	1.58
Proportion of Mean	1.15	2.47	1.15
Severe (Injury & Fatal) Crashes			
LOSS	LOSS III	LOSS IV	LOSS III
CPY	1.52	5.62	1.91
Expected CPY	1.26	1.58	1.58
Proportion of Mean	1.21	3.56	1.21

Crash Type Analyses

A detailed review of the before/after crash record shows the intersection related crash types that were most affected by the roadway improvements. **Table 3** shows a comparison of the total, fatal, and injury crashes.

Table 3. Results of Crash Analyses

	Before	After	No Action (EB) After
Time Period	01/01/2010 – 12/31/2012 (3 yr)	01/01/2015 – 12/31/2017 (3 yr)	01/01/2015 – 12/31/2017 (3 yr)
Total Crashes	**7**	**27**	**8**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	5 (7)	27 (41)	6(9)
PDO	2	5	2
Broadside	**6**	**19**	**7**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	4 (5)	17 (34)	5 (7)
PDO	2	2	2
Approach Turn	**0**	**5**	**0**
Fatal (Fatalities)	0 (0)	0 (0)	0 (0)
Injury (Injuries)	0 (0)	3 (4)	0 (0)
PDO	0	2	0
% Reduction in Total (Fatal/Injury/PDO)	--	0% / -356% / -150%	--

The crash pattern in the after period suggests that most of the broadside crashes occur involving eastbound and southbound vehicles. Involvement of southbound vehicles as the secondary vehicles is a pattern that is consistent in both periods suggesting that issues such as sight distance and placement of the eastbound stop bar might be contributing factors.

Approach Turn crashes in the after period involve mostly northbound vehicles (three of five crashes) and is also likely influenced by the negatively offset left turn bay and sight distance.

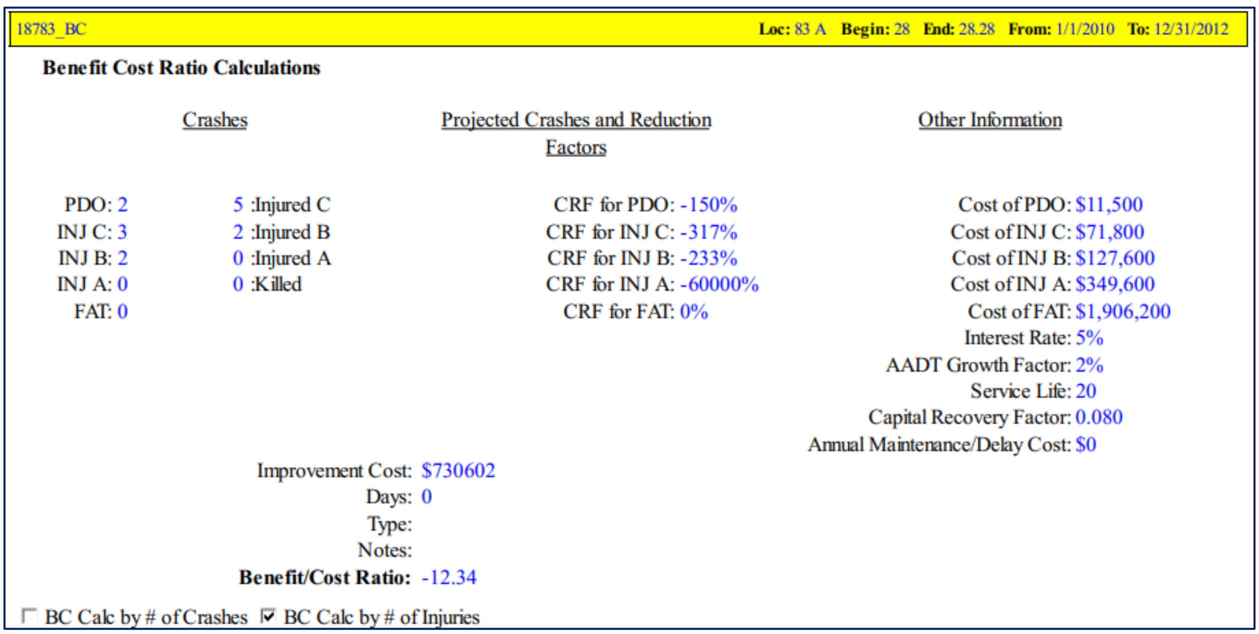
Upon inspection of approach slopes of both roadways in Google Earth it is evident that the approach slopes are greater than 10% on both roadways: downgrade on SH 83 and upgrade on Hwy 105.

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of –12.34 was ultimately realized** and is largely attributed to significant increases in all crash types.

Following implementation of a signal crash data suggests an increase in the targeted crashes. The Resulting B/C analysis would also suggest an ineffective safety project.

Figure 3. Benefit-Cost Analysis Summary



18783_BC **Loc:** 83 A **Begin:** 28 **End:** 28.28 **From:** 1/1/2010 **To:** 12/31/2012

Benefit Cost Ratio Calculations

Crashes		Projected Crashes and Reduction Factors	Other Information
PDO: 2	5 :Injured C	CRF for PDO: -150%	Cost of PDO: $11,500
INJ C: 3	2 :Injured B	CRF for INJ C: -317%	Cost of INJ C: $71,800
INJ B: 2	0 :Injured A	CRF for INJ B: -233%	Cost of INJ B: $127,600
INJ A: 0	0 :Killed	CRF for INJ A: -60000%	Cost of INJ A: $349,600
FAT: 0		CRF for FAT: 0%	Cost of FAT: $1,906,200
			Interest Rate: 5%
			AADT Growth Factor: 2%
			Service Life: 20
			Capital Recovery Factor: 0.080
			Annual Maintenance/Delay Cost: $0

Improvement Cost: $730602
Days: 0
Type:
Notes:
Benefit/Cost Ratio: -12.34

☐ BC Calc by # of Crashes ☑ BC Calc by # of Injuries

Project Information

Project Name: SH 66 & WCR 1 Intersection Improvements

Project Description: Added eastbound right turn lane, northbound and southbound left and right turn lanes, and signal upgrades

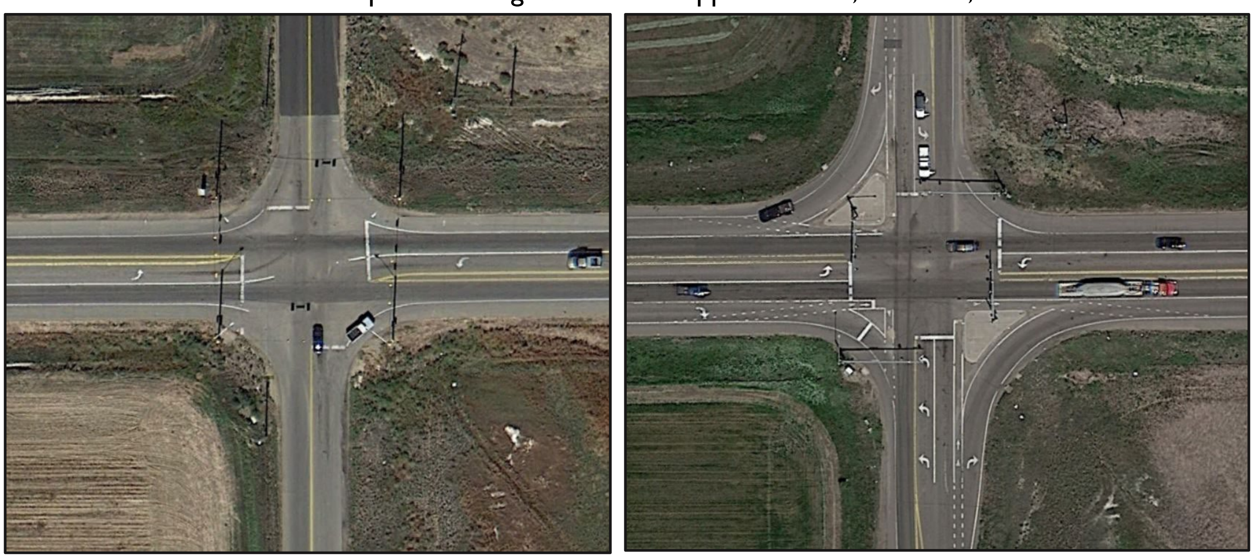
CDOT Region:	4	Project Def:	18787	County:	Boulder & Weld
Location:	SH 66 & WCR 1	Mile Points:	38.82 - 39.02	Length:	N/A
Schedule:		Work Start Date:	2013	Work End Date:	2015

Problem Description:

No problem description was provided for the original HSIP funding application for the intersection improvement project. However, crash data analysis shows overrepresentation of Injury, Approach Turn and Broadside crashes.

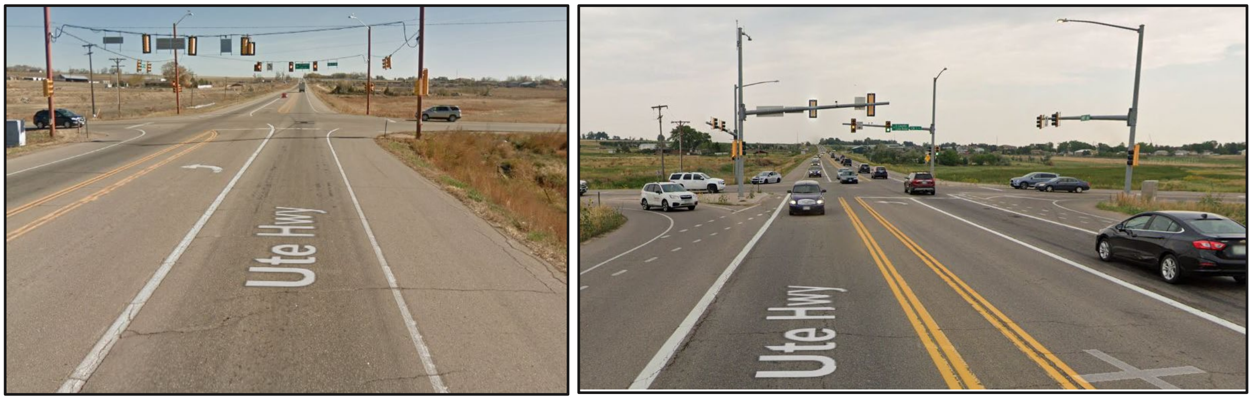
Improvement Description:

The project area is the intersection of State Highway (SH) 66 with WCR 1 in Boulder & Weld Counties, Colorado. This intersection experiences high volumes of approach turn, rear end, and broadside crashes.



SH 66 & WCR 1 – before (left) and after (right) improvements

The project involved adding left turn lanes on SH 66 in Weld County, Colorado. The cost of construction was $2,332,671.12.



SH 66 – Facing East – Before (left) and After (right) improvements

WCR 1 – Facing North – Before (left) and After (right) Improvements

Summary & Findings

The analysis of safety conditions before and after improvements at the intersection of SH 66 with WCR 1 show a significant increase in the total number and severity of crashes. A comparison of approach turn, and broadside crash types before and after the improvements were made showed that there was an increase in affected crashes. The total number of crashes increased from 31 to 71, and Injuries + Fatalities (severe crashes) increased from 14 to 38. The number injuries increased from 20 to 56. The AADT increased by approximately 43% in the after period on SH 66.

Before (2008-2012) & After (2015-2019) Crash Summary

Crashes

	PDO	Injury	Fatal	Inj+Fat	Total
Before:	17	13	1	14	31
After:	33	37	1	38	71
Difference:	16	24	0	24	40

Injuries and Fatalities

	Injured (Poss/Minor)	Injured (Moderate)	Injured (Incapacitating)	Total Injured	Killed
Before:	8	4	1	20	1
After:	22	11	4	56	1
Difference:	14	7	3	36	0

The ratio of benefits of crash reduction to the cost of construction over the life cycle of 20 years for this project was -3.29:1. The result is an improvement that was not justified based on safety improvement and cost effectiveness.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records at the intersection of SH 66 with WCR 1 shows an approximate 129% increase in the number of crashes from the five-year before period (2008-2012) to the five-year after period (2015-2019). The number of severe (fatal and injury) crashes increased by approximately 171%.

- Before Period: 14 severe crashes, 20 injured
- After Period: 38 severe crashes, 56 injured

The crash rate for all crashes at this intersection increased between the before period and after period:

- Before Period: 7.63 crashes per million vehicle miles traveled
- After Period: 10.24 crashes per million vehicle miles traveled

Table 1. Results of Overall Crash Analyses

		Before	After
Time Period:		01/01/2008 – 12/31/2012 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)
AADT	SH 66	13,319	19,077
	WCR 1	5,237	7,483
Crash Filters:		Intersection Related	
Total Crashes:		**31**	**71**
Fatal Crashes (Fatalities):		1 (1)	1 (1)
Injury Crashes (Injuries):		13 (20)	37 (56)
PDO Crashes:		17	33

Safety Performance Functions

SPF plots for both total crashes (**Figure 1**) and for severe (injury and fatal) crashes (**Figure 2**) for the intersection of SH 66 & WCR 1 reflect an increase in the crash record for this project. The intersection is LOSS IV for total and severe frequency of crashes in the before and after period.

It should be noted that SPF methodology is usually applied to segments that are a minimum of one mile in length and the crashes per mile per year for the study segment is likely inaccurate for an intersection.

Figure 1. SPF For Total Crashes

Before: 2008–2012 After: 2015–2019

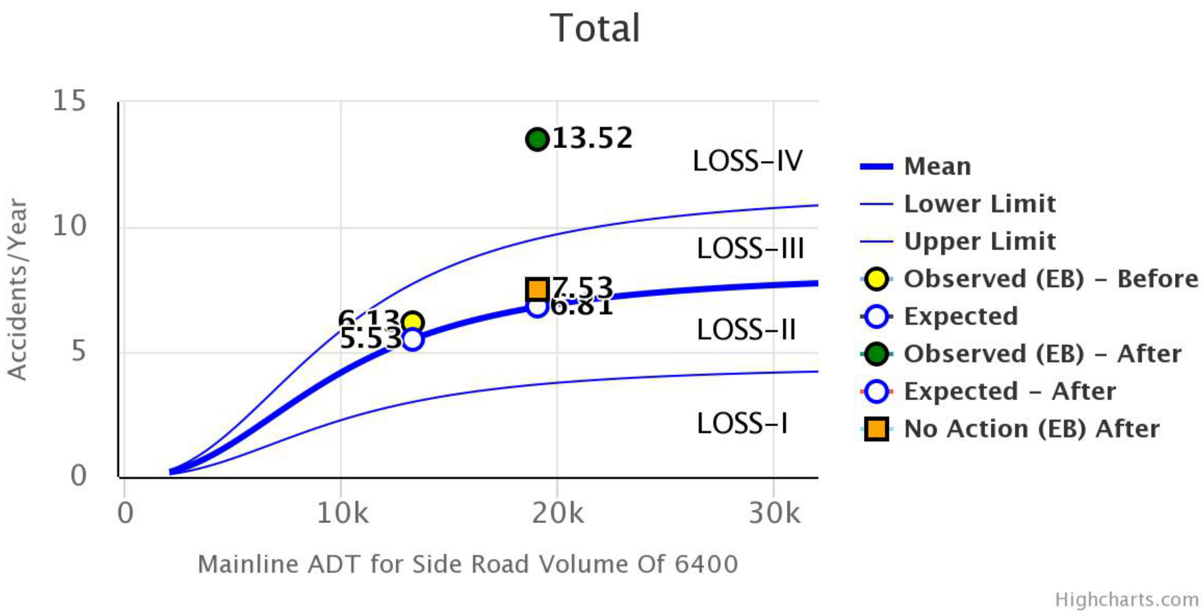


Figure 2. SPF For Severe Crashes

Before: 2008–2012 After: 2015–2019

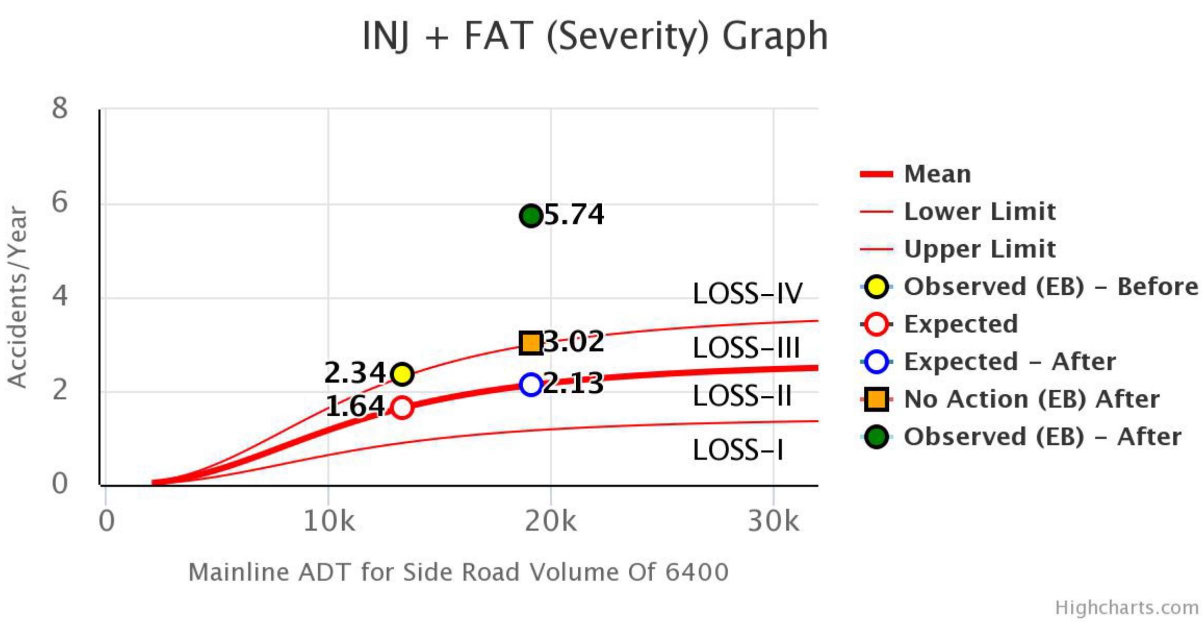


Table 2 provides a summary of the crashes per year (CPY) for the study intersection along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Urban 2-Lane Divided Signalized 4-Leg Intersection		
Total Crashes			
LOSS	LOSS III	LOSS IV	LOSS III
CPY	6.13	13.52	7.53
Expected CPY	5.53	6.81	6.81
Proportion of Mean	1.11	1.99	1.11
Severe (Injury & Fatal) Crashes			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPY	2.34	5.74	3.02
Expected CPY	1.64	2.13	2.13
Proportion of Mean	1.43	2.69	1.42

Crash Type Analyses

A more detailed review of the before and after crash record shows the approach turn, rear end, and broadside crash types that were most affected by the roadway improvements. **Table 3** shows a comparison of the total, fatal, and injury crashes.

The No-Build After crashes were estimated using the change in traffic volumes on SH 66 between the before and after period, as found in **Table 1** (approximately 43% increase).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2008 – 12/31/2012 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)
Total Crashes	**31**	**71**	**39**
Fatal (Fatalities)	1 (1)	1 (1)	1 (1)
Injury (Injuries)	13 (20)	37 (56)	17 (26)
PDO	17	33	21
Approach Turn, Broadside	**17**	**21**	**21**
Fatal (Fatalities)	1 (1)	1 (1)	1 (1)
Injury (Injuries)	9 (16)	6 (20)	11 (20)
PDO	7	14	9
% Reduction in Total (Fatalities/Injuries/PDO)	--	0% / -117% / -57%	--

The before period shows Injury, Approach Turn, Broadside, Human Factor (inexperience) as being overrepresented. The after period doesn't show Approach Turn or Broadside crashes as overrepresented as was the case in the before period. Other overrepresented categories in the after period were Injury, Human Factor (inexperience), Lighting (Dark-Unlighted) and Weather (Rain).

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes at the intersection. **A calculated B/C ratio of -3.29 was ultimately realized** and is largely attributed to significant increase in number of total and severe crashes. This outcome displays that this safety improvement project was not justified.

Following the addition of an eastbound right turn lane, northbound and southbound left and right turn lanes, and signal upgrades, crash data suggests an increase in the targeted crashes. The resulting B/C analysis would also suggest an ineffective safety project.

Figure 3. Benefit-Cost Analysis Summary

18787_BC **Loc:** 66 B **Begin:** 38.82 **End:** 39.02 **From:** 1/1/2008 **To:** 12/31/2012

Benefit Cost Ratio Calculations

Crashes		Projected Crashes and Reduction Factors	Other Information
PDO: 17	11 :Injured C	CRF for PDO: -57%	Cost of PDO: $11,500
INJ C: 8	7 :Injured B	CRF for INJ C: -171%	Cost of INJ C: $71,800
INJ B: 4	2 :Injured A	CRF for INJ B: -44%	Cost of INJ B: $127,600
INJ A: 1	1 :Killed	CRF for INJ A: -93%	Cost of INJ A: $349,600
FAT: 1		CRF for FAT: 0%	Cost of FAT: $1,906,200
			Interest Rate: 5%
			AADT Growth Factor: 2%
			Service Life: 20
			Capital Recovery Factor: 0.080
			Annual Maintenance/Delay Cost: $0

Improvement Cost: $2332671.12
Days: 0
Type:
Notes:
Benefit/Cost Ratio: -3.29

☐ BC Calc by # of Crashes ☑ BC Calc by # of Injuries

Project Information

Project Name: I-70 MP 87.0 - 110.0 Wild Animal Fencing

Project Description: Wild Animal Fencing

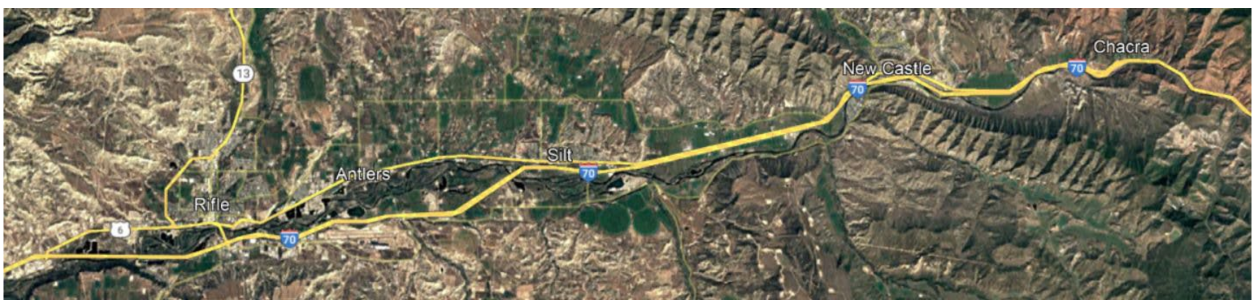
CDOT Region:	3	Project Def:	18841	County:	Garfield
Location:	I-70A	Mile Points:	87.0 – 110.0	Length:	23 Miles
Schedule:		Work Start Date:	2015	Work End Date:	2014

Problem Description:

No problem description was provided for the original HSIP funding application. However, Wildlife crashes were overrepresented in the before period.

Improvement Description:

The project area includes the segment of Interstate (I-) 70 between Mile Points (MP) 87.0 and 110.0 in Garfield County, Colorado. This segment had a high number of wild animal crashes.



I-70 in Garfield County, Colorado

The project involved installing wildlife fencing. The cost of construction was $3,372,017.

I-70 – Southbound – Before (Left) and After (right) improvements

Summary & Findings

The analysis of safety conditions before and after improvements along I-70 shows a significant decrease in the total number of crashes. A comparison of wild animal crash types before and after the improvements were made showed that there was a decrease in total wild animal crashes.

The total number of crashes reduced from 304 to 62 and Injuries + Fatalities (severe crashes) decreased from 27 to 7. The number of injuries decreased from 31 to 12; however, the number of fatalities increased from 0 to 3. The AADT increased by approximately 23% in the after period.

The ratio of benefits of Wild Animal crash reduction to the cost of construction over the life cycle of 15 years for this project was 0.59:1. The result is an improvement that was justified from the safety improvement and cost effectiveness standpoints.

Methodology

Before-After safety conditions were evaluated for the project based on three main criteria: magnitude of safety problems, severity of safety problems, and presence of crash patterns.

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 the aggregate frequency and severity standpoints.

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected frequency and severity. Mean frequency and severity of crashes predicted by the SPF represent a normal or expected number of crashes at a specific level of ADT, and the degree of deviation from the normal can is stratified to represent four 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 or severity at a specific level of ADT.

Study intersections were examined for presence of crash patterns susceptible to correction using diagnostic analyses to compare with similar intersections in Colorado. This analysis uses normative percentages to identify cumulative binomial probability of observing specific crash attributes.

Results of Safety Analyses – I-70

Overall Crash Analyses

Using Vision Zero Suite, the review of before and after crash records along I-70 in the project area shows an approximate 80% decrease in the total number of crashes from the five-year before period (2008-2012) to the five-year after period (2015-2019). The number of severe (fatal and injury) crashes decreased by 74%.

- Before Period: 27 severe crashes, 31 injured, 0 killed
- After Period: 7 severe crashes, 12 injured, 3 killed

The crash rate for all crashes along this corridor decreased by 54% between the before period and after period.

- Before Period: 1.07 crashes per million vehicle miles traveled
- After Period: 0.49 crashes per million vehicle miles traveled

Table 1. Crash Analyses – I-70

		Before	After
Time Period:		01/01/2008 – 12/31/2012 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)
AADT	I-70	20,500	25,120
Total Crashes:		**856**	**499**
Fatal Crashes (Fatalities):		9 (10)	16 (21)
Injury Crashes (Injuries):		190 (261)	140 (211)
PDO Crashes:		657	343
Wild Animal Crashes:		**300**	**62**
Fatal Crashes (Fatalities):		0 (0)	1 (3)
Injury Crashes (Injuries):		27 (31)	6 (12)
PDO Crashes:		273	55

Safety Performance Functions

SPF plots for total crashes (**Figure 1**) show a decrease in the crash record for this project. Severe (injury and fatal) crashes (**Figure 2**) for I-70 in the project area reflect a decrease in the crash record. The intersection is LOSS I for both total frequency of crashes and severe frequency of crashes in both the before and after periods.

Figure 1. SPF For Total Crashes

Before: 2008–2012 After: 2015–2019

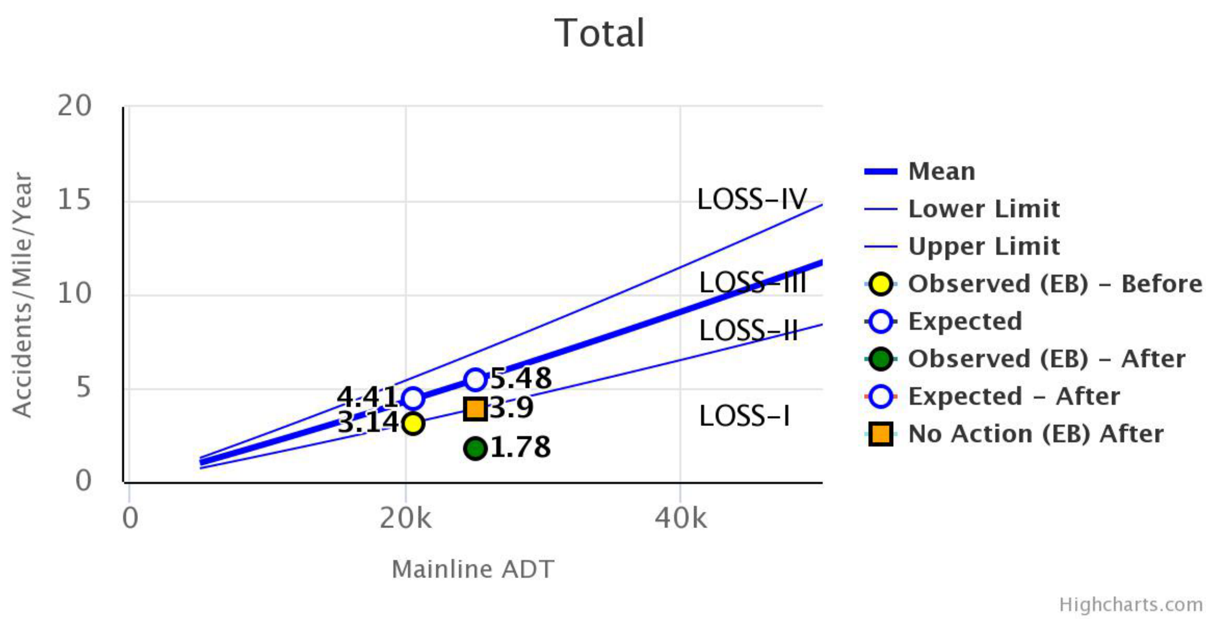


Figure 2. SPF For Severe Crashes

Before: 2008–2012 After: 2015–2019

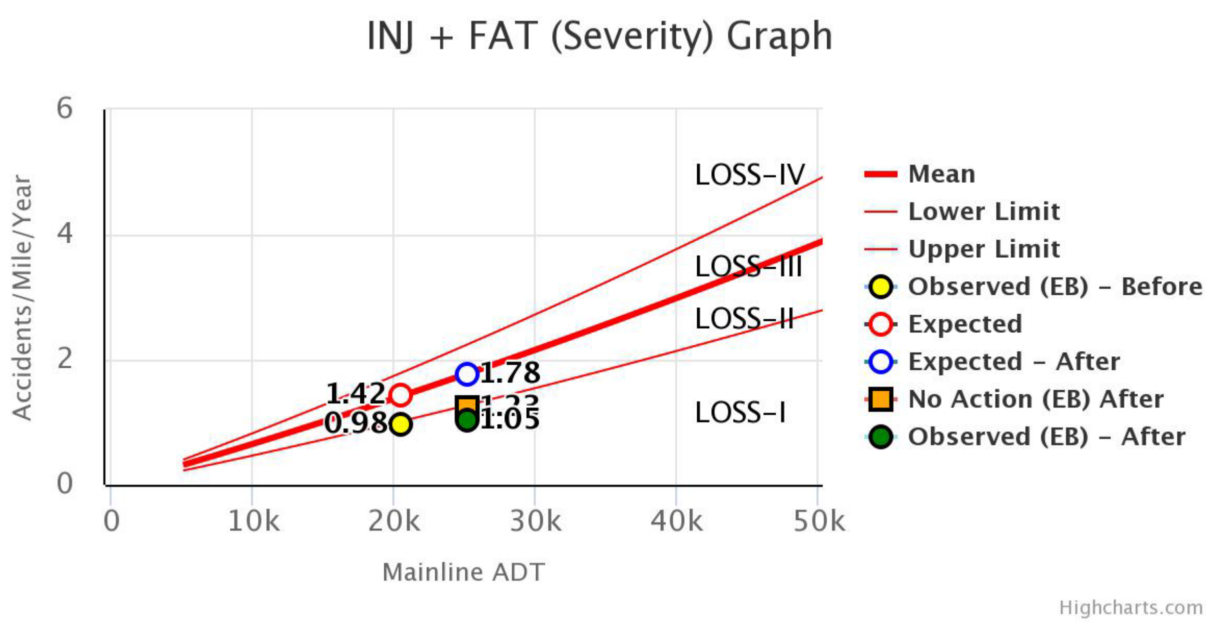


Table 2 provides a summary of the crashes per year per mile (CPYPM) for I-70 along with a comparison with the mean (expected) CPY for the before and after periods.

Table 2. Safety Performance Function (SPF) Summary

	Before	After	No Action After
EB Correction	Yes	Yes	Yes
SPF Graph	Rural Flat and Rolling 4-Lane Divided Highways (2016)		
Total Crashes			
LOSS	LOSS I	LOSS I	LOSS I
CPYPM	3.14	1.78	3.9
Expected CPYPM	4.41	5.48	5.48
Proportion of Mean	0.71	0.32	0.71
Severe (Injury & Fatal) Crashes			
LOSS	LOSS I	LOSS I	LOSS II
CPYPM	0.98	1.05	1.23
Expected CPYPM	1.42	1.78	1.78
Proportion of Mean	0.69	0.59	0.69

Crash Type Analyses

A more detailed review of the before and after crash record shows the wild animal crash types that were most affected by the roadway improvements. **Table 3** shows a comparison of the total, fatal and injury crashes.

The No-Build After crashes were estimated using the change in traffic volumes on I-70 between the before and after period, as found in **Table 1** (approximately 23% increase).

Table 3. Results of Crash Analyses

	Before	After	No Action After
Time Period	01/01/2008 – 12/31/2012 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)	01/01/2015 – 12/31/2019 (5 yr)
Wild Animal Crashes	**300**	**62**	**378**
Fatal (Fatalities)	0 (0)	1 (3)	0 (0)
Injury (Injuries)	27 (31)	6 (12)	34 (39)
PDO	273	55	344
% Reduction in Total (Fatal/Injury/PDO)	--	-300% / 69% / 84%	--

Benefit-Cost Analysis

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes along the segment. **A calculated B/C ratio of 0.59 was ultimately realized**. This outcome displays that this safety improvement project was justified. It should be noted that fatal crashes are often random occurrences and the significant decrease shown for both PDO and injury crashes suggests a very effective safety project.

Following implementation of wild animal fencing, crash data suggests a decrease in the targeted crashes.

Figure 3. Benefit-Cost Analysis Summary

18841_BC **Loc:** 70 A **Begin:** 87 **End:** 110 **From:** 1/1/2008 **To:** 12/31/2012

Benefit Cost Ratio Calculations

Crashes		Projected Crashes and Reduction Factors	Other Information
PDO: 273	10 :Injured C	CRF for PDO: 84%	Cost of PDO: $11,500
INJ C: 8	11 :Injured B	CRF for INJ C: 46%	Cost of INJ C: $71,800
INJ B: 9	10 :Injured A	CRF for INJ B: 100%	Cost of INJ B: $127,600
INJ A: 10	0 :Killed	CRF for INJ A: 62%	Cost of INJ A: $349,600
FAT: 0		CRF for FAT: -30000%	Cost of FAT: $1,906,200
			Interest Rate: 5%
			AADT Growth Factor: 2%
			Service Life: 15
			Capital Recovery Factor: 0.096
			Annual Maintenance/Delay Cost: $0

Improvement Cost: [illegible] 5 Years
Days: 0
Type:
Notes:
Benefit/Cost Ratio: 0.59

☐ BC Calc by # of Crashes ☑ BC Calc by # of Injuries