BEFORE/AFTER SAFETY ANALYSES II Revision 1

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INTRODUCTION

The purpose of this study was to continue past analysis efforts determining the effects of safety improvements on safety performance at locations chosen by the Colorado Department of Transportation (CDOT). This report discusses the 35 locations that were analyzed and the methodology used in the process. Previously, CDOT completed the analysis of 12 locations throughout the state in 2015

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

ANALYSIS AND RESULTS

The 35 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: guard rail, cable rail, concrete barrier, deer fencing, and a queue detection and warning system. Intersection improvements analyzed included: new signals, additional turn lanes, adding protected left-turn phasing, and signal upgrades such as larger signal heads and replacing old span-wire signals.

Table 1 shows 48 individual projects (one project in the 2015 report had two elements in the same vicinity) 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 expected benefit/cost (B/C) ratio, and the resulting B/C ratio. As shown, 29 of the projects had B/C ratios that were greater than anticipated at the time of application for funding. An additional seven of the projects had B/C ratios greater than 1.0, showing that the benefits were greater than the costs. The remaining 12 projects had B/C ratios less than 1.0, showing no improvement or a deterioration in safety performance in the after period. Thus, these projects may not have been justified. The following is a summary of the information in **Table 1**, and includes a brief discussion of the 9 projects that resulted in little or no improvement.

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

Table 1. Summary of Safety Analyses Locations

Def.	Region	Highway/Intersection	MP	Crash Type	Improvement Type	Initial Predicted B/C	Final Observed B/C
ROADWAY PROJECTS							
Median Barriers							
#15645[1]	6	SH 83A – Aurora	69.39 – 70.57	Off-Road Median	Concrete Median	2.11	5.91
#15748[1]	6	I-76A – Adams Co	1.77 – 5.78	Off-Road Median	Cable Rail	14.36	6.16
#15770[1]	2	I-25A – Pueblo Co	102.50 – 107.50	Off-Road Median	Median Cable Rail	2.65	2.26
#16495	6	I-76A – Commerce City	17.08 – 22.38	Off-Road Median	Cable Rail	1.78	1.03
#16563	1	I-70A – Clear Creek Co	221.2 – 224.7	Off-Road Median	Guard Rail	2.36	5.12
#16878	6	I-225A - Aurora SH 83A – Aurora	4.17 – 6.79 66.98 – 67.98	Off-Road Median	Cable Rail Concrete Barrier	2.11	20.55
#17202	4	I-76A – Weld Co	25.14 – 32.00	Off-Road Median	Cable Rail	7.29	1.01
					Range: 1.01 to 20.55	**Average**	**6.07**
Guard Rail							
#15771[1]	2	SH 165A – Pueblo Co	18.65 – 23.90	Off-Road	Guard Rail	4.97	12.67
#15900[1]	3	SH 133A – Pitkin Co	46.00 – 51.50	Off-Road	Guard Rail	4.89	21.54
#17025	2	US 50A – Fremont Co	271.00 – 275.00	Off-Road	Guard Rail	1.26	2.12
#17143	2	SH 115A – Fremont Co	3.80 – 6.80	Off-Road	Guard Rail	3.28	0.71
					Range: 0.71 to 21.54	**Average**	**9.26**
ITS Improvements							
#15828[1]	6	SH 93A – Jefferson Co	7.47 – 11.83	High Winds	Weather Related Road Closures System	1.17	1.42
#17014	1	I-70A – Clear Creek Co	215.35 – 229.00	Downhill Grade	Variable Speed Limit, Descent Speed Warning System	4.24	10.52
					Range: 1.42 to 10.52	**Average**	**5.97**

Def.	Region	Highway/Intersection	MP	Crash Type	Improvement Type	Initial Predicted B/C	Final Observed B/C
Median Improvements							
#16420	3	US 50A – Pueblo	312.89 – 313.83	Broadside	Install Median, Extend Turn Lanes	1.54	4.06
Wildlife Protection							
#15505[1]	5	US 550B – Ouray Co	107.00 – 111.00	Wild Animal	Cattle Guards	1.81	0.24
#15901	3	SH 82A	7.0 – 11.0	Wild Animal	Deer Fence	1.27	5.25
					Range: 0.24 to 5.25	**Average**	**2.74**
INTERSECTION PROJECTS							
Install Signals							
#16010[1]	2	Industrial / Purcell – Pueblo	n/a	Broadside	New Signal	1.12	0.00
#16380	4	US 287 / 19th St – Larimer Co	331.65	Broadside	Install Signal	1.66	15.12
#16595	4	SH 50A / 28.5 Rd – Mesa Co	35.38	Broadside	Install Signal, Dilemma Zone Preemption	1.23	23.89
#16601	6	SH 7D / County Line Rd – Erie	64.14	Intersection	Install Signal, Geometric Improvements	2.06	0.17
#16762	4	SH 14C / I-25 East Frontage Rd – Ft. Collins	139.21	Broadside	Install Signal	1.14	0.44
#16804	3	I-70B – Grand Junction	0.40 – 1.30	Intersection	Install Signal, Geometric Improvements	1.65	5.63
#16814	3	I-70B / Peachtree – Grand Junction	11.72 – 12.17	Broadside	Install Signal, Consolidate Access	1.88	12.44
#17115	4	SH 402A / CR 11 – Loveland	1.00	Rear-End	Install Signal, Geometric Improvements	1.19	0.81
					Range: 0.00 to 23.89	**Average**	**7.31**

Def.	Region	Highway/Intersection	MP	Crash Type	Improvement Type	Initial Predicted B/C	Final Observed B/C
Signal Upgrades							
#15828[1]	6	SH 93A / SH 72A – Jefferson Co	7.57	Broadside, Rear-end, Approach Turn	New Signal, Protected Left Turns	1.72	14.93
#15862[1]	4	US 34A / 11th Avenue – Weld Co	112.23	Rear-End	Modernize to Current Standards	2.03	9.69
#16313	6	US 40C / Youngfield St – Lakewood	289.38	Rear-End, Broadside	Upgrade Signal, Left-Turn Phasing, Geometric Improvements	1.18	3.33
#16314	6	SH 391A / 20th St US 40C / Newland St – both Lakewood	6.77 293.38	Broadside, Approach Turn	Upgrade Signals, Left-Turn Phasing	2.47 1.70	12.04
#16498	4	US 287C / 37th St - Loveland	335.75	Rear-End, Approach Turn	Signal Upgrade, Geometric Improvements	2.69	0.57
#16600	6	US 285D / Brady Ct – Englewood	258.69	Rear-End, Broadside	Upgrade Signal	1.98	7.26
#16625	4	US 287C / Swallow Rd US 287C / Rutgers Ln – both Fort Collins	343.72 344.67	Rear-end Approach Turn, Pedestrian, SS Same	Geometric Improvements, Upgrade Signal, Pedestrian Improvement	4.63 1.09	1.14
#16642	6	US 285D – Denver	257.69 – 258.06	Rear-End, Sideswipe Same Dir	Queue Detection System, Blank-out Warning Sign	2.17	6.29
#16941	6	SH 121A / Chatfield Ave – Jefferson Co	1.22	Broadside	Signal Upgrade, Dilemma Zone Preemption	1.24	4.35
#16957	6	US 285D / Sherman St – Englewood	260.30	Approach Turns	Signal Upgrades, Left Turn Phasing	1.42	2.34
#17034	3	US 550B / Niagara Rd – Montrose	128.24	Intersection	Signal Upgrade, Geometric Improvements	1.55	1.30
					Range: 0.57 to 14.93	**Average**	**5.75**

Def.	Region	Highway/Intersection	MP	Crash Type	Improvement Type	Initial Predicted B/C	Final Observed B/C
Geometric Improvements							
#14963	6	Kipling St / 58th Ave – Arvada	n/a	Intersection Sight Distance	Geometric Improvements, Dual Left-Turn Lanes	2.50	6.41
#15861[1]	4	SH 52 / 95th Street – Boulder Co	3.16	Broadside, Approach Turn,	Left-Turn Lanes, Protected Left Turns	2.52	13.37
#15873	3	SH 82A / Smith Way – Pitkin Co	34.48	Broadside	Intersection Improvements, Acceleration Lane	1.06	0.05
#16005[1]	2	US 50A / Purcell Blvd - Pueblo	309.78	Broadside, Approach Turn,	Second Through Lanes, Dual Left-Turn Lanes	1.77	4.00
#16006[1]	2	SH 45A / Red Creek Springs – Pueblo	3.95	Rear-End	Right-Turn Lanes	1.18	0.08
#16011	6	El Paso St / Fillmore St – Colorado Springs	n/a	Broadside, Approach Turn, Rear-End, Sideswipe Same Dir, Pedestrian	Geometric Improvements, Pedestrian Improvements	1.31	0.00
#16623	4	SH 392B / WCR 31 – Weld Co	11.54	Rear-End	Construct Left-Turn Lane	1.44	9.02
#17015	4	US 287C / LCR 21C – Larimer Co	352.35	Broadside	Geometric Improvements	1.86	2.75
#17016	4	SH 392A / LCR 9 – Larimer Co	98.50	Rear-End	Construct Left-Turn Lane	1.42	0.42
#17116	4	SH 119A / Hover St – Longmont	54.41	Rear-End, Sideswipe Same Dir	Left-Turn Lane Extension, Acceleration Lane	0.76	15.77
					Range: 0.00 to 15.77	**Average**	**5.19**

Def.	Region	Highway/Intersection	MP	Crash Type	Improvement Type	Initial Predicted B/C	Final Observed B/C
Roundabout							
#15367	4	US 6D / 9th St – Silt	99.24	Broadside	Roundabout	1.53	0.67
#16730	3	23 Rd / G Rd – Grand Junction	n/a	Injury, Fatal	Roundabout	2.54	15.36
#17249	1	I-76A / 96th Ave Interchange – Commerce City	11.450 – 11.65	Intersection	Roundabouts	1.78	1.60
					Range: 0.67 to 15.36	**Average**	**5.94**

[1] Project descriptions can be found in the 2015 report

ROADWAY PROJECTS

Median Barriers – All seven barrier improvements (guard rail, cable rail, and concrete barrier) had B/C ratios greater than one, ranging from 1.01 to 20.55. Only three of the projects exceeded their predicted B/C ratio. Two projects barely exceeded a B/C ratio of 1.0 (#16495 for 1.03 and #17202 for 1.01).

Guard Rail – Three of the four projects where guard rail was installed along two lane highways resulted in B/C ratios that exceeded their predicted ratio, ranging from 2.12 to 21.54. The success of most of these barrier installation projects indicates that these are excellent safety improvements when crash data indicates there is a run-off-the-road pattern. The primary goal of these roadway barriers is to reduce the risk of severe crashes that can occur when a vehicle leaves the roadway. The barrier helps to reduce severe crash types such as overturning and fixed object (such as trees, embankments, etc.) crashes.

> **#17143** – This project along SH 115 had a B/C ratio of 0.71. There was a large number of guard rail crashes in the after period that was not offset by a reduction in other fixed object crashes. It is unclear why crashes increased on SH 115 after guard rail was installed.

ITS Improvements – There were two projects that added Intelligent Transportation Systems (ITS) devices along an existing roadway. The SH 93A project (#15828) in Jefferson County added weather detection, road closures systems, and variable message signs due to the windy, snowy, and/or icy conditions that often exist across Rocky Flats. The resulting B/C ratio for this project was 1.42. The I-70A project was intended to install downhill variable speed limits and speed warning signs east of the Eisenhower-Johnson Tunnel (#17014). The predicted B/C ratio was 0.28 and the resulting ratio was 10.52. However, only phase one of two phases was completed and the variable speed limit signs and ITS hardware was never installed. Therefore, it is difficult to determine if the crash reduction was the result of this project. The safety improvement may have been attributed to the combined effort of CSP and CDOT to improve traffic operations and safety during adverse weather conditions and has contributed to moderate crash reduction under icy and snowy conditions.

Median Improvements – There was one project that involved installing a median, which was on SH 50A. This project had a resulting B/C ratio of 4.06, which was better than predicted.

Wildlife Protection – Two wildlife protection projects were analyzed. The wildlife fencing project along SH 82A between Glenwood Springs and Carbondale (#15901) resulted in a positive B/C ratio of 5.25. The other project (#15505) along SH 550B north of Ridgway had a B/C ratio of 0.24.

> **#15505** – Double cattle guards were added on US 550 at the main entrance to Ridgway State Park. The number of wild animal crashes was reduced following construction as would be expected. However, crashes were more severe in the after period causing the B/C ratio to be below one.

INTERSECTION PROJECTS

Install New Signals – Of the eight projects that included signalizing an intersection, only four had B/C ratios greater than one, indicating that signalizing an intersection may not always be justifiable from a safety perspective. The four that had a positive outcome had a noticeable reduction in broadside crashes that outweighed the increase in rear-end crashes. At the other intersections, the reduction in broadside and approach turn crashes was offset by an increase in rear-end crashes.

> **#16010** – New signal at Industrial and Purcell. The number of broadside crashes decreased after the signal was constructed, but several other crash types saw an increase in number of crashes including approach turns, rear-ends, and sideswipes. In addition, the severity of crashes increased. The signal was warranted, but the results suggest that an intersection with volumes that just meet warrants might have a better safety outcome with a roundabout.
>
> **#16601** – Geometric improvements and signal installation at the intersection of SH 7 with County Line Road. The installation of the signal successfully reduced broadside injury crashes. However, there was a large increase in rear-end injury crashes in the after period.
>
> **#16762** – Signal installation at the intersection of SH 14 with the I-25 east frontage road. This project successfully reduced the number of injury broadside crashes from seven injury crashes in the before period to no injury crashes in the after period. However, as is typical with signals, the number of rear-ends increased. This increase in rear-ends offset the decrease in broadsides resulting in no overall benefit from the improvement.
>
> **#17115** – Signal installation at the intersection of SH 402 with CR 11. There was a large reduction in total crashes with this project with 33 crashes in the before period and 10 crashes in the after period. However, the number of injuries did not change significantly, so the overall benefits were not enough to offset the cost of the project

Upgrade Existing Signals – Of the eleven intersection projects that included upgrading the signals (such as replacing signal heads, installing new signal poles, etc., usually with geometric or phasing improvements), ten had B/C ratios greater than one, ranging from 1.14 to 14.93. The project (#16625) that had a B/C ratio of 1.14 did not exceed its predicted ratio. The one project that did not have a positive result was #16498.

> **#16498** – Signal upgrade and geometric improvements at the intersection of US 287 and 37th Street. There was almost no change in the overall number of crashes or the number of injury crashes after this improvement.

Geometric Improvements – Six of the ten geometric improvements had positive results with B/C ratios ranging from 2.75 to 15.77. These improvements included fixing geometry so split phasing is not required, adding turn lanes, and adding channelization and protected left-turn phasing, all of which might have involved some changes to signal configurations. Four projects did not have positive outcomes with B/C ratios ranging from 0.00 to 0.42.

#15873 – Intersection improvements and an acceleration lane at SH 82 and Smith Way. The number of crashes decreased in the after period, but the number of injury crashes remained the same and the number of injuries increased. While the increase in injuries impacted the B/C ratio, it should be noted that the number of people injured is subject to chance.

#16006 - Intersection improvements at SH 45 and Red Creek Springs. The number of crashes in the before and after period were approximately the same, but the severity of crashes increased in the after period. It is unclear why the severity of crashes increased following this improvement project.

#16011 – Geometric improvements were made to correct an offset in the intersection of El Paso Street / Fillmore Street in addition to pedestrian crossing improvements. The number of approach turn crashes decreased after the improvements, but there was an increase in broadside crashes. Overall, there was no decrease in crashes at the intersection.

#17016 – Left-turn lane construction at the intersection of SH 392 with LCR 9. There was a reduction of crashes as a result of this improvement. However, there was no reduction in injury crashes and a slight increase in injuries in the after period. It should be noted that the number of people injured is subject to chance.

Roundabouts **–** There were three roundabout construction projects. Of these, two had a B/C ratio greater than one, although one did not exceed its predicted ratio. The one (#15367) that did not have a ratio greater than one had a B/C ratio of 0.67

#15367 – Roundabout construction on SH 6 at the intersection with 9th Street. The number of broadside crashes was reduced following construction as were the overall intersection crashes. However, the crash reduction was not enough to offset the cost of construction.

SUMMARY AND RECOMMENDATIONS

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

APPENDIX A. STATEWIDE METHODOLOGY

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

By

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.

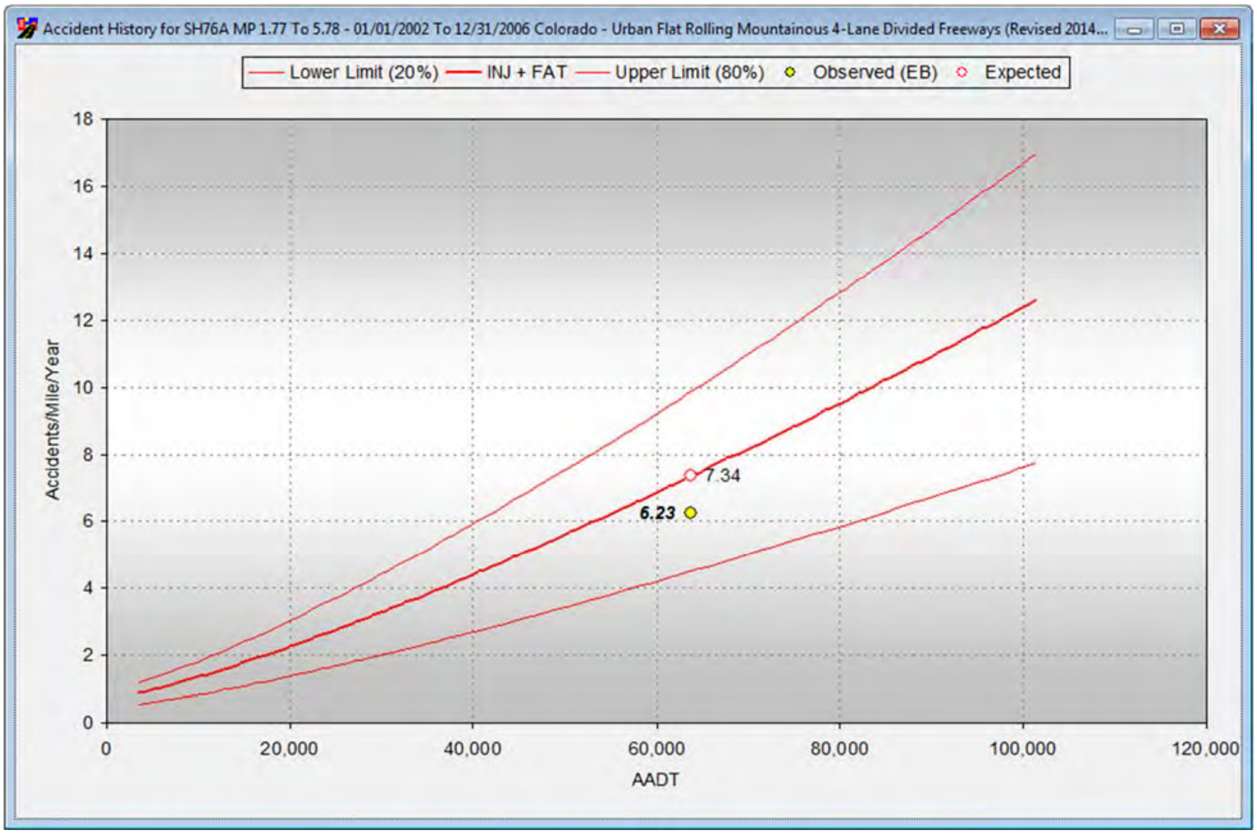


Figure 1 EB Corrected SPF Inj+Fat - I-76 (MP 1.77 to MP 5.78) (Before Period - 1/1/2002-12/31/2006)

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.

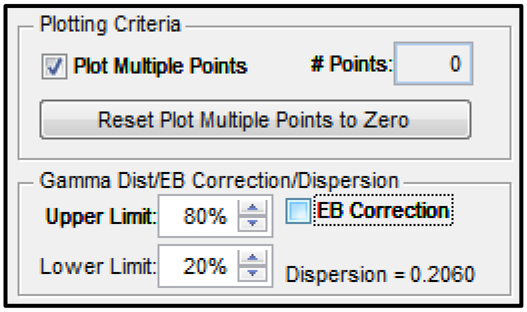


Figure 2 EB Correction Turned Off

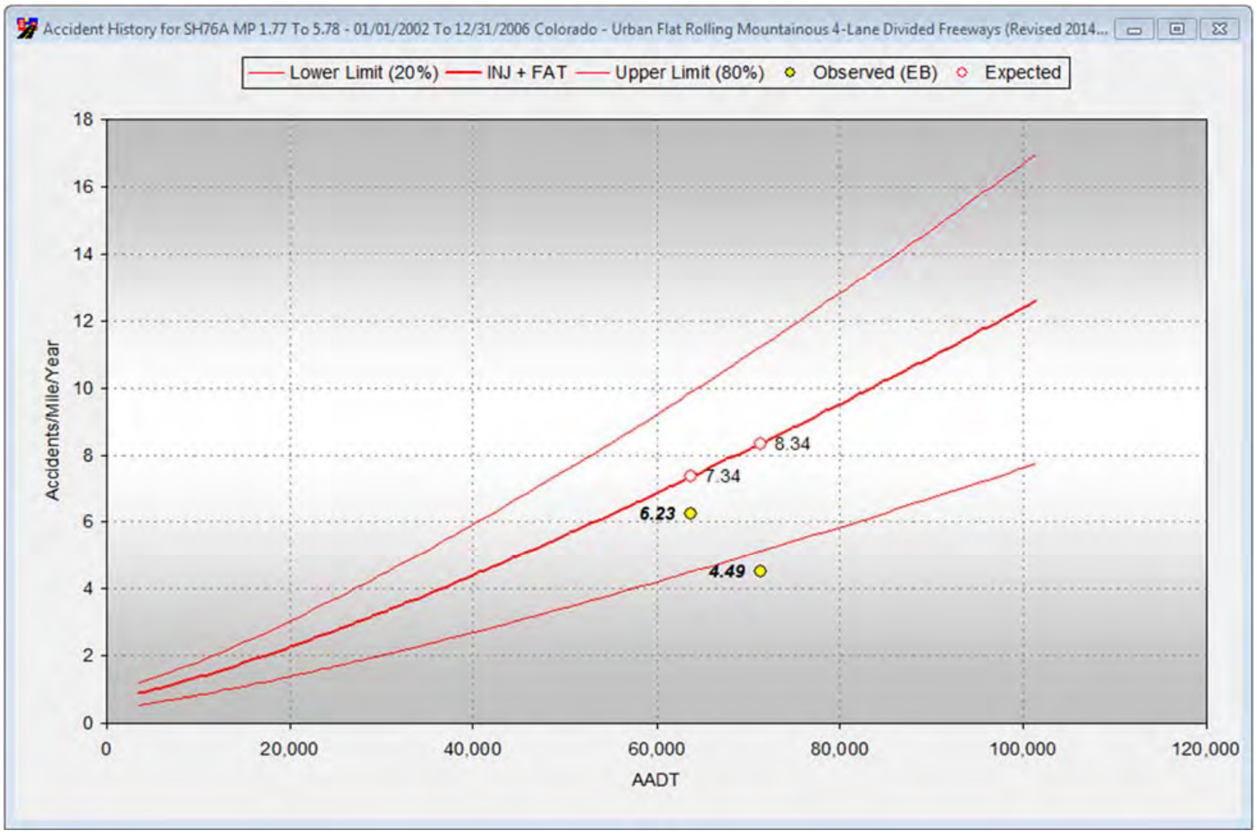


Figure 3 SPF Inj+Fat - I-76 (MP 1.77 to MP 5.78)
(EB Corrected Before Period- 1/1/2002-12/31/2006) and
(After Period - 1/1/2008-12/31/2012)

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)

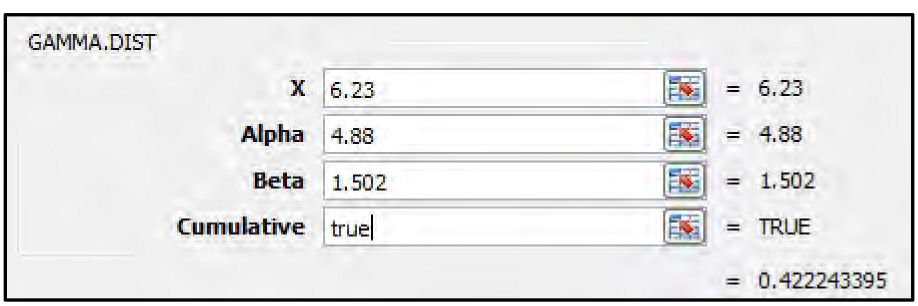


Figure 4 Cumulative Probability of Gamma Function in Excel

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)

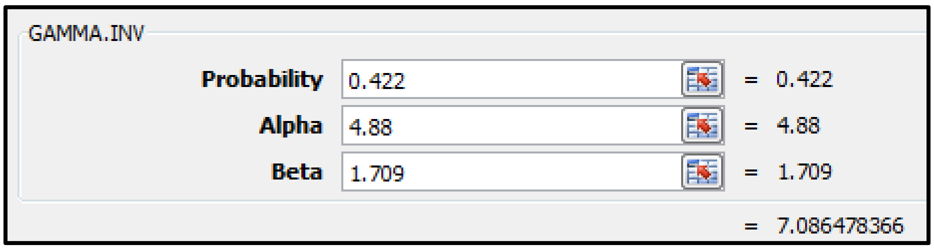


Figure 5 Inverse Gamma Function for a Specified Percentile in Excel

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.

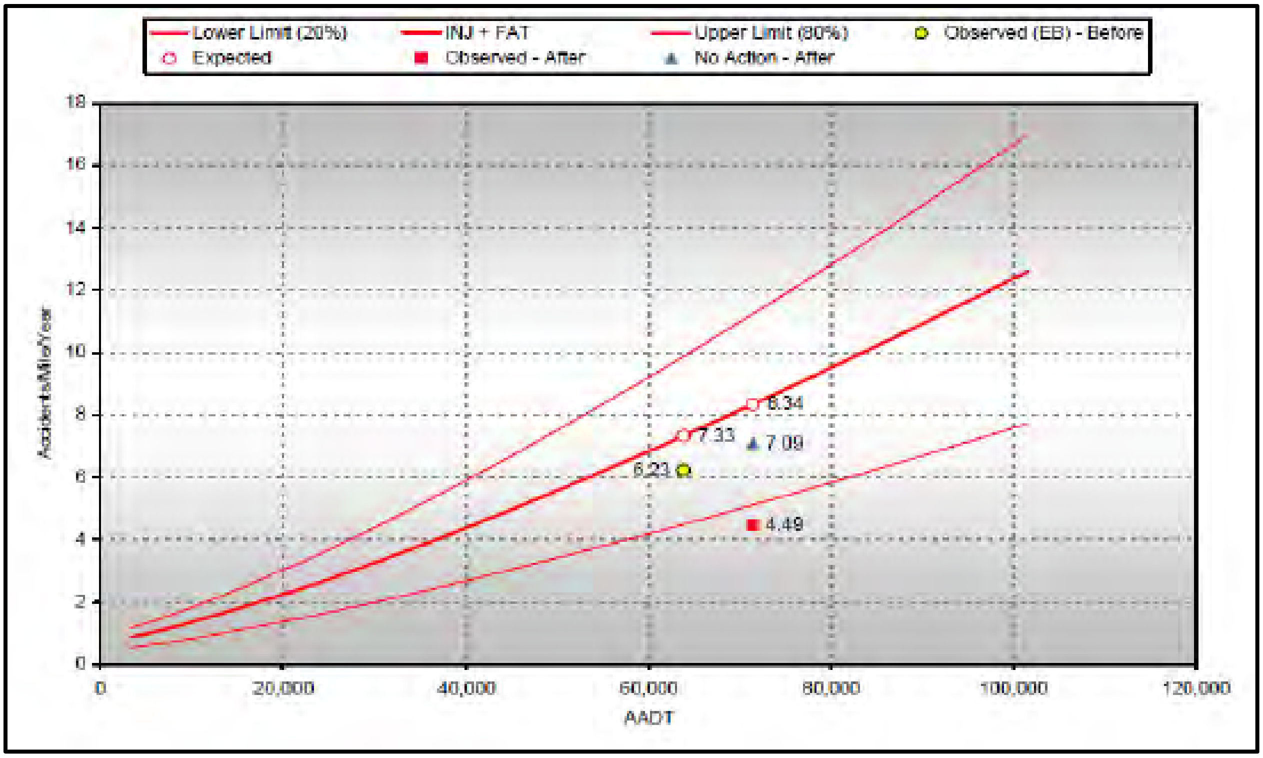


Figure 3 SPF Inj+Fat - I-76 (MP 1.77 to MP 5.78)
(EB Corrected Before Period, Before Without Construction, and After Period)

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

Var(CMF) = variance of the CMF

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

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

The cumulative probability factors for common confidence intervals are provided in **Table 2**.

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

Table 2 Cumulative Probability Factors

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

EMPIRICAL BAYES BEFORE-AFTER METHOD

Similar to the comparison group method, the effect of the safety treatment is estimated by comparing the sum of the estimates of $N_{exp.\ TA}$ for all treated sites with the number of crashes actually observed after treatment. The advantage of the empirical Bayes approach is that it correctly accounts for the changes in crash history that may be due to the regression-to-the-mean (RTM) phenomenon. RTM phenomenon reflects the tendency for random events, such as vehicle crashes to move toward the average during the course of an experiment or over time. The existence of the RTM bias has been long recognized and is now effectively addressed by using the Empirical Bayes (EB) method[4]. Additionally it provides a better approach than the comparison group method for accounting for changes in safety performance due to traffic volumes. The application of the empirical Bayes method requires the use of the Safety Performance Functions (SPF) and related over-dispersion parameters provided in the Colorado-specific safety knowledge base. **Table 3** provides information to support example calculations using the empirical Bayes Before-After Method. For this simplified example, a weight (W) of 0.25 is assumed for the SPF prediction for all sites, and there are no traffic volume changes at the treated sites.

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

Table 3 Example Data for Empirical Bayes Before-After Study

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

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

Where

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

n = number of years in the before or after period

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

α = Over-dispersion Parameter derived from SPF

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

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

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

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

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

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

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

APPENDIX B. SAFETY REPORTS

- #14963 – Kipling Street / 58th Avenue
- #15367 – US 6 / 9th Street Intersection Improvements
- #15873 – SH 82 / Smith Way – Pitkin
- #15901 – SH 82 – Deer Fence Install/Repair
- #16011 – El Paso / Fillmore Street
- #16313 – Colfax Avenue (US 40) / Youngfield Street
- #16314 – Upgrade Signals on Kipling (SH 391) and Colfax Avenue (US 40)
- #16380 – US 287 / 19th Street Intersection Improvements
- #16420 – US 50 West of Morris / Fortino Phase 1
- #16495 – I-76 Burlington Canal to Bromley Lane
- #16498 – US 287 / 37th Street – Loveland
- #16563 – Bakerville to Silver Plume
- #16595 – US 50 / 28 ½ Road Intersection Improvements
- #16600 – US 285 / Brady Court
- #16601 – Upgrade Signal at SH 7 / County Line Road
- #16623 – SH 392 / WCR 31
- #16625 – US 287 Intersections – Fort Collins
- #16642 – Queue Detection System
- #16730 – 23 Road / G Road in Grand Junction
- #16762 – SH 14 E/O I-25 Larimer County Signal
- #16804 – I-70B Intersection Improvements
- #16814 – I-70B at Peachtree Center
- #16878 – I-225 Median Cable Barrier Installation
- #16941 – SH 121 Conduit and Signal Improvement
- #16957 – US 285 / Sherman Street Signal Upgrades
- #17014 – I-70 Variable Speed Limit Pilot Program
- #17015 – US 287 / LCR 21C
- #17016 – SH 392 / LCR 9 Intersection
- #17025 – Install Guard Rail on US 50 West

- #17034 – US 550 / Niagara Road
- #17115 – SH 402 / CR 11 Construction and ROW
- #17116 – SH 119 / Hover Street Intersection Improvements
- #17143 – Guard Rail Installation on SH 115
- #17202 – I-76 Median Cable Lochbuie North
- #17249 – I-76 / 96th Avenue Interchange

Project Information

Project Name: Kipling Street at 58th Avenue

Project Description: Realign Left Turn Lanes

CDOT Region: 6	Project Def: 14963	County: Jefferson
Location: Off-Sys	Mile Points: N/A	Length: N/A
Schedule:	Work Start Date: approx. 1/2008	Completion Date: 8/30/2008

Problem Description: According to the original HSIP funding application, the existing offsets of opposing left turn lanes resulted in blocked views of approaching traffic for drivers waiting to turn left, exasperated by the grade on Kipling (the north-south road).

Improvement Description: In summer 2008 medians were modified and double lefts created to replace single left turn lanes southbound and westbound, while offset left turn lanes were created northbound and eastbound. All left turns remained protected/permitted. Total cost of construction was $1,066,441.

HSIP analysis assumed approach turn crashes would be affected by the improvement with CRF of 35%. Predicted B/C was 2.50.

Summary and Findings

The analysis of safety before and after the intersection at Kipling Street and 58th Avenue was improved showed some reduction in total crashes and in the number of persons injured, and reductions in some crash types that were not necessarily the targets of the improvement. Approach Turn crashes, the targeted type, were not reduced after construction of the intersection improvements. For this intersection there were 188 total crashes during the 5-year period before the improvement (2002 – 2006). In the 5 years after construction (2009 – 2013) the number of crashes decreased to 154.

The left turn lane modifications were apparently responsible for the decreased total number of crashes, and for decreased rear-end, broadside, sideswipe opposite-direction and head-on crashes at and approaching the intersection. The ratio of benefits to costs for this project shows that benefits outweigh costs by a ratio of 6.41 to one, showing that the improvement was justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 188 during the five-year period (2002 to 2006) before the turn lane modifications (see **Table 1** and **Exhibit 1**) to 154 during the five-year after period (2010 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes remained the same, while the number of people injured decreased in the five-year period after the improvements, despite the increase in traffic volume:

- Before (2002 – 2006) – no fatal crashes and 43 injury crashes with 75 injuries
- After (2009 – 2013) – no fatal crashes and 43 injury crashes with 59 injuries

Traffic volumes increased at the intersection, but the crash rates at the intersection decreased:

- Before (2002 – 2006) 2.03 crashes per million entering vehicles (cpmev)
- After (2009 – 2013) 1.53 cpmev

Table 1 – Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
AADT (Kipling/58th Ave)	28,600/22,100 vpd	32,900/22,100 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**188**	**154**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	43 (75)	43 (59)
Property Damage Only	145	111
Crash Types: # (%) [significance]		
Rear-End	90 (47.9%) [99.99%]	65 (42.2%)
Broadside	38 (20.2%)[97.20%]	18 (11.7%)
Approach Turn	33 (17.6%)	52 (33.8%)[100.00%]
Sideswipe Same	10 (5.3%)	9 (5.8%)
Sideswipe Opposite	6 (3.2%)[99.99%]	0
Head On	4 (2.1%)[99.67%]	0

The magnitude of safety problems on select highway facilities 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

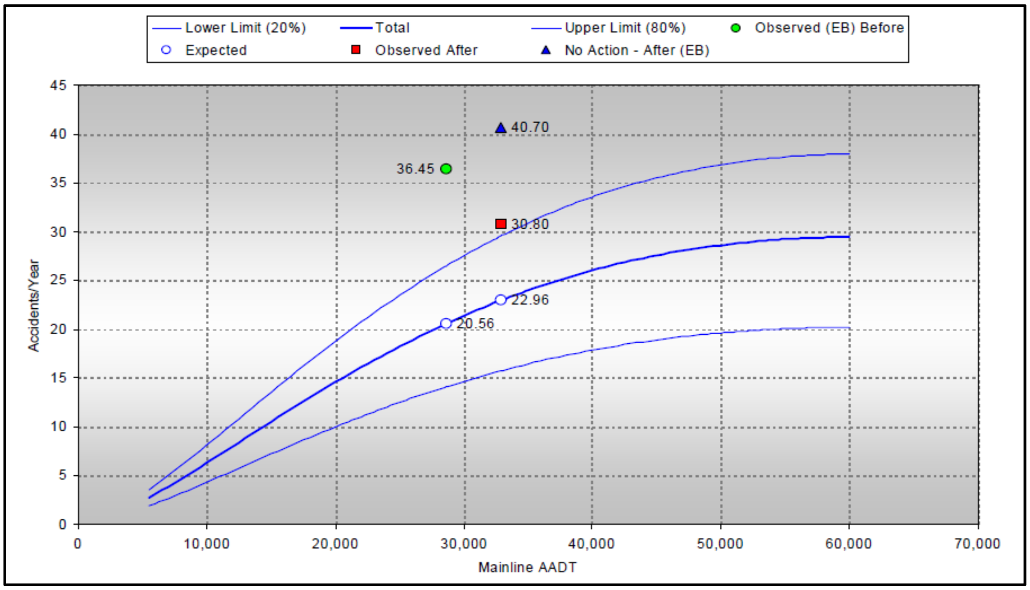
LOSS Boundaries are calibrated by computing the 20th and the 80th percentiles using the Gamma Distribution Probability Density Function. Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT increases.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

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. The frequency and severity of crashes both remained in the LOSS-IV category for the before and after periods, however; both showed improvement in the after period. (See **Table 2**).

Figure 1 – SPF for Total Crashes

Kipling Street / 58th Avenue

Before: 2002 thru 2006 After: 2009 thru 2013

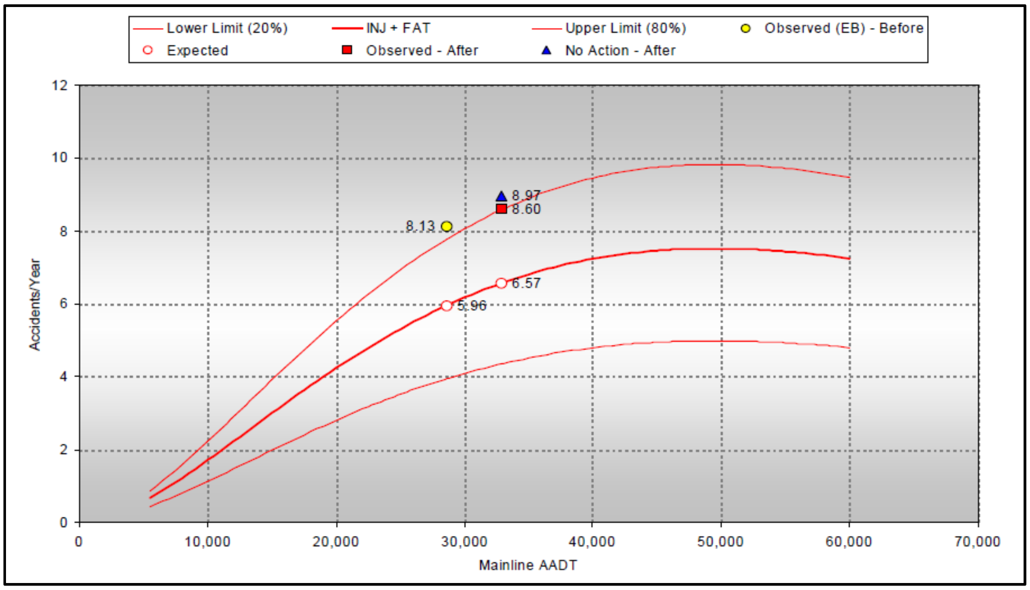


Note: Safety Performance Function (SPF) Model: Colorado – Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 2 – SPF for Injury and Fatal Crashes

Kipling Street / 58th Avenue

Before: 2002 thru 2006 After: 2009 thru 2013



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

Table 2 – Safety Performance Functions (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPY	36.45	30.80	40.70
Mean CPY	20.56	22.96	22.96
Proportion of Mean	1.77	1.34	1.77
Fatal & Injury Crashes:			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPY	8.13	8.60	8.97
Mean CPY	5.96	6.57	6.57
Proportion of Mean	1.36	1.31	1.36

A more detailed review of the before and after crash record reveals that rear end, broadside, head-on and sideswipe, opposite direction crashes were reduced after construction of the improvements. Total approach turn crashes, the targeted type, were not reduced. Northbound approach turns were reduced, by 25%, but eastbound approach turns went from none before to 3 after, westbound from 5 to 7, and southbound from 14 before to 35 after. Late in the after period, approximately November 15, 2012, the southbound left turn was converted to fully protected. There were no southbound approach turns in 2013. **Table 3** shows a comparison of primary types of crashes that are most directly affected by the improvement: rear-end and sideswipe same direction, as well as the total intersection crashes. The No Build After crashes were estimated using the change in mean CPY found in **Table 1** (increase is 1.117 = 40.70/36.45).

Table 3 – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2002 to 12/31/2006 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
Crash Types:			
Total Crashes	**188**	**154**	**210**
Injury (injuries)	43 (75)	43 (59)	48 (84)
PDO	145	111	162
% Reduction in Total (Injuries/PDO)		30% / 31%	
Rear-Ends – Total	**90**	**65**	**100**
Injury (injuries)	12 (19)	11 (11)	13 (21)
PDO	78	54	87
% Reduction in Total (Injuries/PDO)		48% / 38%	
Broadsides – Total	**38**	**18**	**42**
Injury (injuries)	14 (28)	6 (15)	16 (31)
PDO	24	12	27
% Reduction in Total (Injuries/PDO)		52% / 56%	
Head On + Sideswipe Opposite – Total	**10**	**0**	**11**
Injury (injuries)	2 (4)	0	2 (6)
PDO	8	0	9
% Reduction in Total (Injuries/PDO)		100% / 100%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crash types at the intersection. As shown, the B/C ratio for all crashes is 6.41, showing that the improvement was justified, even though approach turn was not improved as expected. Late in the after period, approximately November 15, 2012, the southbound left turn was converted to fully protected. There were no southbound approach turns in 2013.

Figure 3 – Benefit Cost Analysis – All Crash Types – Intersection and Intersection Related Crashes Only

COLORADO Department of Transportation

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

09/26/2016

Job #: 20160926224621

Location: Accident History for KIPLING and 58 **From:**01/01/2002 **To:**12/31/2006

Benefit Cost Ratio Calculations

Crashes				Projected Crashes and Reduction Factors			Other Information	
PDO:	145			Weighted PDO:	35.62	31% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	43	75	:Injured	Weighted INJ:	18.43	30% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0	:Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,500,000
				B/C Weighted Year Factor:	5.00	30% :Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
		Cost:	$ 1,066,441				Service Life:	20
		From:	01/01/2002				Capital Recovery Factor:	0.080
		To:	12/31/2006	Days: 1826			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: **6.41** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: INTERSECTION IMPROVEMENTS - MODIFY MEDIANS - RECONFIGURE LEFT TURNS

Special Notes:

Location: Accident History for KIPLING and 58 **From:** 01/01/2002 **To:** 12/31/2006

At Intersection and Intersection Related Crashes Only

Severity

PDO:	145	
INJ:	43	75 :Injured
FAT:	0	0 :Killed
Total:	**188**	

Number of Vehicles

One Vehicle:	4
Two Vehicles:	167
Three or More:	17
Unknown:	0
Total:	**188**

Location

On Road:	183
Off Road Left:	4
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	1
Total:	**188**

Lighting Conditions

Daylight:	128
Dawn or Dusk:	10
Dark - Lighted:	47
Dark - Unlighted:	1
Unknown:	2
Total:	**188**

Weather Conditions

None:	169
Rain:	6
Snow/Sleet/Hail:	10
Fog:	0
Dust:	0
Wind:	0
Unknown:	3
Total:	**188**

Crash Rates

PDO:	N/A *
INJ:	N/A *
FAT:	N/A **
Total:	**N/A** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	38	Embankment:	0
Head On:	4	Curb:	4
Rear End:	90	Delineator Post:	0
Sideswipe (Same):	10	Fence:	0
Sideswipe (Opposite):	6	Tree:	0
Approach Turn:	33	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	1	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	5
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	1
Bridge Rail:	0	Total Other Objects:	1
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**188**
Concrete Barrier:	1		

Mainline/Ramps/Frontage Roads

Mainline:	0
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	188
Total:	**188**

Road Description

At Intersection:	162
At Driveway Access:	0
Intersection Related:	26
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**188**

Road Conditions

Dry:	162
Wet:	12
Muddy:	0
Snowy:	5
Icy:	2
Slushy:	1
Foreign Material:	1
With Road Treatment:	0
Dry w/Icy Road Treatment:	2
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	3
Total:	**188**

Location: Accident History for KIPLING and 58 **From:**01/01/2002 **To:**12/31/2006

At Intersection and Intersection Related Crashes Only

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	137	139	9
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	35	29	4
Pickup Truck/Utility Van w/Trl:	0	2	0
SUV:	5	6	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	2	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	2	1	0
Bicycle:	1	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	1	0
Other:	0	0	0
Unknown:	5	5	3
Total:	**188**	**184**	**17**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	108	152	11
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	6	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	17	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	3	0	0
Physical Disability:	0	0	0
Unknown:	52	32	6
Total:	**188**	**184**	**17**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	179	184	17
Alcohol Involved:	6	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	2	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**188**	**184**	**17**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	80	84	2
Slowing:	9	6	0
Stopped in Traffic:	3	66	12
Making Right Turn:	27	16	0
Making Left Turn:	58	8	0
Making U-Turn:	0	0	0
Passing:	2	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	3	1	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	5	3	3
Total:	**188**	**184**	**17**

Direction	Veh 1	Veh 2	Veh 3
North:	48	52	3
Northeast:	2	2	0
East:	38	34	2
Southeast:	4	2	0
South:	45	48	5
Southwest:	1	1	0
West:	44	39	4
Northwest:	5	5	0
Unknown:	1	1	3
Total:	**188**	**184**	**17**

Exhibit 2

Location: Accident History for KIPLING and 58 **From:** 01/01/2009 **To:** 12/31/2013

At Intersection and

Severity

PDO:	111		
INJ:	43	59	:Injured
FAT:	0	0	:Killed
Total:	**154**		

Number of Vehicles

One Vehicle:	9
Two Vehicles:	135
Three or More:	10
Unknown:	0
Total:	**154**

Location

On Road:	149
Off Road Left:	3
Off Road Right:	2
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**154**

Lighting Conditions

Daylight:	103
Dawn or Dusk:	10
Dark - Lighted:	40
Dark - Unlighted:	1
Unknown:	0
Total:	**154**

Weather Conditions

None:	37
Rain:	6
Snow/Sleet/Hail:	5
Fog:	0
Dust:	0
Wind:	1
Unknown:	105
Total:	**154**

Crash Rates

PDO:	N/A *
INJ:	N/A *
FAT:	N/A **
Total:	**N/A** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	18	Embankment:	0
Head On:	0	Curb:	2
Rear End:	65	Delineator Post:	0
Sideswipe (Same):	9	Fence:	1
Sideswipe (Opposite):	0	Tree:	1
Approach Turn:	52	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	1	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	8
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	3	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**154**
Concrete Barrier:	1		

Mainline/Ramps/Frontage Roads

Mainline:	0
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	154
Total:	**154**

Road Description

At Intersection:	117
At Driveway Access:	0
Intersection Related:	37
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**154**

Road Conditions

Dry:	137
Wet:	10
Muddy:	0
Snowy:	2
Icy:	5
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**154**

Location: Accident History for KIPLING and 58 **From:**01/01/2009 **To:**12/31/2013

At Intersection and

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	94	88	4
Passenger Car/Van w/Trl:	0	1	0
Pickup Truck/Utility Van:	19	23	2
Pickup Truck/Utility Van w/Trl:	2	0	0
SUV:	36	30	4
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	2	0
Unknown:	0	0	0
Total:	**154**	**145**	**10**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	59	71	4
Slowing:	3	8	0
Stopped in Traffic:	0	45	6
Making Right Turn:	17	9	0
Making Left Turn:	66	10	0
Making U-Turn:	0	0	0
Passing:	1	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	0
Changing Lanes:	5	1	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	3	0	0
Unknown:	0	0	0
Total:	**154**	**145**	**10**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	11	40	3
Asleep at the Wheel:	0	0	0
Illness:	3	0	0
Distracted by Passenger:	5	0	0
Driver Inexperience:	13	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	43	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	78	105	7
Total:	**154**	**145**	**10**

Direction	Veh 1	Veh 2	Veh 3
North:	38	71	4
Northeast:	1	1	0
East:	23	21	1
Southeast:	0	0	0
South:	58	28	2
Southwest:	1	0	0
West:	33	24	3
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**154**	**145**	**10**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	142	144	10
Alcohol Involved:	12	1	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**154**	**145**	**10**

Project Information

Project Name: US 6 / 9th St in Silt, Intersection Improvements

Project Description: Hazard Elimination, Replace Intersection with Roundabout

CDOT Region: 4 Project Def: 15367 County: Garfield

Location: SH 6D Mile Points: 99.24, SH 70E MP 0.22 Length: N/A

Schedule: Work Start Date: est 5/2009 Completion Date: est 10/2009

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the crash history showed a higher than expected proportion of broadside crashes at the unsignalized intersection of 9th Street (SH 070E) with US 6 (Main Street) in Silt. There were 11 of these crashes during the five-year (1998 – 2002) time period considered in the HSIP application.

Improvement Description: In late 2009 a roundabout was constructed to replace the intersection. The cost of construction was $987,022.

The HSIP application anticipated that all intersection crashes would be impacted by this improvement. It was anticipated that there would be approximately an 80% crash reduction for these crashes. The expected benefit/cost ratio was estimated to be 1.53.

Summary and Findings

The analysis of safety before and after a roundabout was constructed at the intersection of US 6 and 9th Street showed safety improved by reduction of broadside crashes and other types, including elimination of injury crashes. For this intersection, there were 17 total crashes during the five-year period before the improvement (2004 – 2008). In the five years after construction (2010 – 2014), the number of crashes decreased to 9.

The new roundabout was apparently responsible for the elimination of injury crashes at the intersection, and also was apparently responsible for reduction of other crash types. The ratio of benefits to cost for this project shows that benefits of crash reduction were outweighed by the costs of construction by a ratio of 0.67 to one, showing that the improvement was not justified from the safety improvement standpoint alone.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 17 during the five-year period (2004 to 2008) before intersection was replaced with a roundabout (see **Table 1** and **Exhibit 1**) to 9 during the five-year after period (2010 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes also decreased in the five-year period after the improvements:

- Before (2004 – 2008) – no fatal crashes and 2 injury crashes with 2 injuries
- After (2010 – 2014) – no fatal crashes and no injury crashes

Traffic volumes at the intersection decreased slightly, the crash rates at the intersection decreased significantly:

- Before (2004 – 2008): 0.96 crashes per million entering vehicles (cpmev)
- After (2010 – 2014): 0.51 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
AADT (SH 6/9th St SW)	6,031/ 3,700 vpd	5,907 / 3,700 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related Roundabout
Total Crashes	**17**	**9**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	2 (2)	0(0)
Property Damage Only	15	9
Crash Types: # (%) [significance]		
Broadside	6 (35.3%)	2 (22.2%)
Rear End	4 (23.5%)	3 (33.3%)

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

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

level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

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

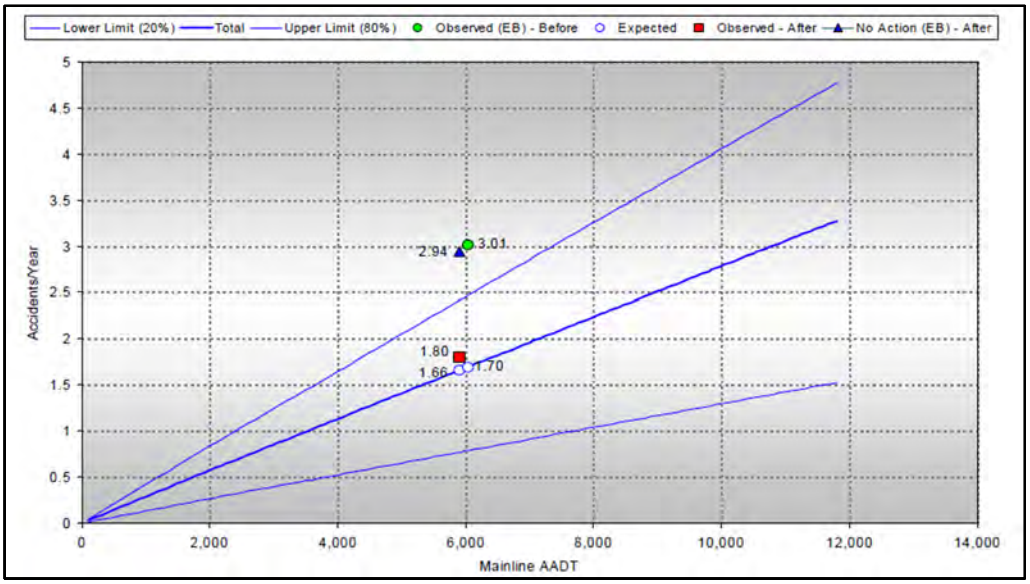
LOSS boundaries are calibrated by computing the 20^{th} and the 80^{th} percentiles using the Gamma Distribution Probability Density Function. Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT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

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. The frequency of crashes remained in the LOSS IV category for the before and after period, while the severity of crashes remained in the LOSS III category. However, both showed improvement within their given category in the after period (see **Table 2**).

Figure 1 - SPF for Total Crashes

SH 6D (Main St)(MP 99.24) at 9th St (SH 70E MP 0.22)

Before: 2004 thru 2008 After: 2010 thru 2014

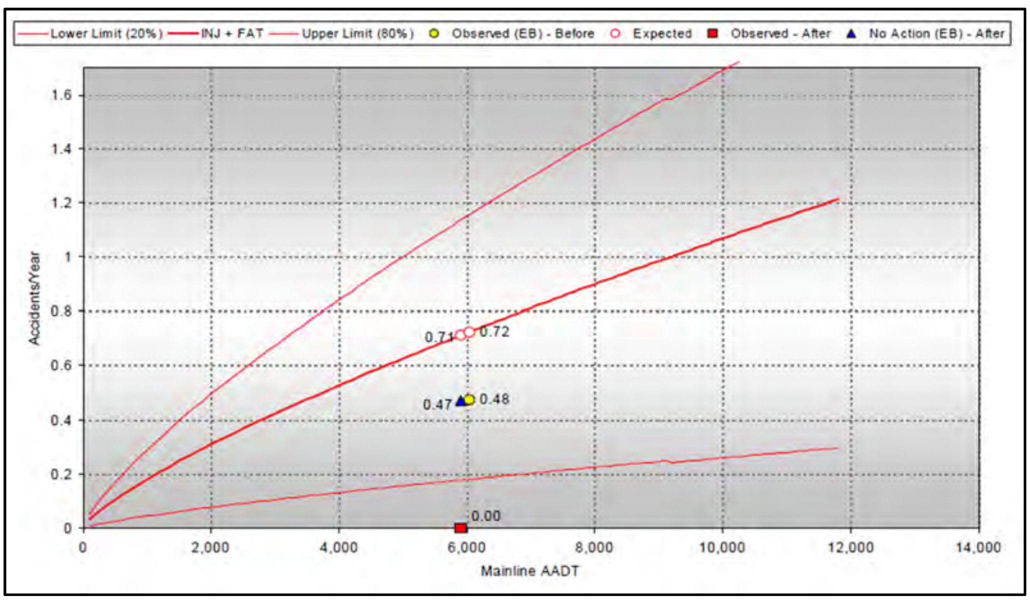


Note: Safety Performance Function (SPF) Model: Colorado – Urban 2-Lane Undivided Unignalized 4-Leg Intersection

Figure 2 – SPF Injury and Fatal Crashes

SH 6D (Main St)(MP 99.24) at 9th St (SH 70E MP 0.22)

Before: 2004 thru 2008 After: 2010 thru 2014



Note: Safety Perfromance Function (SPF) Model: Colorado – Urban 2-Lane Undivided Unignalized 4-Leg Intersection

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	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 III*	LOSS IV
CPY	3.01	1.80	2.94
Mean CPY	1.70	1.66	1.66
Proportion of Mean	1.77	1.08	1.77
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS I*	LOSS IV
CPY	0.48	0.00	0.47
Mean CPY	0.72	0.71	0.71
Proportion of Mean	0.67	0.00	0.67

**Intersection type changed by project to Roundabout, so LOSS shown is not necessarily correct for the After period, but it provides a useful comparison.*

A more detailed review of the before and after crash record reveals that improvement in safety can be attributed to replacement of the intersection with a roundabout. The roundabout accomplished the intended goal of reducing broadsides, as well as rear ends, same direction sideswipes, and approach turns, but not by the anticipated total percentage. **Table 3** shows a comparison of primary types of crashes that are most directly affected by the improvement: broadside and rear end, as well as the total intersection crashes. The No Build After crashes were estimated using the change in mean CPY found in **Table 2** (decrease is 0.938 = 1.66/1.77).

Table 3 – Results of Crash Analyses

	Before	**After**	**No Build After**
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
Crash Types:			
Total Crashes	**17**	**9**	**16**
Injury (injuries)	2 (2)	0 (0)	2 (2)
PDO	15	9	14
% Reduction in Total (Injuries/PDO)		100% / 36%	
Broadsides – Total	**6**	**0**	**6**
Injury (injuries)	1(1)	0 (0)	1(1)
PDO	5	0	5
% Reduction in Total (Injuries/PDO)		100% / 100%	
Rear End – Total	**4**	**3**	**4**
Injury (injuries)	0 (0)	0	0 (0)
PDO	4	3	4
% Reduction in Total (Injuries/PDO)		Undefined / 25%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the impacted crash types. As shown, the B/C ratio for the intersection and intersection related crashes is 0.66, showing that the improvement was not justified considering the safety improvement alone, reflecting that the intersection was performing well in terms of crash severity in the before period. There are also operational benefits of a roundabout in terms of decreased delay, which are not considered in the analysis.

Figure 3 – Benefit Cost Analysis – Intersection and Intersection Related Crashes Only

CDOT
COLORADO Department of Transportation

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

09/29/2016
Job #: 20160929163844

Location: 6D 70E **Begin:** 99.20 **End:** 99.28 **From:** 01/01/2004 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	15		Weighted PDO:	3.69	36% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	2	2 :Injured	Weighted INJ:	0.49	100% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	43% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 987,022
From: 01/01/2004
To: 12/31/2008 Days: 1827

Benefit Cost Ratio: **0.66** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: INTERSECTION - REPLACE WITH ROUNDABOUT
Special Notes: ALL INTERSSECTION AND INTERSECTION RELATED CRASHES

Exhibit 1

10/10/2016

Job #: 20161010092248

Location: 6D 70E **Begin:** 99.21 **End:** 99.27 **From:** 01/01/2004 **To:** 12/31/2008

BEFORE

Severity

PDO:	15	
INJ:	2	2 :Injured
FAT:	0	0 :Killed
Total:	**17**	

Number of Vehicles

One Vehicle:	2
Two Vehicles:	15
Three or More:	0
Unknown:	0
Total:	**17**

Location

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

Lighting Conditions

Daylight:	12
Dawn or Dusk:	1
Dark - Lighted:	3
Dark - Unlighted:	0
Unknown:	1
Total:	**17**

Weather Conditions

None:	13
Rain:	0
Snow/Sleet/Hail:	3
Fog:	0
Dust:	0
Wind:	0
Unknown:	1
Total:	**17**

Crash Rates

PDO:	22.41 *
INJ:	2.99 *
FAT:	0.00 **
Total:	**25.40** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	6	Embankment:	0
Head On:	1	Curb:	0
Rear End:	4	Delineator Post:	0
Sideswipe (Same):	2	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	1	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	2
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	1
Cable Rail:	0	**Total:**	**17**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	17
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

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

Road Description

At Intersection:	14
At Driveway Access:	0
Intersection Related:	3
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**17**

Road Conditions

Dry:	12
Wet:	1
Muddy:	0
Snowy:	0
Icy:	2
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	2
Total:	**17**

ADT: 6,005 **Length:** 0.06

Location: 6D 70E **Begin:** 99.21 **End:** 99.27 **From:** 01/01/2004 **To:** 12/31/2008

BEFORE

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	9	6	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	4	5	0
Pickup Truck/Utility Van w/Trl:	2	1	0
SUV:	0	1	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	2	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	1	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**17**	**15**	**0**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	4	7	0
Slowing:	1	1	0
Stopped in Traffic:	0	4	0
Making Right Turn:	2	0	0
Making Left Turn:	7	2	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	1	1	0
Total:	**17**	**15**	**0**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	8	10	0
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	3	4	0
Driver Unfamilar with Area:	1	1	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	2	0	0
Total:	**17**	**15**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	6	4	0
Northeast:	0	0	0
East:	2	4	0
Southeast:	0	0	0
South:	5	2	0
Southwest:	0	0	0
West:	3	4	0
Northwest:	0	0	0
Unknown:	1	1	0
Total:	**17**	**15**	**0**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	16	15	0
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**17**	**15**	**0**

ADT: 6,005 **Length:** 0.06

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

Exhibit 2

10/10/2016

Job #: 20161010092448

Location: 6D 70E **Begin:** 99.21 **End:** 99.27 **From:** 01/01/2010 **To:** 12/31/2014

AFTER

Severity

PDO:	9	
INJ:	0	0 :Injured
FAT:	0	0 :Killed
Total:	**9**	

Number of Vehicles

One Vehicle:	3
Two Vehicles:	6
Three or More:	0
Unknown:	0
Total:	**9**

Location

On Road:	6
Off Road Left:	0
Off Road Right:	3
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**9**

Lighting Conditions

Daylight:	7
Dawn or Dusk:	0
Dark - Lighted:	2
Dark - Unlighted:	0
Unknown:	0
Total:	**9**

Weather Conditions

None:	3
Rain:	0
Snow/Sleet/Hail:	6
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**9**

Crash Rates

PDO:	12.97 *
INJ:	0.00 *
FAT:	0.00 **
Total:	**12.97** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	9
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**9**

Road Description

At Intersection:	2
At Driveway Access:	0
Intersection Related:	2
Non Intersection:	0
In Alley:	0
Roundabout:	5
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**9**

Road Conditions

Dry:	3
Wet:	0
Muddy:	0
Snowy:	3
Icy:	3
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**9**

ADT: 5,847 **Length:** 0.06

Location: 6D 70E	Begin: 99.21	End: 99.27	From: 01/01/2010	To: 12/31/2014

AFTER

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

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	3	6	0
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	2	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	1	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	3	0	0
Total:	**9**	**6**	**0**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	9	6	0
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**9**	**6**	**0**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	1	0	0
Slowing:	4	2	0
Stopped in Traffic:	0	3	0
Making Right Turn:	1	0	0
Making Left Turn:	1	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	2	1	0
Unknown:	0	0	0
Total:	**9**	**6**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	1	2	0
Northeast:	0	0	0
East:	0	0	0
Southeast:	0	0	0
South:	3	1	0
Southwest:	1	0	0
West:	4	3	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**9**	**6**	**0**

ADT: 5,847 **Length:** 0.06

Project Information

Project Name: SH 82A/Smith Way – Pitkin

Project Description: Auxiliary Lanes, Channelization, Regrading, & Dilemma Zone

CDOT Region: 3 **Project Def:** 15873 **County:** Pitkin

Location: SH 82A/Smith Way Near Woody Creek (MP 34.46 to MP 34.50)

Schedule: Work Start Date: 11/12/2008 Completion Date: 7/23/2009

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history showed a higher than expected number of broadside type crashes. The intersection was unsignalized, but met signal warrants.

Improvement Description: In late 2008 and early 2009, an auxiliary lane (approximately 725 feet in length) for left-turning Smith Way traffic to accelerate onto eastbound SH 82, channelization, and regrading were constructed at this intersection. The traffic signal and related dilemma zone consideration were not installed. The cost of construction was $1,439,441.

The HSIP application anticipated that three crash types would be impacted by this improvement include: approach turn, broadside, and pedestrian type crashes. It was anticipated that there would be a 35% crash reduction for these crash types. The initial benefit/cost ratio was estimated to be 1.06.

Summary and Findings

The analysis of safety before and after the acceleration lane, channelization, and regrading improvements were constructed at the intersection of SH 82A / Smith Way / Juniper Hill Road showed only a minor improvement in safety. For the eastbound SH 82A intersection only, there were six total crashes during the five-year period before the improvements (2003 – 2007). In the five years after construction (2010 – 2014), the number of crashes decreased to three. However, there was an increase in the number of broadside crashes and the resulting number of injuries. The motivation for safety improvements was to reduce broadside type crashes, which did not happen.

The ratio of benefits and cost for this project shows that there was no benefit resulting from the improvement, giving a B/C ratio of 0.05. The result is an improvement that was likely not justified solely from the standpoint of safety.

However, it should be noted that this intersection had a significant broadside crash problem in the past (prior to 2001). In that year, the westbound auxiliary right-turn lane was shifted to improve sight distance for Smith Way traffic. The B/C ratio resulting from this previous improvement project was 49.53, based on a conservative assumption that the construction costs were no more than $500,000.

Results of Safety Analyses

The intersection of SH 82A, Smith Way, and Juniper Hill Road has a unique configuration. Eastbound and westbound SH 82A are separated by an open median that is approximately 150 feet wide. This means that the two intersections are separate operationally. From the construction plans, it appears that the westbound SH 82A intersection was essentially unchanged by the project. The short section of roadway through the median was widened, and an acceleration lane along the median was added for Smith Way traffic that is turning left onto eastbound SH 82A. Vision Zero Suite (VZS) was utilized to review before and after crash records for the eastbound intersection and its immediate vicinity. Crash records for eastbound SH 82 show a decrease in the number of crashes (see **Table 1**). Unfortunately, the number of injury crashes remained the same, but the number of people injured increased. **Exhibit 1** provides crash summaries for the before period (2003 through 2007) for the entire intersection (both eastbound and westbound directions), and **Exhibit 2** provides similar information for the after period (2010 through 2014).

Table 1 - SH 82A (MP 34.46 to MP 34.50) - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2003 to 12/31/2007 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
AADT (SH 82A)	17,665 vpd	17,000 vpd
Filters:	At Eastbound Intersection & EB Intersection Related	At Eastbound Intersection & EB Intersection Related
Total Crashes	**6**	**3**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	2 (2)	2 (5)
Property Damage Only	4	1
Crash Types: # (% of total crashes) [cumulative probability]		
Rear-End	4 (66.7%) [95.69%]	1 (33.3%)
Sideswipe Same	1 (16.7%)	0
Broadside	0	2 (66.7%)
Wild Animal	1 (16.7%)	0

Normally, the magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. However, in the case of the SH 82A/Smith Way intersection which is a rural, unsignalized intersection, no SPF has been developed. In addition, the split configuration of the two intersections is unique, and a normal SPF would probably not be reflective of the actual safety situation.

Specific types of crashes can be analyzed in determining the potential benefits resulting from an improvement project. In this case, the previously mentioned HSIP application anticipated that three crash types would be impacted by this improvement include: approach turn, broadside, and pedestrian type crashes. To this list, rear-end and sideswipe (same) type crashes can also be added, due to the nature of the improvement. **Table 2** shows a comparison of three types of crashes that are affected by the improvement project: rear-end, broadside, and sideswipe (same) type crashes. The No Build After crashes were estimated using the decrease in the average daily traffic volumes found in **Table 1** (increase is 0.96 = 17,000 / 17,665).

Table 2 – SH 82A (MP 34.46 to MP 34.50) - Results of Before & After Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2003 to 12/31/2007 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
Crash Types:			
Rear End – Total	**4**	**1**	**4**
Fatal (fatalities)	0	0	0
Injury (injuries)	2 (2)	0	2 (2)
PDO	2	1	2
% Reduction in Total		75%	
Sideswipe (Same)– Total	**1**	**0**	**1**
Injury (injuries)	0	0	0
PDO	1	0	1
% Reduction in Total		100%	
Broadside – Total	**0**	**2**	**0**
Injury (injuries)	0	2 (5)	0
PDO	0	0	0
% Reduction in Total			

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis calculations are shown in **Figure 1** for rear end, sideswipe (same), and broadside crashes. The increase in injuries (from 2 to 5) was factored into the analysis by increasing the cost of construction for the project by $242,100 (3 x $80,700). The B/C ratio resulting from this improvement project is 0.05, showing that the improvement was likely not justified solely from the standpoint of safety.

Figure 1 – Results of Benefit / Cost Analysis – SH 82A (MP 34.46 to MP 34.50)

CDOT
COLORADO Department of Transportation

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

05/03/2016

Job #: 20160503081757

Location: 82A **Begin:** 34.46 **End:** 34.50 **From:** 01/01/2003 **To:** 12/31/2007

SH 82A - AP0115 - #15873 - SH 82A and Smith Way

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	4		Weighted PDO:	0.98	75% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	2	2 :Injured	Weighted INJ:	0.49	0% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	50% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 100

Cost: $ 1,681,545
From: 01/01/2003
To: 12/31/2007 Days: 1826

Benefit Cost Ratio: 0.05 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: EB Intersection Improvements - acceleration lane and channelization
Special Notes: Construction costs incrased by $242,100 (3 x $80,700) to account for additional injuries

During the course of this analysis, one of the investigators remembered that this intersection had a significant broadside crash problem in the past (prior to 2001). In that year, a Safety Assessment Report recommended shifting the westbound auxiliary right-turn lane to improve sight distance for Smith Way traffic. As shown in **Figure 2**, there was a marked decrease in broadside crashes after the improvement was made. **Table 3** provides a comparison of broadside crashes the marked decrease between the before period (1998 through 2001) and the after period (2002 through 2005). **Figure 3** shows that the B/C ratio resulting from this previous improvement project was 49.53, based on conservative assumption that the construction costs were no more than $500,000.

Table 2 - Results of Broadside Crash Analyses (1998 through 2005) – SH 82A (MP 34.46 to MP 34.50)

	Before	After
Time Period:	1/1/1998 to 12/31/2001 (4 yr.)	1/1/2002 to 12/31/2005 (4 yr.)
Filters:	Broadside Crashes Only	Broadside Crashes Only
Total Crashes	**16**	**3**
Fatal Crashes (Fatalities)	1 (4)	1 (1)
Injury Crashes (Injuries)	11 (28)	1 (4)
Property Damage Only	4	1

Figure 2 – Cumulative Broadside Crash Graph (1998 to 2013) – SH 82A (MP 34.46 to MP 34.50)

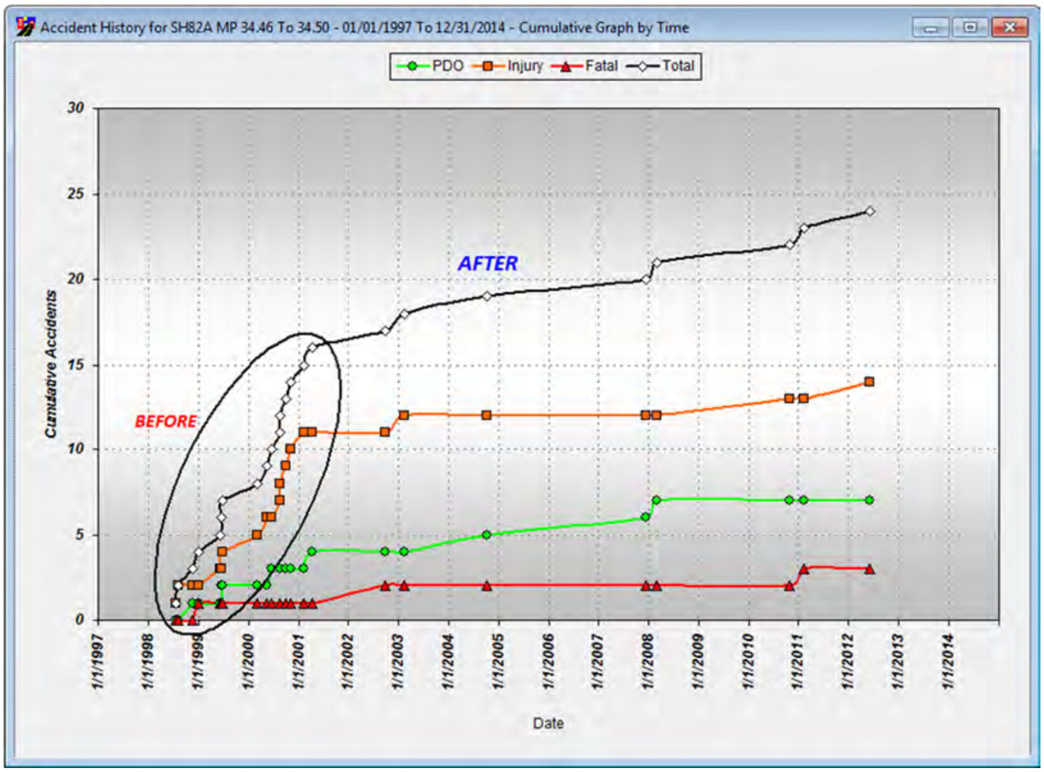


Figure 3 – Benefit Cost Analysis – SH 82A (MP 34.46 to MP 34.50) – Results of Benefit / Cost Analysis

CDOT COLORADO Department of Transportation

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

05/03/2016

Job #: 20160503083557

Location: 82A **Begin:** 34.46 **End:** 34.50 **From:** 01/01/1998 **To:** 12/31/2001

SH 82A - AP0115 - #15873 - SH 82A and Smith Way - Broadside Crashes Only

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	4		Weighted PDO:	1.23	75% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	11	28 :Injured	Weighted INJ:	8.60	86% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	1	4 :Killed	Weighted FAT:	1.23	75% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	82% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
	Cost: $ 500,000					Service Life:	20
	From: 01/01/1998					Capital Recovery Factor:	0.080
	To: 12/31/2001		Days: 1461			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: 49.53 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: 2001 Intersection Improvements
Special Notes: Broadside Crashes only - Construction Costs were conservatively estimated to be $500,000

Location: 82A **Begin:** 34.46 **End:** 34.50 **From:** 01/01/2003 **To:** 12/31/2007

SH 82A - AP0115 - #15873 - SH 82A and Smith Way

Severity

PDO:	7	
INJ:	2	2 :Injured
FAT:	0	0 :Killed
Total:	**9**	

Number of Vehicles

One Vehicle:	2
Two Vehicles:	6
Three or More:	1
Unknown:	0
Total:	**9**

Location

On Road:	8
Off Road Left:	0
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**9**

Lighting Conditions

Daylight:	5
Dawn or Dusk:	1
Dark - Lighted:	1
Dark - Unlighted:	2
Unknown:	0
Total:	**9**

Weather Conditions

None:	7
Rain:	0
Snow/Sleet/Hail:	2
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**9**

Crash Rates

PDO:	5.43 *
INJ:	1.55 *
FAT:	0.00 **
Total:	**6.98** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	9
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**9**

Road Description

At Intersection:	8
At Driveway Access:	0
Intersection Related:	1
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**9**

Road Conditions

Dry:	6
Wet:	0
Muddy:	0
Snowy:	1
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**9**

ADT: 17,665 **Length:** 0.04

Location: 82A **Begin:** 34.46 **End:** 34.50 **From:**01/01/2003 **To:**12/31/2007

SH 82A - AP0115 - #15873 - SH 82A and Smith Way

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

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	5	7	1
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	0	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	1	0	0
Total:	**9**	**7**	**1**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	9	7	1
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**9**	**7**	**1**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	6	4	1
Slowing:	1	0	0
Stopped in Traffic:	0	2	0
Making Right Turn:	0	0	0
Making Left Turn:	1	1	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**9**	**7**	**1**

Direction	Veh 1	Veh 2	Veh 3
North:	1	1	0
Northeast:	0	0	0
East:	3	2	0
Southeast:	0	0	0
South:	3	0	0
Southwest:	1	1	0
West:	1	3	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**9**	**7**	**1**

ADT: 17,665 **Length:** 0.04

Exhibit 2

05/03/2016

Job #: 20160503090004

Location: 82A **Begin:** 34.46 **End:** 34.50 **From:**01/01/2010 **To:**12/31/2014

SH 82A - AP0115 - #15873 - SH 82A and Smith Way

Severity

PDO:	2	
INJ:	2	5 :Injured
FAT:	1	1 :Killed
Total:	**5**	

Number of Vehicles

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

Location

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

Lighting Conditions

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

Weather Conditions

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

Crash Rates

PDO:	1.61 *
INJ:	1.61 *
FAT:	80.54 **
Total:	**4.03** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	5
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

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

Road Description

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

Road Conditions

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

ADT: 17,000 **Length:** 0.04

Location: 82A **Begin:** 34.46 **End:** 34.50 **From:**01/01/2010 **To:**12/31/2014

SH 82A - AP0115 - #15873 - SH 82A and Smith Way

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

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

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

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

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

ADT: 17,000 **Length:** 0.04

Project Information

Project Name: SH 82 – Deer Fence Install/Repair SH 133A in Carbondale

Project Description: Install New Deer Fencing, Repair Existing Deer Fencing, Install Deer/Elk Passage Components

CDOT Region: 3 Project Def: 15901 County: Garfield

Location: SH 82A Mile Points: 7.0 – 11.0 Length: 4.0 miles

Schedule: Work Start Date: 8/31/2009 Completion Date: 5/1/2010

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the three-year crash history (2001 – 2003) showed that there were a total of 31 injury crashes, 103 PDO crashes, and two fatal crashes. This total included 56 PDO and four injury crashes related to wildlife. There was a need repair the existing deer fence as well as install new fence and install deer/elk passage components (i.e. dirt mounds or deer fence gates), as needed.

Improvement Description: Between May 25, 2009 and June 1, 2010, these wildlife protection improvements were installed along this four-mile section of SH 82A. The cost of construction was $949,554.68.

The HSIP application anticipated that a 50% reduction in wildlife type crashes might be realized by the improvement. The initial benefit/cost ratio was estimated to be 1.27.

Summary and Findings

The analysis of safety before and after the new (and repaired) wildlife barrier fence was installed along SH 82A showed a reduction in the number and severity of wildlife type crashes. Along this segment of 4-lane divided arterial highway, there were 218 total crashes during the four-year period before the wildlife fence was installed (2005 – 2008). In the four years after construction (2011 – 2014), the number of crashes decreased to 68. This decrease in crashes was accompanied by a more modest decrease in AADT.

A comparison of wildlife and fence type crashes before and after the wildlife barrier fence improvement was installed showed that there was a decrease in injury crashes (from 14 INJ in four years before to 2 INJ in the four years after). The number of PDO crashes was reduced from 115 to 18. The actual reduction in wildlife and fence type crashes that was realized by the project was an improvement of approximately 82%. The ratio of benefits and cost for this project shows that benefits outweighed costs as the B/C ratio is 5.25 to one. The result is an improvement that was certainly justified from an economic standpoint.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records shows a decrease in the number of crashes; the total number of non-intersection crashes decreased from 218 during the four-year period (2005 to 2008) before the wildlife barrier fence project was constructed (see **Table 1** and **Exhibit 1**) to 68 during the four-year after period (201 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes also showed a decrease in the after period:

- Before (2005 – 2008) – no fatal crashes and 40 injury crashes with 46 injuries
- After (2011 – 2014) – no fatal crashes and 11 injury crashes with 13 injuries

This decrease in the total number of crashes was a larger percent decrease (69%) than the more modest decrease in traffic volumes on SH 82: 23,400 vehicles per day (vpd) for the before period and 19,200 vpd in the after period (an 18% decrease).

Table 1 - SH 82A (MP 7.0 to MP 11.0) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT	23,429 vpd	19,160 vpd
Filters:	Non-Intersection	Non-Intersection
Total Crashes	**218**	**68**
Fatal Crashes (Fatalities)	0 (0)	0
Injury Crashes (Injuries)	40 (46)	11 (13)
Property Damage Only	178	57
Crash Types: # (% of total crashes) [cumulative probability]		
Wild Animal	128 (58.7%) [100.00%]	16 (23.5%)
Fixed Objects	38 (17.4%)	28 (41.2%) [99.89%]
Overturning	25 (11.5%) [99.69%]	11 (16.2%) [98.80%]
Sideswipe Same	10 (4.6%)	2 (2.9%)
Rear End	7 (3.2%)	4 (5.9%)
Other Object	6 (2.8%)	6 (8.8%)
Fixed Object Crashes: # (% of FO) [cumulative probability]		
Embankment	13 (34.2%) [99.12%]	11 (39.3%) [99.98%]
Guard Rail	7 (18.4%)	7 (25.0%)
Delineator Post	5 (13.2%)	4 (14.3%)
Large Boulder/Rock	4 (10.5%)	1 (3.6%)
Fence	1 (2.6%)	4 (14.3%)

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

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

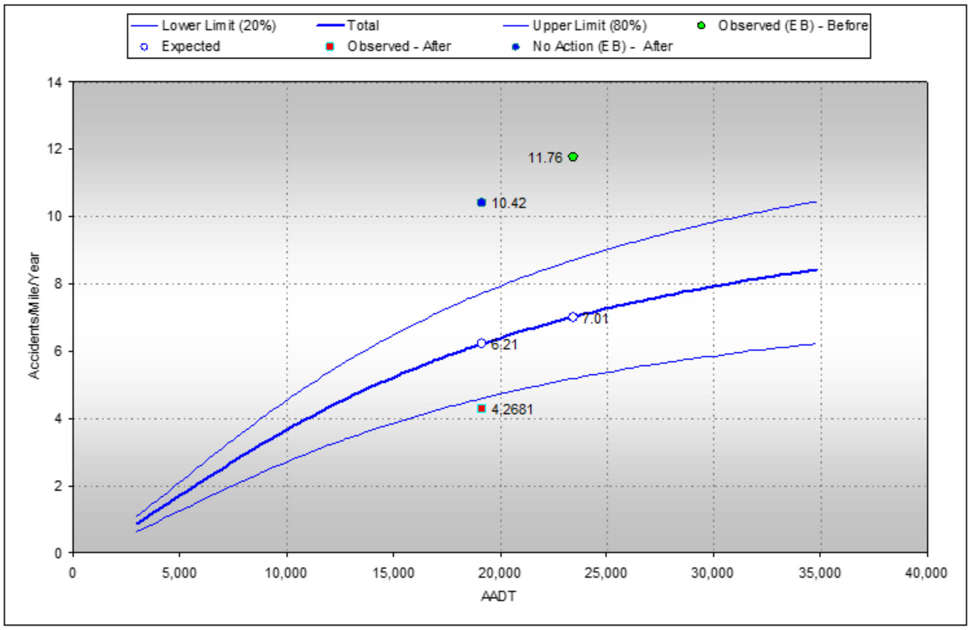
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect this improvement in the crash record. LOSS improved from the LOSS IV range for total crashes in the before period to LOSS I in the after period. Injury/Fatal crashes improved to LOSS I in the after period from the LOSS III range in the before period (see **Table 2**). However, it is difficult to conclude that the overall decrease in almost all types of crashes can be attributed solely to the installation of the wildlife fencing along this four-mile section of SH 82A. **Figures 1** and **2** also show that the number and severity of crashes during the period after construction was much improved in comparison to what it could have been without the project.

Figure 1 - SPF for Total Crashes

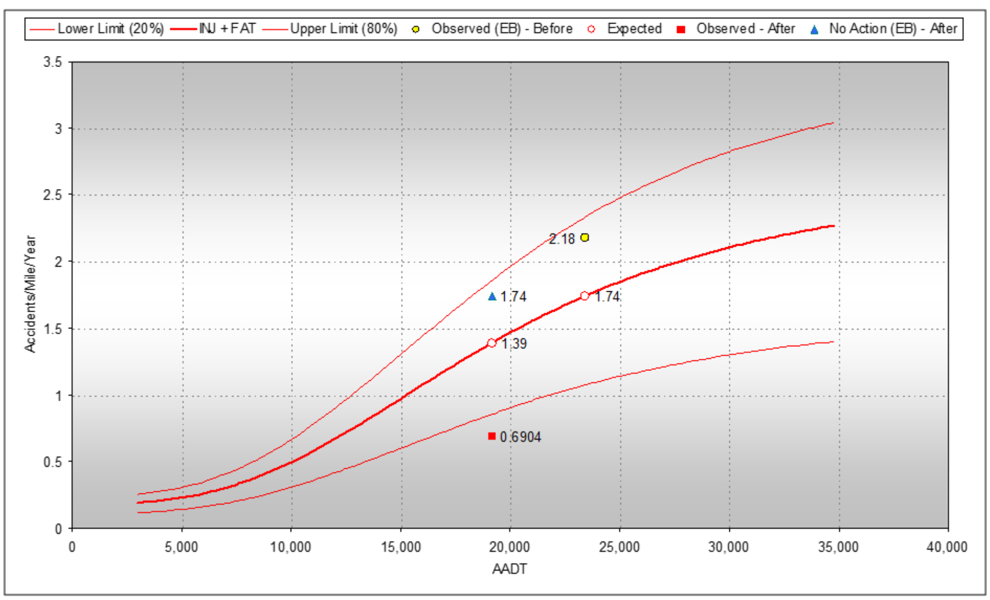
US 82 (MP 7.0 to MP 11.0)
Before: 2005 to 2008 After: 2011 to 2014



Note: Safety Performance Function (SPF) Model: Colorado - Rural Mountain 4-Lane Divided Highway

Figure 2 - SPF for Injury and Fatal Crashes

US 82 (MP 7.0 to MP 11.0)
Before: 2005 to 2008 After: 2011 to 2014



Note: Safety Performance Function (SPF) Model: Colorado - Rural Mountain 4-Lane Divided Highway

Table 2 – SH 82A (MP 7.0 to MP 11.0) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Rural, Mountainous, 4-lane Divided Highway	Rural, Mountainous, 4-lane Divided Highway	Rural, Mountainous, 4-lane Divided Highway
Total Crashes:			
LOSS	LOSS IV	LOSS I	LOSS IV
CPMPY	11.76	4.27	10.42
Mean CPMPY	7.01	6.21	6.21
Proportion of Mean	1.678	0.688	1.678
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS I	LOSS III
CPMPY	2.18	0.69	1.74
Mean CPMPY	1.74	1.39	1.39
Proportion of Mean	1.253	0.647	1.253

A more detailed review of the before and after crash record reveals that a significant portion of the overall improvement in safety can be attributed to the installation and repair of the wildlife fencing. **Table 3** provides a comparison of the wildlife and fence type crashes. The No Build After crashes were estimated using the decrease in the mean of the SPF for total crashes found in **Table 2** (decrease is 0.886 = 10.42/11.76). **Table 3** shows a decrease in injury crashes (from 14 in the before period to 2 in the after period). The number of PDO crashes was reduced from 115 to 18.

Table 3 – SH 82A (MP 7.0 to MP 11.0) - Results of Wildlife Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:			
Wildlife – Total	**128**	**16**	**113**
Injury (injuries)	14 (15)	2 (2)	12 (13)
PDO	114	14	101
Fence Total	**1**	**4**	**1**
PDO	1	4	1
Total	**129**	**20**	**114**
Injury (injuries)	14 (15)	2 (2)	12 (13)
PDO	115	18	102
% Reduction in Total – (Injuries/ PDO)		85% / 82%	

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 wildlife and fence type crashes. **Figure 3** shows the result of the Benefit/Cost calculation is a B/C ratio of 5.25. This result shows that the project was justified from an economic standpoint due to the significant decrease in the number and severity of wildlife type crashes.

One other finding of interest is that 14 of the 16 wildlife type crashes in the after period occurred between MP 7.0 and MP 8.0 – at the northwest end of the project. It appears from CDOT's OTIS/Windshield and Google StreetView that the fencing starts at MP 7.13 (approximately) on the west side of the highway. There is significant development on the east side through MP 8.0. Thus, there may be limited opportunity for further improvement in wildlife type crashes.

Figure 3 – SH 82A (MP 7.0 to MP 11.0) - Benefit Cost Analysis – Wildlife Crashes Only

COLORADO Department of Transportation

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

05/10/2016

Job #: 20160510072623

Location: 82A **Begin:** 7.00 **End:** 11.00 **From:** 01/01/2005 **To:** 12/31/2008

SH 82A - AP0110 - #15901 - After non-intersection - wildlife

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	102		Weighted PDO:	29.57	85% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	12	13 :Injured	Weighted INJ:	3.77	82% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	100% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	84% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
	Cost:	$ 949,554				Service Life:	15
	From:	01/01/2005				Capital Recovery Factor:	0.096
	To:	12/31/2008	Days:	1461		Annual Maintenance/Delay Cost:	$ 500

Benefit Cost Ratio: 5.25 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Wildlife and Fence Type Crashes
Special Notes:

Location: 82A **Begin:** 7.00 **End:** 11.00 **From:** 01/01/2005 **To:** 12/31/2008

SH 82A - AP0110 - #15901 - Before Deer Fence Project - Non-Intersection Crashes

Severity

PDO:	178		
INJ:	40	46	:Injured
FAT:	0	0	:Killed
Total:	**218**		

Number of Vehicles

One Vehicle:	187
Two Vehicles:	28
Three or More:	3
Unknown:	0
Total:	**218**

Location

On Road:	157
Off Road Left:	27
Off Road Right:	33
Off Road at Tee:	0
Off in Median:	1
Unknown:	0
Total:	**218**

Lighting Conditions

Daylight:	69
Dawn or Dusk:	18
Dark - Lighted:	3
Dark - Unlighted:	128
Unknown:	0
Total:	**218**

Weather Conditions

None:	191
Rain:	6
Snow/Sleet/Hail:	20
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**218**

Crash Rates

PDO:	1.30	*
INJ:	0.29	*
FAT:	0.00	**
Total:	**1.59**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	25	Bridge Abutment:	0
Other Non Collision:	3	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	13
Head On:	0	Curb:	0
Rear End:	7	Delineator Post:	5
Sideswipe (Same):	10	Fence:	1
Sideswipe (Opposite):	0	Tree:	1
Approach Turn:	0	Large Boulders or Rocks:	4
Overtaking Turn:	1	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	1
Domestic Animal:	0	Total Fixed Objects:	38
Wild Animal:	128	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	3
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	2	Involving Other Object:	3
Bridge Rail:	0	Total Other Objects:	6
Guard Rail:	7	Unknown:	0
Cable Rail:	0	**Total:**	**218**
Concrete Barrier:	3		

Mainline/Ramps/Frontage Roads

Mainline:	218
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**218**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	218
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**218**

Road Conditions

Dry:	173
Wet:	14
Muddy:	0
Snowy:	7
Icy:	16
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	4
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	1
Icy w/Icy Road Treatment:	2
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**218**

ADT: 23,429 **Length:** 4.00

Location: 82A **Begin:** 7.00 **End:** 11.00 **From:** 01/01/2005 **To:** 12/31/2008

SH 82A - AP0110 - #15901 - Before Deer Fence Project - Non-Intersection Crashes

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	128	13	2
Passenger Car/Van w/Trl:	1	0	0
Pickup Truck/Utility Van:	57	9	1
Pickup Truck/Utility Van w/Trl:	4	0	0
SUV:	20	6	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	7	3	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	1	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**218**	**31**	**3**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	165	30	3
Asleep at the Wheel:	7	1	0
Illness:	3	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	11	0	0
Driver Fatigue:	4	0	0
Driver Preoccupied:	15	0	0
Driver Unfamilar with Area:	2	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	10	0	0
Total:	**218**	**31**	**3**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	210	31	3
Alcohol Involved:	7	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**218**	**31**	**3**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	171	19	2
Slowing:	5	6	1
Stopped in Traffic:	0	1	0
Making Right Turn:	0	0	0
Making Left Turn:	0	1	0
Making U-Turn:	1	0	0
Passing:	5	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	5	0	0
Avoiding Object/Veh in Road:	16	2	0
Weaving:	3	0	0
Other:	12	1	0
Unknown:	0	1	0
Total:	**218**	**31**	**3**

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	112	20	2
Southeast:	0	0	0
South:	0	0	0
Southwest:	0	0	0
West:	106	10	1
Northwest:	0	0	0
Unknown:	0	1	0
Total:	**218**	**31**	**3**

ADT: 23,429 **Length:** 4.00

Location: 82A **Begin:** 7.00 **End:** 11.00 **From:** 01/01/2011 **To:** 12/31/2014

SH 82A - AP0110 - #15901 - After Deer Fence Project - Non-Intersection Crashes

Severity

PDO:	57		
INJ:	11	13	:Injured
FAT:	0	0	:Killed
Total:	**68**		

Number of Vehicles

One Vehicle:	57
Two Vehicles:	11
Three or More:	0
Unknown:	0
Total:	**68**

Location

On Road:	29
Off Road Left:	10
Off Road Right:	29
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**68**

Lighting Conditions

Daylight:	38
Dawn or Dusk:	3
Dark - Lighted:	1
Dark - Unlighted:	26
Unknown:	0
Total:	**68**

Weather Conditions

None:	45
Rain:	6
Snow/Sleet/Hail:	16
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**68**

Crash Rates

PDO:	0.51 *
INJ:	0.10 *
FAT:	0.00 **
Total:	**0.61** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	11	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	11
Head On:	0	Curb:	0
Rear End:	4	Delineator Post:	4
Sideswipe (Same):	2	Fence:	4
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	1
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	1	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	1
Domestic Animal:	0	Total Fixed Objects:	28
Wild Animal:	16	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	3
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	3
Bridge Rail:	0	Total Other Objects:	6
Guard Rail:	7	Unknown:	0
Cable Rail:	0	**Total:**	**68**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	68
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**68**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	68
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**68**

Road Conditions

Dry:	37
Wet:	10
Muddy:	0
Snowy:	7
Icy:	10
Slushy:	2
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	1
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	1
Unknown:	0
Total:	**68**

ADT: 19,160 **Length:** 3.98

Location: 82A	Begin: 7.00	End: 11.00	From: 01/01/2011	To: 12/31/2014

SH 82A - AP0110 - #15901 - After Deer Fence Project - Non-Intersection Crashes

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	32	5	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	16	3	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	15	3	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	3	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	2	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**68**	**11**	**0**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	34	7	0
Slowing:	1	1	0
Stopped in Traffic:	0	1	0
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	1	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	1	1	0
Weaving:	0	0	0
Other:	30	0	0
Unknown:	0	0	0
Total:	**68**	**11**	**0**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	37	9	0
Asleep at the Wheel:	1	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	8	1	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	9	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	11	1	0
Total:	**68**	**11**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	34	8	0
Southeast:	2	0	0
South:	0	0	0
Southwest:	0	0	0
West:	32	3	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**68**	**11**	**0**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	65	11	0
Alcohol Involved:	3	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**68**	**11**	**0**

ADT: 19,160 **Length:** 3.98

Project Information

Project Name: El Paso Street at Fillmore

Project Description: Realign El Paso Street Approaches

CDOT Region: 6 Project Def: 16011 County: El Paso

Location: Off-Sys Mile Points: N/A Length: N/A

Schedule: Work Start Date: approx. 8/2009 Completion Date: 7/07/2010

Problem Description: According to the original HSIP funding application, the existing offset of the north and south legs (El Paso Street) at the intersection, the lack of sidewalk on the south side of Fillmore Street east of the intersection and the lack of crosswalks crossing El Paso Street contributed to broadside, approach turn, rear end, same direction sideswipe and pedestrian crashes at the intersection.

Improvement Description: In late 2009 and early 2010 the north approach was realigned to match the south leg, sidewalks were constructed and pedestrian crosswalks were added crossing El Paso Street. The traffic signal was also reconstructed. In the new configuration it became possible to operate the northbound and southbound phases simultaneously. It also became possible to operate left turns from eastbound and westbound Fillmore simultaneously (they had overlapping paths in the existing configuration). Left turns from El Paso are now permissive (green ball), while lefts from Fillmore are now protected/permitted (flashing yellow arrow in a 4 section head). Total cost of the improvements was $ 506,536.

HSIP analysis assumed broadside, approach turn, rear end, same direction sideswipe and pedestrian crashes would be affected by the improvements with CRF of 20%. Predicted B/C was 1.31.

Summary and Findings

The analysis of safety before and after the intersection at Fillmore Street and El Paso Street was improved showed no change in total crashes or in the number of persons injured. There were reductions in some crash types that were the targets of the improvement, and increases in others. Approach Turn crashes, were eliminated after construction of the intersection improvements, but broadside crashes, which did not occur prior to construction of the intersection improvements, increased. For this intersection there were 20 total crashes during the 4-year period before the improvement (2005 – 2008). In the 4 years after construction (2011 – 2014) the number of crashes remained at 20.

The approach geometry changes and signal modifications apparently responsible for the decreased number of approach turn crashes, and for increased broadside crashes at the intersection. There was no net benefit from the improvement in terms of safety, and the project was not justified from the safety improvement standpoint. There are also operational advantages in terms of reduced delay since northbound and southbound traffic can be served simultaneously in the new configuration (which was not possible with the offset alignments before) and eastbound left turns and westbound left turns can be served simultaneously in the new configuration, since the turning paths no longer overlap.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows no change in the number of crashes; the total number of crashes were 20 during the five-year period (2002 to 2006) before the alignment and signal modifications (see **Table 1** and **Exhibit 1**) and remained at 20 during the five-year after period (2010 to 2014) (see **Table 1** and **Exhibit 2**). The number of serious crashes decreased, while the number of people injured remained constant in the four-year period after the improvements:

- Before (2005 – 2008) – no fatal crashes and 5 injury crashes with 7 injuries
- After (2011 – 2014) – no fatal crashes and 4 injury crashes with 7 injuries

Since entering volume is unknown, the crash rate for the before period cannot be computed.

Using the reported volume on Fillmore of 32,000 VPD and an estimated volume for El Paso of 2,000 VPD we compute a crash rate of 0.322 crashes per million entering vehicles.

Table 1 – Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT (Fillmore/El Paso)	Not Available	32,000/ Estimated 2000
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**20**	**20**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	5 (7)	4 (7)
Property Damage Only	15	16
Crash Types: # (%) [significance]		
Rear-End	11 (55.0%)	11 (55.0%)
Broadside	0 (0.0%)	5 (25.0%)
Approach Turn	3 (15.0%)	0 (0.0%)
Sideswipe Same	4 (20.0%) [98.4]	3 (15.0%)
Pedestrian	0 (0.0%)	0 (0.0%)

The magnitude of safety problems on select highway facilities 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.

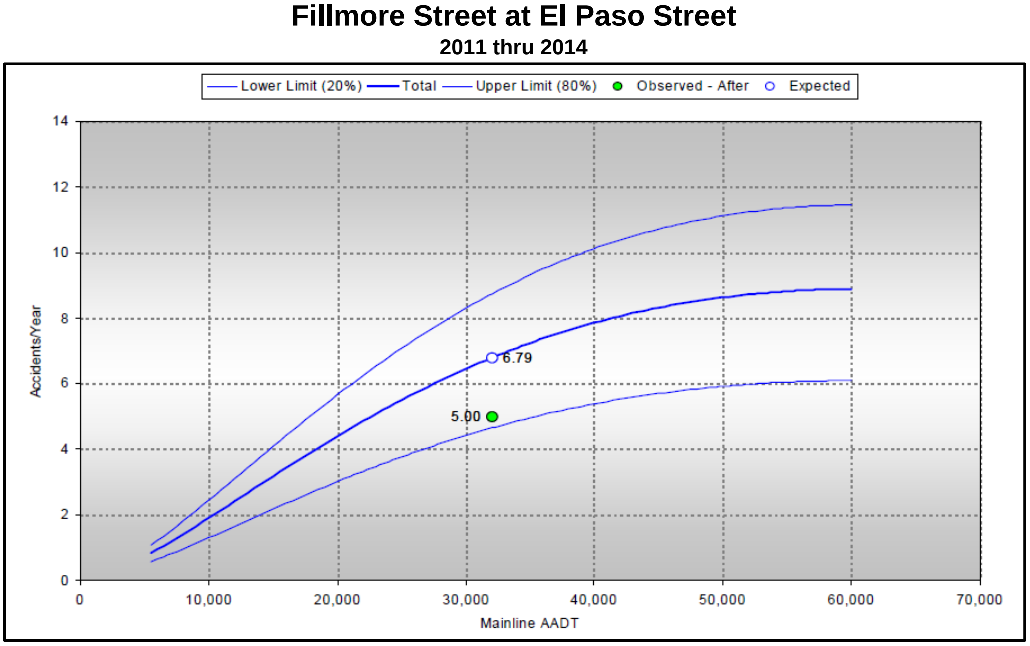
Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted 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 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 on intersection is performing in regard to its expected crash frequency at a specific level of ADT.

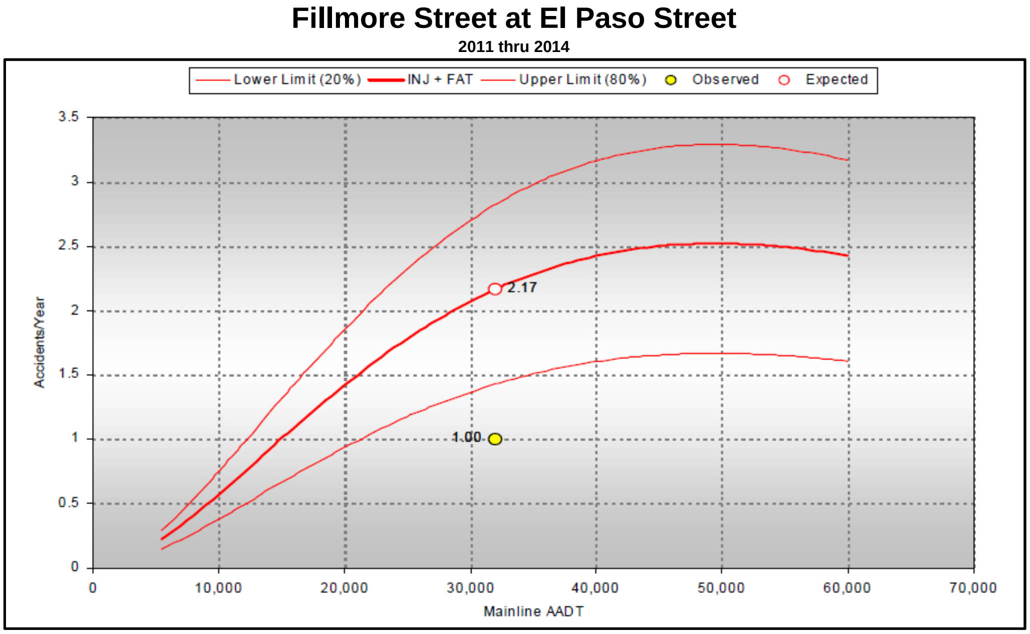
Since volume data is not available for the before period for this intersection, SPF's cannot be prepared showing the expected changes as volumes change over time. **Figure 1** shows the observed performance of the intersection in the after-improvements period in terms of total crashes. It shows LOSS-II category performance. **Figure 2** shows the observed performance of the intersection in the after period in terms of severity. It shows LOSS-I category performance. Despite the fact that the project was not justified by observed safety improvement, it is operating very well from the safety standpoint.

Figure 1 – SPF for Total Crashes – After Intersection Improvements



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

Figure 2 – SPF for Injury and Fatal Crashes – After Intersection Improvements



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

A more detailed review of the before and after crash record reveals that rear end crashes were unchanged. Approach turn crashes were eliminated and same direction sideswipe were reduced, but broadside crashes increased in the after period. There were no pedestrian crashes in either the before or after periods. **Table 2** shows a comparison of primary types of crashes that were expected to be directly affected by the improvement.

Table 2 – Results of Crash Analyses

	Before	**After**
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:		
Total Crashes	**20**	**20**
Injury (injuries)	5 (7)	4 (7)
PDO	15	16
% Reduction in Total (Injuries/PDO)		0.0% / -6.7%
Rear-Ends – Total	**11**	**11**
Injury (injuries)	2 (3)	3 (6)
PDO	9	8
% Reduction in Total (Injuries/PDO)		-100.0% / 11.1%
Broadsides – Total	**0**	**5**
Injury (injuries)	0 (0)	1 (1)
PDO	0	5
% Reduction in Total (Injuries/PDO)		Undefined / Undefined
Approach Turn	**3**	**0**
Injury (injuries)	1 (1)	0 (0)
PDO	2	0
% Reduction in Total (Injuries/PDO)		100% / 100%
Sideswipe Same Direction	**4**	**3**
Injury (injuries)	2 (3)	0 (0)
PDO	2	3
% Reduction in Total (Injuries/PDO)		100% / -50%

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. Since total crashes and the total number of injured people did not decrease, there is no net safety benefit, so the B/C is equal to zero, and the project is not justified from the safety standpoint. As mentioned previously, there are operational advantages to the new configuration which reduce delay.

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

Exhibit 1

10/10/2016

Job #: 20161010091442

Location: Accident History for FILLMORE and EL PASO **From:** 01/01/2005 **To:** 12/31/2008

BEFORE

Severity

PDO:	15		
INJ:	5	7	:Injured
FAT:	0	0	:Killed
Total:	**20**		

Number of Vehicles

One Vehicle:	0
Two Vehicles:	17
Three or More:	3
Unknown:	0
Total:	**20**

Location

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

Lighting Conditions

Daylight:	19
Dawn or Dusk:	0
Dark - Lighted:	1
Dark - Unlighted:	0
Unknown:	0
Total:	**20**

Weather Conditions

None:	16
Rain:	0
Snow/Sleet/Hail:	2
Fog:	0
Dust:	0
Wind:	0
Unknown:	2
Total:	**20**

Crash Rates

PDO:	N/A *	* MVMT
INJ:	N/A *	** 100 MVMT
FAT:	N/A **	**Total:** **N/A** *

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	0
Head On:	1	Curb:	0
Rear End:	11	Delineator Post:	0
Sideswipe (Same):	4	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	3	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	0
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**20**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	0
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

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

Road Description

At Intersection:	14
At Driveway Access:	0
Intersection Related:	6
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**20**

Road Conditions

Dry:	18
Wet:	2
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**20**

Location: Accident History for FILLMORE and EL PASO **From:**01/01/2005 **To:**12/31/2008

BEFORE

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	15	13	2
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	3	4	1
Pickup Truck/Utility Van w/Trl:	1	1	0
SUV:	0	1	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	1	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**20**	**20**	**3**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	8	8	0
Slowing:	0	0	0
Stopped in Traffic:	0	10	3
Making Right Turn:	2	0	0
Making Left Turn:	3	1	0
Making U-Turn:	1	0	0
Passing:	0	0	0
Backing:	3	1	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	3	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**20**	**20**	**3**

Direction	Veh 1	Veh 2	Veh 3
North:	2	2	0
Northeast:	0	0	0
East:	10	8	2
Southeast:	0	0	0
South:	4	3	1
Southwest:	0	0	0
West:	4	7	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**20**	**20**	**3**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	11	17	3
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	5	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	4	3	0
Total:	**20**	**20**	**3**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	18	20	3
Alcohol Involved:	2	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**20**	**20**	**3**

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

Exhibit 2

10/10/2016

Job #: 20161010091655

Location: 392B **Begin:** 111.51 **End:** 111.57 **From:** 01/01/2011 **To:** 12/31/2014

AFTER

Severity

PDO:	11		
INJ:	6	9	:Injured
FAT:	0	0	:Killed
Total:	**17**		

Number of Vehicles

One Vehicle:	2
Two Vehicles:	14
Three or More:	1
Unknown:	0
Total:	**17**

Location

On Road:	15
Off Road Left:	0
Off Road Right:	2
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**17**

Lighting Conditions

Daylight:	13
Dawn or Dusk:	0
Dark - Lighted:	1
Dark - Unlighted:	3
Unknown:	0
Total:	**17**

Weather Conditions

None:	15
Rain:	0
Snow/Sleet/Hail:	0
Fog:	1
Dust:	0
Wind:	1
Unknown:	0
Total:	**17**

Crash Rates

PDO:	20.85	*
INJ:	11.38	*
FAT:	0.00	**
Total:	**32.23**	*

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	17
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

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

Road Description

At Intersection:	12
At Driveway Access:	0
Intersection Related:	5
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**17**

Road Conditions

Dry:	16
Wet:	0
Muddy:	0
Snowy:	0
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**17**

ADT: 6,119 **Length:** 0.05

Location: 392B **Begin:** 111.51 **End:** 111.57 **From:** 01/01/2011 **To:** 12/31/2014

AFTER

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	6	6	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	7	3	1
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	2	6	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	2	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**17**	**15**	**1**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	8	15	1
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	1	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	3	0	0
Total:	**17**	**15**	**1**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	17	15	1
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**17**	**15**	**1**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	6	7	0
Slowing:	0	1	0
Stopped in Traffic:	0	6	0
Making Right Turn:	2	0	0
Making Left Turn:	4	1	1
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	2	0	0
Enter/Leave Parked Position:	1	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	2	0	0
Unknown:	0	0	0
Total:	**17**	**15**	**1**

Direction	Veh 1	Veh 2	Veh 3
North:	6	5	0
Northeast:	0	0	0
East:	5	1	0
Southeast:	0	0	0
South:	0	4	0
Southwest:	0	0	0
West:	6	5	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**17**	**15**	**1**

ADT: 6,119 **Length:** 0.05

Project Information

Project Name: Colfax Avenue (US 40) / Youngfield Street

Project Description: Upgrade signal

CDOT Region: 6 Project Def: 16313 County: Jefferson (Lakewood)

Location: US 40 Mile Points: 289.38 Length: N/A

Schedule: Work Start Date: Approx. 2009 Completion Date: Approx. 2010

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the three-year crash history showed a higher than expected number of rear-end and broadside type crashes. The cause of these crashes was assumed to be old span wire mounted signals that were subject to wind damage and visibility problems on gusty days.

Improvement Description: In 2009/2010, the intersection was realigned to improve turns and add a protected/permissive southbound left-turn lane. The span wire was replaced with mast arms. The cost of construction was $622,904.

The HSIP application anticipated that four crash types would be impacted by this improvement: rear-end, approach turn, broadside, and pedestrian type crashes. It was anticipated that there would be a 20% crash reduction for these crash types. The initial benefit/cost ratio was estimated to be 1.18.

Summary and Findings

The analysis of safety before and after the geometry and signal was upgraded at US 40 and Youngfield Street showed safety improvements. For this intersection, there were 36 total crashes during the four-year period before the upgrades (2004 – 2007). In the four years after construction (2011 – 2014), the number of crashes was decreased to 19. While daily volumes slightly decreased, the crash rate was still reduced. In addition, the number of injuries also diminished.

The signal and geometry upgrade was responsible for decreases in the number and severity of rear-end and broadside crashes. The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 3.33 to one, showing that the improvement was justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 36 during the four-year period (2004 to 2007) before the signal was upgraded (see **Table 1** and **Exhibit 1**) to 19 during the four-year after period (2011 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes showed a large decrease, and the number of injuries also decreased:

- Before (2004 – 2007) – no fatal crashes and 11 injury crashes with 16 injuries
- After (2011 – 2014) – no fatal crashes and 6 injury crashes with 10 injuries

This decrease in injuries occurred in spite of slightly lower traffic volumes at the intersection. This resulted in a decrease in the crash rates:

- Before (2004 – 2007): 0.78 crashes per million entering vehicles (cpmev)
- After (2011 – 2014): 0.40 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2004 to 12/31/2007 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT (SH 40/Youngfield St)	27,450/4,000 vpd	26,250/6,700 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**36**	**19**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	11 (16)	6 (10)
Property Damage Only	25	13
Crash Types: # (%) [significance]		
Rear End	19 (52.7%)	7 (36.8%)
Broadside	9 (25.0%) [95.8%]	3 (15.8%)
Approach Turn	7 (19.4%)	7 (36.8%) [98.0%]

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

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

level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

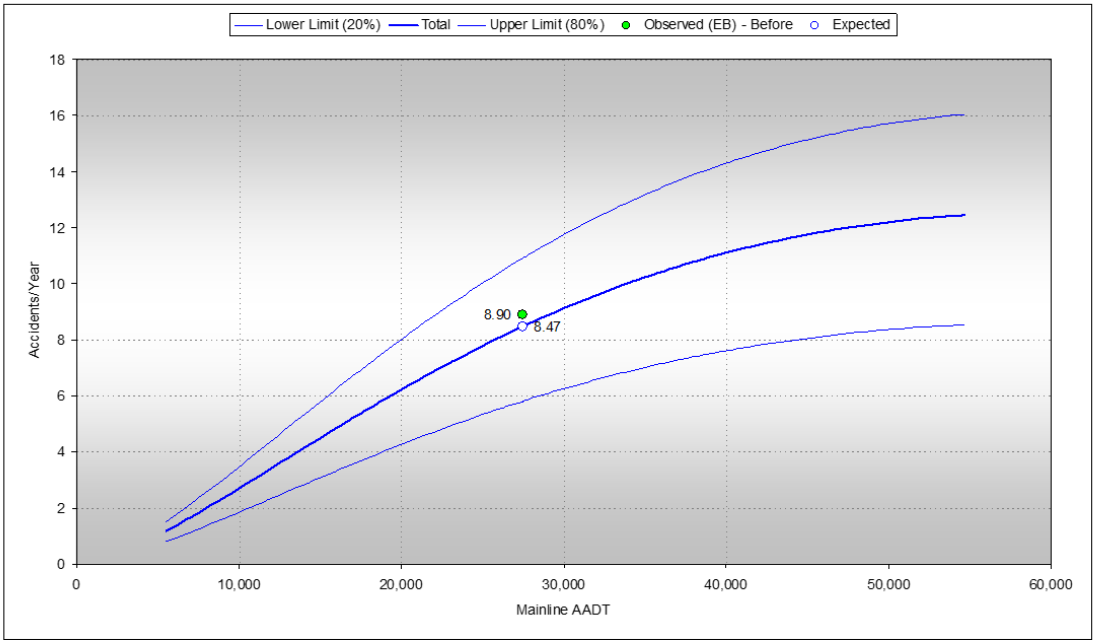
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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

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

Figure 1 - SPF for Total Crashes - Before

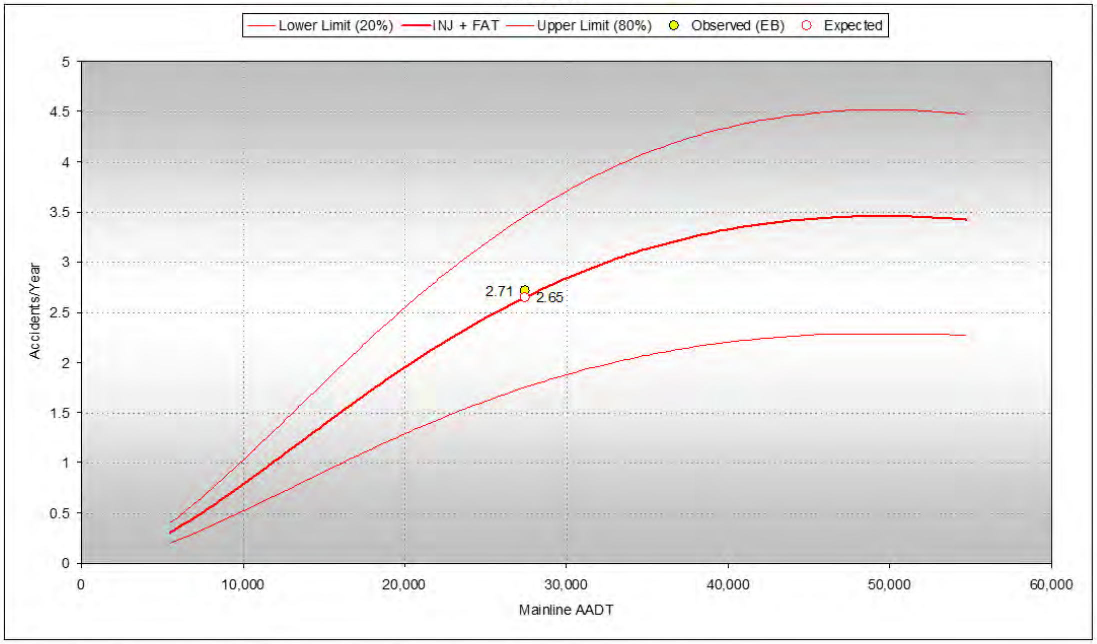
SH 40 (MP 289.38)
2004 to 2007



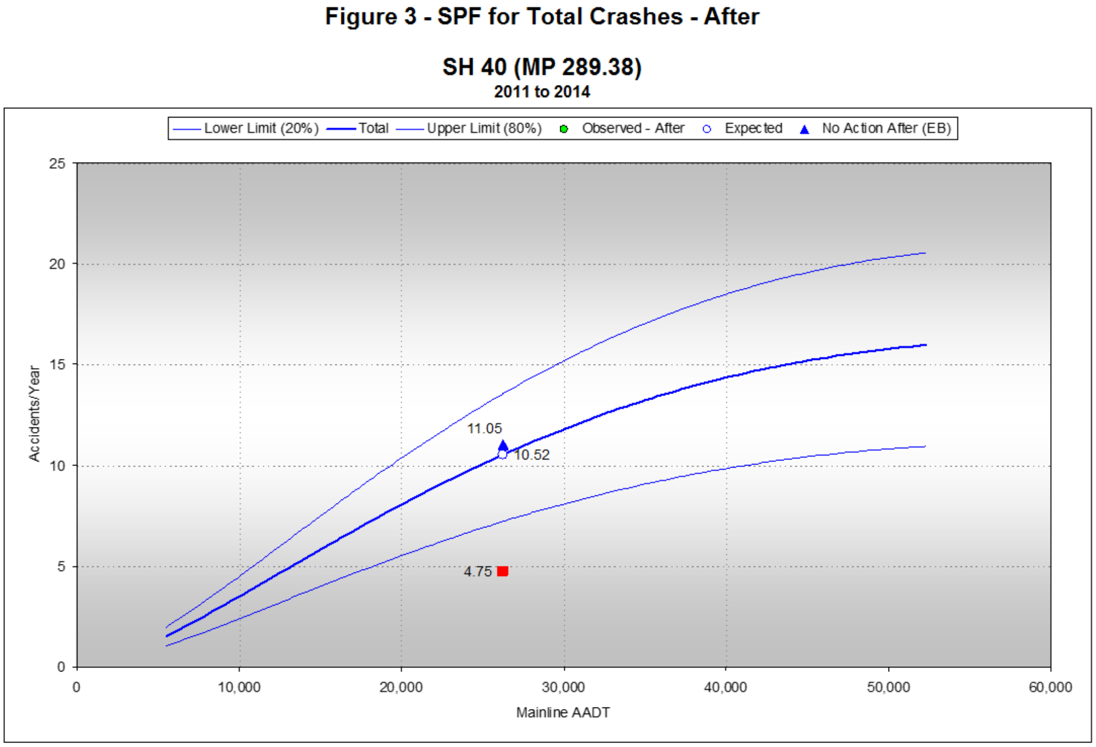
Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 2 - SPF for Injury and Fatal Crashes - Before

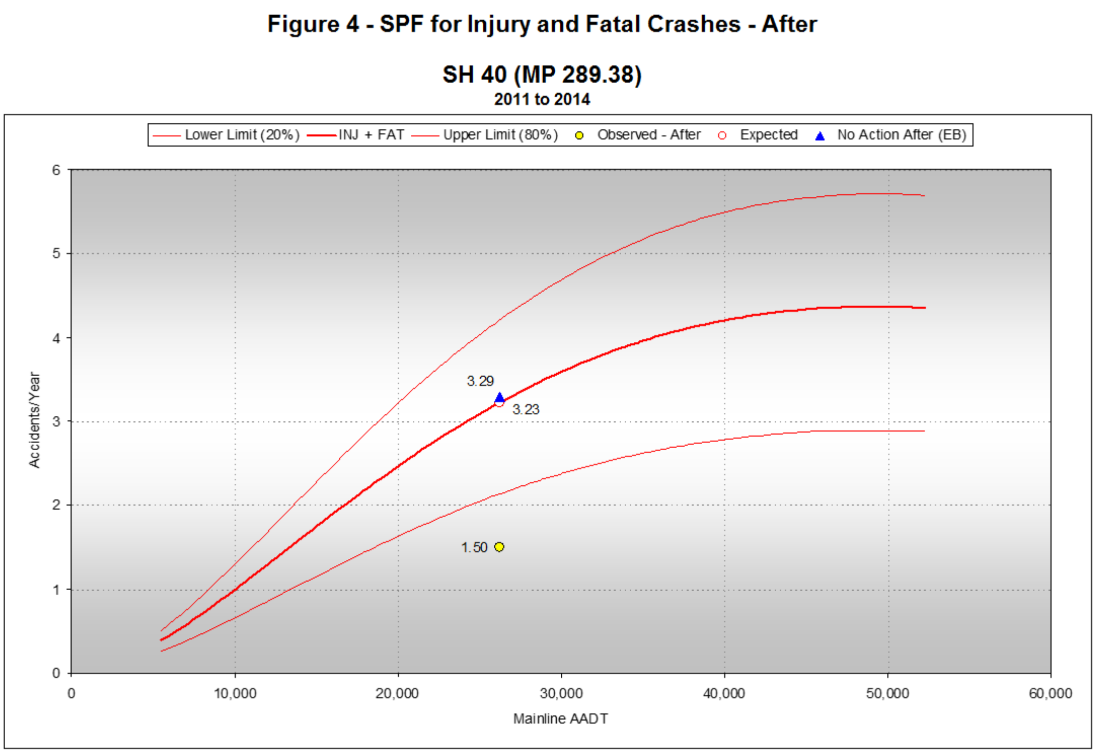
SH 40 (MP 289.38)
2004 to 2007



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



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



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

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS III	LOSS I	LOSS III
CPY	8.90	4.75	11.05
Mean CPY	8.47	10.52	10.52
Proportion of Mean	1.05	0.45	1.05
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS I	LOSS III
CPY	2.71	1.50	3.29
Mean CPY	2.65	3.23	3.23
Proportion of Mean	1.02	0.46	1.02

A more detailed review of the before and after crash record reveals that a significant improvement in safety can be attributed to the upgrade of the signal. **Table 3** shows a comparison of three types of crashes that are most directly affected by the improvement: rear-end, approach turn, and broadside. The No Build After crashes were estimated using the increase in the median of the SPF for total crashes found in **Table 2** (increase is 1.24 = 10.52/8.47).

Table 3 – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2004 to 12/31/2007 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:			
Rear Ends – Total	**19**	**7**	**23**
Fatal (fatalities)	0	0	0
Injury (injuries)	5 (5)	2 (2)	6 (6)
PDO	14	5	17
% Reduction in Total		70%	
Broadsides – Total	**9**	**3**	**11**
Injury (injuries)	2 (3)	1 (2)	2 (3)
PDO	7	2	9
% Reduction in Total		73%	
Approach Turns – Total	**7**	**7**	**9**
Injury (injuries)	4 (8)	2 (5)	5 (10)
PDO	3	5	4
% Reduction in Total		22%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for the impacted crash types. As shown, the B/C ratio for rear-end, approach turn, and broadside crashes is 3.33, showing that the improvement was justified.

Figure 5 – Benefit Cost Analysis – Rear-End, Approach Turn, Broadside Crashes Only

CDOT COLORADO Department of Transportation

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

08/10/2016

Job #: 20160810132557

Location: 40C **Begin:** 289.36 **End:** 289.40 **From:** 01/01/2004 **To:** 12/31/2007

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	30		Weighted PDO:	8.23	60% : CRF for PDO	Cost of PDO:	$ 9,300
INJ:	13	19 : Injured	Weighted INJ:	5.21	53% : CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 : Killed	Weighted FAT:	0.00	100% : CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	57% : Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	10
						Capital Recovery Factor:	0.129
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 622,904
From: 01/01/2004
To: 12/31/2007 Days: 1461

Benefit Cost Ratio: 3.33 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SIGNALS - UPGRADE
Special Notes: BROADSIDE, REAR-END, APPROACH TURN CRASHES

Location: 40C **Begin:** 289.36 **End:** 289.40 **From:** 01/01/2004 **To:** 12/31/2007

Severity

PDO:	25		
INJ:	11	16	:Injured
FAT:	0	0	:Killed
Total:	**36**		

Number of Vehicles

One Vehicle:	0
Two Vehicles:	33
Three or More:	3
Unknown:	0
Total:	**36**

Location

On Road:	36
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**36**

Lighting Conditions

Daylight:	31
Dawn or Dusk:	0
Dark - Lighted:	4
Dark - Unlighted:	1
Unknown:	0
Total:	**36**

Weather Conditions

None:	33
Rain:	1
Snow/Sleet/Hail:	2
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**36**

Crash Rates

PDO:	15.58 *
INJ:	6.86 *
FAT:	0.00 **
Total:	**22.44** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	9	Embankment:	0
Head On:	1	Curb:	0
Rear End:	19	Delineator Post:	0
Sideswipe (Same):	0	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	7	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	0
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**36**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	36
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**36**

Road Description

At Intersection:	25
At Driveway Access:	0
Intersection Related:	11
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**36**

Road Conditions

Dry:	29
Wet:	2
Muddy:	0
Snowy:	1
Icy:	0
Slushy:	2
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	1
Unknown:	0
Total:	**36**

ADT: 27,454 **Length:** 0.04

Location: 40C **Begin:** 289.36 **End:** 289.40 **From:** 01/01/2004 **To:** 12/31/2007

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	21	21	3
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	9	9	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	5	4	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	1	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**36**	**36**	**3**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	19	34	2
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	4	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	13	2	1
Total:	**36**	**36**	**3**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	35	36	3
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**36**	**36**	**3**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	21	11	0
Slowing:	2	2	1
Stopped in Traffic:	0	16	1
Making Right Turn:	4	1	0
Making Left Turn:	9	6	1
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**36**	**36**	**3**

Direction	Veh 1	Veh 2	Veh 3
North:	1	4	0
Northeast:	0	0	0
East:	10	5	0
Southeast:	0	0	0
South:	11	15	1
Southwest:	0	0	0
West:	14	12	2
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**36**	**36**	**3**

ADT: 27,454 **Length:** 0.04

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

Exhibit 2

08/09/2016

Job #: 20160809171332

Location: 40C **Begin:** 289.36 **End:** 289.40 **From:** 01/01/2011 **To:** 12/31/2014

Severity

PDO:	13		
INJ:	6	10	:Injured
FAT:	0	0	:Killed
Total:	**19**		

Number of Vehicles

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

Location

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

Lighting Conditions

Daylight:	14
Dawn or Dusk:	1
Dark - Lighted:	4
Dark - Unlighted:	0
Unknown:	0
Total:	**19**

Weather Conditions

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

Crash Rates

PDO:	9.45	*
INJ:	4.36	*
FAT:	0.00	**
Total:	**13.82**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	3	Embankment:	0
Head On:	0	Curb:	0
Rear End:	7	Delineator Post:	0
Sideswipe (Same):	2	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	7	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	0
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**19**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	19
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

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

Road Description

At Intersection:	14
At Driveway Access:	0
Intersection Related:	5
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**19**

Road Conditions

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

ADT: 21,890 **Length:** 0.04

Location: 40C **Begin:** 289.36 **End:** 289.40 **From:** 01/01/2011 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	10	14	2
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	0	3	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	7	2	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**19**	**19**	**2**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	8	12	0
Slowing:	0	1	0
Stopped in Traffic:	0	6	2
Making Right Turn:	1	0	0
Making Left Turn:	9	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**19**	**19**	**2**

Direction	Veh 1	Veh 2	Veh 3
North:	3	0	1
Northeast:	0	0	0
East:	9	5	0
Southeast:	0	0	0
South:	0	2	0
Southwest:	1	1	0
West:	6	11	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**19**	**19**	**2**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	6	19	2
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	2	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	3	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	6	0	0
Total:	**19**	**19**	**2**

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

ADT: 21,890 **Length:** 0.04

Project Information

Project Name: Upgrade Signals on Kipling (SH 391) and Colfax (SH 40)

Project Description: Reconstruct Traffic Signals at Kipling/20th and Colfax/Newland

CDOT Region: 6 Project Def: 16314 County: Jefferson (Lakewood)

Location: SH 391 / SH 40 Mile Points: 6.77 / 293.40 Length: N/A

Schedule: Work Start Date: Late 2008/2009 Completion Date: Approx. 2010

Problem Description: This project includes two signals located in Lakewood: SH 391/20th Street and SH 40/Newland Street. The crash history at the intersection of SH 391 and 20th Street experienced 58 property damage only crashes, 13 injury crashes, and 1 fatal crash during the five-year crash history. The intersection showed a higher than expected number of broadside and approach turn type crashes.

The intersection of SH 40 and Newland Street had 23 property damage only and 10 injury crashes during the five-year crash history. This intersection had a higher than expected number of broadside crashes. Both of these intersections had signals not centered over lanes, incandescent bulbs, and 8-inch signal heads that were thought to contribute to the crashes.

Improvement Description: Between late 2008 and 2010, the signals were replaced. The new signals had heads located over lanes and had 12-inch heads with LED bulbs, black housings, and backplates. In addition, pedestrian countdown timers were installed at each intersection. At the intersection of SH 391 and 20th Street, the northbound and southbound left-turns were changed to protected only phasing. The cost of construction was $442,337.

The HSIP application anticipated that four crash types would be impacted by the improvements: rear-end, approach turn, broadside, and pedestrian type crashes. It was anticipated that there would be approximately a 15% crash reduction for these crash types. The initial benefit/cost ratio was estimated to be 2.47 at the intersection of SH 391 and 20th Street and 1.70 at the intersection of SH 40 and Newland Street.

Summary and Findings

The analysis of safety before and after the signal was upgraded at SH 391 and 20th Street showed no safety improved for intersection. While the number of property damage only crashes decreased, the number of injuries increased from 2 to 12 between the before and after periods. Additionally, there was a fatality in the after period when there had not been a fatality in the before period.

The intersection of SH 40 and Newland Street showed significant safety improvements with the signal upgrade. There was a fatality in the before period and no fatality in the after period. Injuries decreased from 9 during the before period to 1 in the after period. The overall ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 12.04 to one, showing that the improvement was justified from a safety standpoint.

Results of Safety Analyses

The signal at the intersection of SH 40 and Newland Street was removed in late 2014/early 2015. As a result, 2014 crashes were excluded from any comparison and only a three-year crash history was used for both intersection analyses.

Using VZS, the review of before and after crash records at the intersection of SH 391 and 20th Street shows approximately the same number of crashes for both periods; the total number of crashes increased from 21 during the three-year period (2005 to 2007) before the signal was upgraded (see **Table 1** and **Exhibit 1**) to 23 during the three-year after period (2011 to 2013) (see **Table 1** and **Exhibit 2**). The number of severe crashes increased:

- Before (2005 – 2007) – no fatal crashes and 2 injury crashes with 2 injuries
- After (2011 – 2013) – 1 fatal crash with 1 fatality and 8 injury crashes with 12 injuries

The number of crashes increased slightly along with a slight increase in traffic volumes at the intersection. This resulted in a small increase in the crash rates:

- Before (2005 – 2007): 0.42 crashes per million entering vehicles (cpmev)
- After (2011 – 2013): 0.44 cpmev

Table 1 – SH 391 / 20th Street – Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2005 to 12/31/2007 (3 yr.)	1/1/2011 to 12/31/2013 (3 yr.)
AADT (SH 391/20th St)	36,700/9,300 vpd	38,300/9,300 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**21**	**23**
Fatal Crashes (Fatalities)	0	1 (1)
Injury Crashes (Injuries)	2 (2)	8 (12)
Property Damage Only	19	14
Crash Types: # (%) [significance]		
Rear-End	10 (47.6%)	17 (73.9%) [99.9%]
Approach Turn	4 (19.0%)	5 (21.7%)
Broadside	2 (9.5%)	0
Pedestrian	1 (4.8%)	0

A review of before and after crash records at the intersection of SH 40 and Newland Street also shows approximately the same number of crashes for both periods; the total number of crashes decreased from 11 during the three-year period (2005 to 2007) before the signal was upgraded (see **Table 2** and **Exhibit 3**) to 9 during the three-year after period (2011 to 2013) (see **Table 2** and **Exhibit 4**). The number of severe crashes also decreased:

- Before (2005 – 2007) – 1 fatal crash with 1 fatality and 3 injury crashes with 9 injuries
- After (2011 – 2013) – no fatal crashes and 1 injury crash with 1 injury

The number of crashes decreased slightly along with a slight decrease in traffic volumes at the intersection. This resulted in a small decrease in the crash rates:

- Before (2005 – 2007): 0.33 cpmev
- After (2011 – 2013): 0.30 cpmev

Table 2 – SH 40 / Newland Street – Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2005 to 12/31/2007 (3 yr.)	1/1/2011 to 12/31/2013 (3 yr.)
AADT (SH 40/Newland St)	30,100/400 vpd	27,000/400 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**11**	**9**
Fatal Crashes (Fatalities)	1 (1)	0
Injury Crashes (Injuries)	3 (9)	1 (1)
Property Damage Only	7	8
Crash Types: # (%) [significance]		
Rear-End	5 (45.5%)	3 (33.3%)
Broadside	5 (45.5%) [99.9%]	0
Approach Turn	1 (9.1%)	2 (22.2%)

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

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

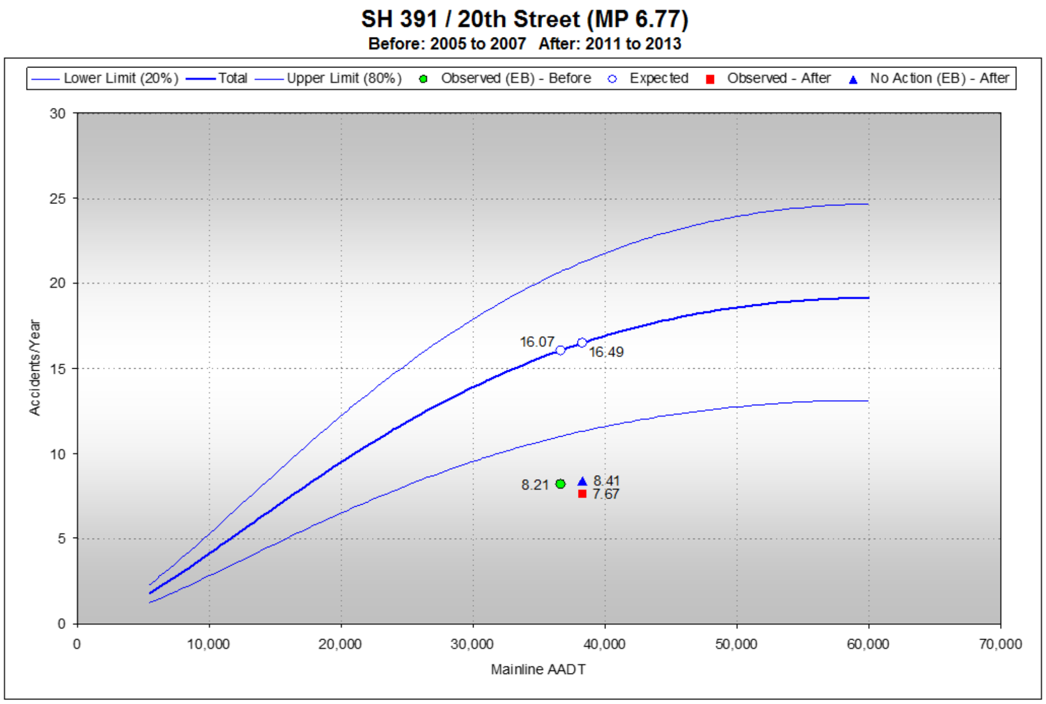
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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

SPF plots were created for the intersection of SH 391 and 20th Street for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**). Both the frequency and severity of crashes remained in the LOSS I range for the before and after period (see **Table 3**).

For the intersection of SH 40 and Newland Street, SPF plots were created for both total crashes (see **Figure 3**) and for fatal and injury crashes (see **Figure 4**). The frequency of crashes remained in the LOSS IV range for the before and after period. The severity of crashes improved from LOSS III in the before period to LOSS I in the after period (see **Table 4**).

Figure 1 - SPF for Total Crashes

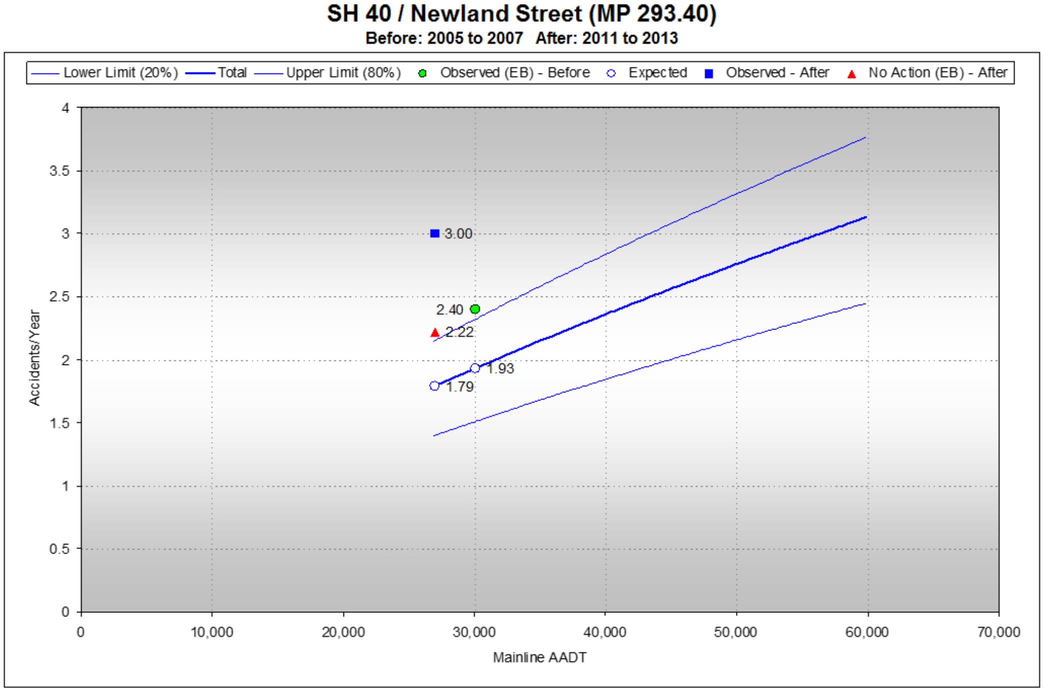


Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 2 - SPF for Injury and Fatal Crashes

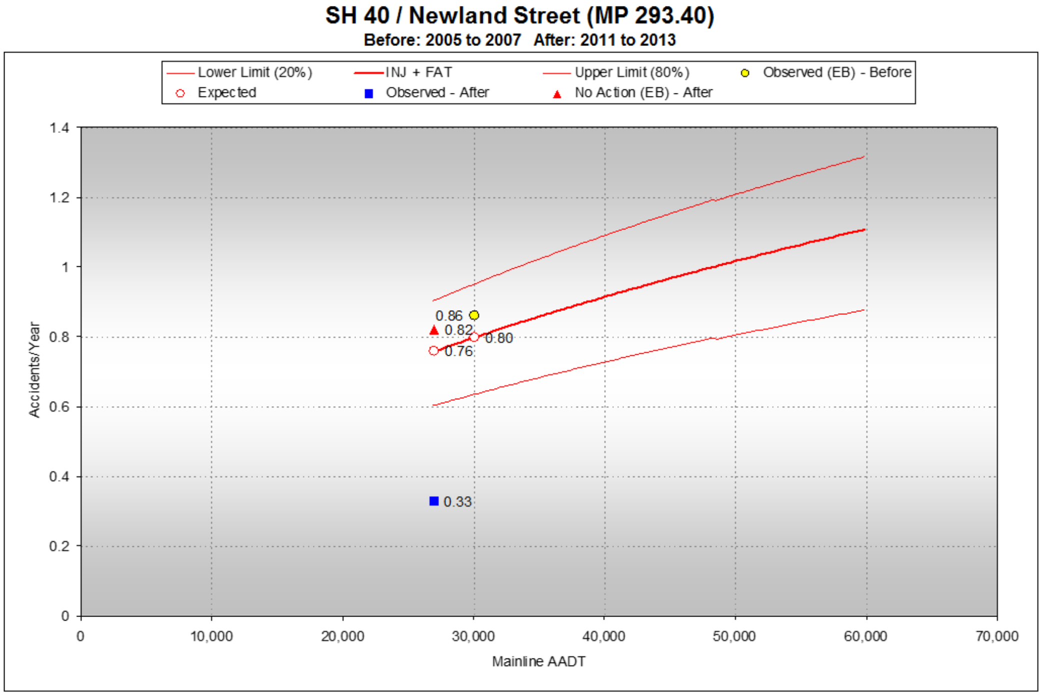
Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 3 - SPF for Total Crashes



Note: Safety Performance Function (SPF) Model: Colorado - Urban 6-Lane Divided Signalized 4-LegIntersection

Figure 4 - SPF for Injury and Fatal Crashes



Note: Safety Performance Function (SPF) Model: Colorado - Urban 6-Lane Divided Signalized 4-Leg Intersection

Table 3 – SH 391 / 20th Street – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS I	LOSS I	LOSS I
CPY	8.21	7.67	8.41
Mean CPY	16.07	16.49	16.49
Proportion of Mean	0.51	0.47	0.51
Fatal & Injury Crashes:			
LOSS	LOSS I	LOSS I	LOSS I
CPY	1.94	3.00	1.97
Mean CPY	4.71	4.80	4.80
Proportion of Mean	0.41	0.63	0.41

Table 4 – SH 40 / Newland Street – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPY	2.40	3.00	2.22
Mean CPY	1.93	1.79	1.79
Proportion of Mean	1.24	1.68	1.24
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS I	0.82
CPY	0.86	0.33	1.97
Mean CPY	0.80	0.76	0.76
Proportion of Mean	1.08	0.43	1.08

A more detailed review of the before and after crash record reveals that only a minor improvement in safety can be attributed to the upgrade of the signal at the intersection of SH 391 and 20th Street. **Table 5** shows a comparison of four types of crashes that are most directly affected by the improvement: rear end, approach turn, pedestrian, and broadside. While there was a decrease in pedestrian and broadside crashes, there was an increase in the overall severity of crashes. The No Build After crashes were estimated using the increase in the mean of the SPF for total crashes found in **Table 3** (increase is 1.03 = 16.49/16.07).

Table 5 – SH 391 / 20th Street – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2005 to 12/31/2007 (3 yr.)	1/1/2011 to 12/31/2013 (3 yr.)	1/1/2011 to 12/31/2013 (3 yr.)
Crash Types:			
Intersection Total	**21**	**23**	**22**
Fatal (fatalities)	0	1 (1)	0
Injury (injuries)	2 (2)	8 (12)	2 (2)
PDO	19	14	20
% Reduction in Total (Fatalities/Injuries/PDO)		NA / -500% / 30%	
Rear Ends – Total	**10**	**17**	**10**
Injury (injuries)	1 (1)	6 (10)	1 (1)
PDO	9	11	9
% Reduction in Total (Injuries/PDO)		90% / -22%	
Approach Turns – Total	**4**	**5**	**4**
Fatal (fatalities)	0	1 (1)	0
Injury (injuries)	0	2 (2)	0
PDO	4	3	4
% Reduction in Total (Fatalities/Injuries/PDO)		NA / NA / 25%	
Broadsides – Total	**2**	**0**	**2**
PDO	2	0	2
% Reduction in Total		100%	
Pedestrian – Total	**1**	**0**	**1**
Injury (injuries)	1 (1)	0	1 (1)
% Reduction in Total		100%	

A review of the before and after crashes at the intersection of SH 40 and Newland Street shows that some improvement in safety can be attributed to the upgrade of the signal. **Table 6** shows a comparison of crash types that are most directly affected by the improvement: rear end, approach turn, and broadside. There were no broadsides at the intersection in the after period, while there were 5 including a fatality in the before period. The No Build After crashes were estimated using the decrease in the mean of the SPF for total crashes found in **Table 4** (increase is 0.93 = 1.79/1.93).

Table 6 – SH 40 / Newland Street – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2005 to 12/31/2007 (3 yr.)	1/1/2011 to 12/31/2013 (3 yr.)	1/1/2011 to 12/31/2013 (3 yr.)
Crash Types:			
Intersection Total	**11**	**9**	**10**
Fatal (fatalities)	1 (1)	0	1 (1)
Injury (injuries)	3 (9)	1 (1)	3 (9)
PDO	7	8	6
% Reduction in Total (Fatalities/Injuries/PDO)		100% / 89% / -33%	
Rear Ends – Total	**5**	**3**	**5**
PDO	5	3	5
% Reduction in Total		40%	
Broadsides – Total	**5**	**0**	**5**
Fatal (fatalities)	1 (1)	0	1 (1)
Injury (injuries)	2 (7)	0	2 (7)
PDO	2	0	2
% Reduction in Total (Fatalities/Injuries/PDO)		100%/100%/100%	
Approach Turns – Total	**1**	**2**	**1**
Injury (injuries)	1 (1)	1 (1)	1 (1)
PDO	0	1	0
% Reduction in Total (Injuries/PDO)		0% / NA	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for the SH 391 / 20th Street signal upgrade. There was an increase in severe crashes after the improvement. The increase in severe crashes was factored into the analysis by increasing the cost of construction for the improvement. During the three-year after period, there was an additional fatality and 10 additional injuries. Over the design life of 10 years for the signal, the increased cost of crashes would be $7,690,000 (33.3 INJ = $2,690,000 and 3.3 fatalities = $5,000,000). The resulting B/C ratio is 0.02 (See **Figure 5**).

Figure 6 provides the B/C analysis for the signal at SH 40 and Newland Street. Similar to the previous analysis, there were also new crashes at this intersection. The increase in crashes was also factored in by increasing the cost of construction for the project. During the three-year after period, there was 2 additional property damage only. Over the design life of 10 years for the signal, the increased cost of crashes would be $62,000 (6.7 PDO = $62,000). As shown in **Figure 6**, the B/C ratio for the SH 40 signal improvement is 12.02. When combined with the SH 391 signal improvement, the resulting B/C ratio for the safety project is 12.04 (0.02 + 12.02), showing that the improvement was certainly justified.

Figure 5 – SH 391 / 20th Street – Benefit Cost Analysis – Intersection Crashes Only

CDOT COLORADO Department of Transportation

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

10/06/2016
Job #: 20161006212218

Location: 391A **Begin:** 6.75 **End:** 6.79 **From:** 01/01/2005 **To:** 12/31/2007

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	20		Weighted PDO:	7.32	30% : CRF for PDO	Cost of PDO:	$ 9,300
INJ:	2	2 : Injured	Weighted INJ:	0.73	0% : CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 : Killed	Weighted FAT:	0.00	0% : CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	3.00	27% : Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	10
						Capital Recovery Factor:	0.129
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 8,132,337
From: 01/01/2005
To: 12/31/2007 Days: 1095

Benefit Cost Ratio: 0.02 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SIGNALS - UPGRADE SIGNALS
Special Notes:

Figure 6 – SH 40 / Newland Street – Benefit Cost Analysis – Intersection Crashes Only

CDOT COLORADO Department of Transportation

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

10/06/2016
Job #: 20161006213515

Location: 40C **Begin:** 293.38 **End:** 293.42 **From:** 01/01/2005 **To:** 12/31/2007

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	6		Weighted PDO:	2.20	0% : CRF for PDO	Cost of PDO:	$ 9,300
INJ:	3	9 : Injured	Weighted INJ:	3.29	89% : CRF for INJ	Cost of INJ:	$ 80,700
FAT:	1	1 : Killed	Weighted FAT:	0.37	100% : CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	3.00	36% : Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	10
						Capital Recovery Factor:	0.129
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 504,337
From: 01/01/2005
To: 12/31/2007 Days: 1095

Benefit Cost Ratio: 12.02 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SIGNALS - UPGRADE SIGNALS
Special Notes:

Location: 40C	Begin: 293.38	End: 293.42	From: 01/01/2005	To: 12/31/2007

Severity

PDO:	7	
INJ:	3	9 :Injured
FAT:	1	1 :Killed
Total:	**11**	

Number of Vehicles

One Vehicle:	0
Two Vehicles:	9
Three or More:	2
Unknown:	0
Total:	**11**

Location

On Road:	11
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**11**

Lighting Conditions

Daylight:	9
Dawn or Dusk:	0
Dark - Lighted:	2
Dark - Unlighted:	0
Unknown:	0
Total:	**11**

Weather Conditions

None:	11
Rain:	0
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**11**

Crash Rates

PDO:	5.19 *
INJ:	2.22 *
FAT:	74.08 **
Total:	**8.15** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	11
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**11**

Road Description

At Intersection:	6
At Driveway Access:	0
Intersection Related:	5
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**11**

Road Conditions

Dry:	10
Wet:	0
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**11**

ADT: 30,067 **Length:** 0.04

Location: 40C **Begin:** 293.38 **End:** 293.42 **From:** 01/01/2005 **To:** 12/31/2007

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	9	8	1
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	1	1	1
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	1	2	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**11**	**11**	**2**

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

Direction	Veh 1	Veh 2	Veh 3
North:	0	3	0
Northeast:	0	0	0
East:	4	3	0
Southeast:	0	0	0
South:	0	2	1
Southwest:	0	0	0
West:	7	3	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**11**	**11**	**2**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	3	10	2
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	4	1	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	3	0	0
Total:	**11**	**11**	**2**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	10	11	2
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**11**	**11**	**2**

ADT: 30,067 **Length:** 0.04

Location: 40C **Begin:** 293.38 **End:** 293.42 **From:** 01/01/2011 **To:** 12/31/2013

Severity

PDO:	8	
INJ:	1	1 :Injured
FAT:	0	0 :Killed
Total:	**9**	

Number of Vehicles

One Vehicle:	3
Two Vehicles:	4
Three or More:	2
Unknown:	0
Total:	**9**

Location

On Road:	6
Off Road Left:	2
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**9**

Lighting Conditions

Daylight:	6
Dawn or Dusk:	0
Dark - Lighted:	3
Dark - Unlighted:	0
Unknown:	0
Total:	**9**

Weather Conditions

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

Crash Rates

PDO:	6.76 *
INJ:	0.84 *
FAT:	0.00 **
Total:	**7.60** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	9
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**9**

Road Description

At Intersection:	7
At Driveway Access:	0
Intersection Related:	2
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**9**

Road Conditions

Dry:	8
Wet:	0
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	1
Total:	**9**

ADT: 27,000 **Length:** 0.04

Location: 40C **Begin:** 293.38 **End:** 293.42 **From:** 01/01/2011 **To:** 12/31/2013

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

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	2	6	2
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	1	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	3	0	0
Total:	**9**	**6**	**2**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	8	6	2
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**9**	**6**	**2**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	5	2	0
Slowing:	0	1	1
Stopped in Traffic:	0	2	0
Making Right Turn:	0	1	0
Making Left Turn:	3	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	1	0	0
Weaving:	0	0	0
Other:	0	0	1
Unknown:	0	0	0
Total:	**9**	**6**	**2**

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	5	4	1
Southeast:	0	0	0
South:	2	0	1
Southwest:	0	0	0
West:	2	2	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**9**	**6**	**2**

ADT: 27,000 **Length:** 0.04

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

Exhibit 3

Job #: 20161006083658

Location: 391A **Begin:** 6.75 **End:** 6.79 **From:** 01/01/2005 **To:** 12/31/2007

Severity

PDO:	19	
INJ:	2	2 :Injured
FAT:	0	0 :Killed
Total:	**21**	

Number of Vehicles

One Vehicle:	1
Two Vehicles:	19
Three or More:	1
Unknown:	0
Total:	**21**

Location

On Road:	20
Off Road Left:	0
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**21**

Lighting Conditions

Daylight:	17
Dawn or Dusk:	1
Dark - Lighted:	3
Dark - Unlighted:	0
Unknown:	0
Total:	**21**

Weather Conditions

None:	20
Rain:	0
Snow/Sleet/Hail:	1
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**21**

Crash Rates

PDO:	11.82 *
INJ:	1.24 *
FAT:	0.00 **
Total:	**13.07** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	1	Culvert/Headwall:	0
Broadside:	2	Embankment:	0
Head On:	1	Curb:	0
Rear End:	10	Delineator Post:	0
Sideswipe (Same):	0	Fence:	0
Sideswipe (Opposite):	1	Tree:	0
Approach Turn:	4	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	1
Traffic Signal Pole:	1	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	1
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**21**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	21
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**21**

Road Description

At Intersection:	16
At Driveway Access:	0
Intersection Related:	5
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**21**

Road Conditions

Dry:	18
Wet:	1
Muddy:	0
Snowy:	0
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	1
Total:	**21**

ADT: 36,695 **Length:** 0.04

Location: 391A **Begin:** 6.75 **End:** 6.79 **From:** 01/01/2005 **To:** 12/31/2007

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	11	17	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	3	1	0
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	2	1	1
SUV w/Trl:	1	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	2	0	0
Other:	1	0	0
Unknown:	0	1	0
Total:	**21**	**20**	**1**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	15	5	0
Slowing:	1	1	0
Stopped in Traffic:	0	8	1
Making Right Turn:	2	1	0
Making Left Turn:	2	5	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**21**	**20**	**1**

Direction	Veh 1	Veh 2	Veh 3
North:	8	9	0
Northeast:	0	0	0
East:	2	3	0
Southeast:	0	0	0
South:	8	5	0
Southwest:	0	0	0
West:	2	3	1
Northwest:	0	0	0
Unknown:	1	0	0
Total:	**21**	**20**	**1**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	11	18	1
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	1	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	3	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	1	0	0
Physical Disability:	0	0	0
Unknown:	5	1	0
Total:	**21**	**20**	**1**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	21	20	1
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**21**	**20**	**1**

ADT: 36,695 **Length:** 0.04

Location: 391A **Begin:** 6.75 **End:** 6.79 **From:** 01/01/2011 **To:** 12/31/2013

Severity

PDO:	14	
INJ:	8	12 :Injured
FAT:	1	1 :Killed
Total:	**23**	

Number of Vehicles

One Vehicle:	1
Two Vehicles:	20
Three or More:	2
Unknown:	0
Total:	**23**

Location

On Road:	22
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	1
Off in Median:	0
Unknown:	0
Total:	**23**

Lighting Conditions

Daylight:	18
Dawn or Dusk:	0
Dark - Lighted:	5
Dark - Unlighted:	0
Unknown:	0
Total:	**23**

Weather Conditions

None:	22
Rain:	1
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**23**

Crash Rates

PDO:	8.55 *	* MVMT
INJ:	4.89 *	** 100 MVMT
FAT:	61.07 **	**Total: 14.05** *

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	23
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**23**

Road Description

At Intersection:	11
At Driveway Access:	0
Intersection Related:	12
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**23**

Road Conditions

Dry:	20
Wet:	3
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**23**

ADT: 38,308 **Length:** 0.03

Location: 391A **Begin:** 6.75 **End:** 6.79 **From:** 01/01/2011 **To:** 12/31/2013

Vehicle Type

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	12	15	1
Passenger Car/Van w/Trl:	0	1	0
Pickup Truck/Utility Van:	5	2	0
Pickup Truck/Utility Van w/Trl:	2	1	0
SUV:	3	1	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	2	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**23**	**22**	**2**

Vehicle Movement

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	14	6	0
Slowing:	2	2	0
Stopped in Traffic:	1	13	2
Making Right Turn:	0	1	0
Making Left Turn:	5	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**23**	**22**	**2**

Direction

Direction	Veh 1	Veh 2	Veh 3
North:	8	9	0
Northeast:	0	0	0
East:	2	2	0
Southeast:	0	0	0
South:	11	10	2
Southwest:	0	0	0
West:	2	1	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**23**	**22**	**2**

Contributing Factor

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	5	20	2
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	4	0	0
Driver Unfamilar with Area:	3	0	0
Driver Emotionally Upset:	0	1	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	8	1	0
Total:	**23**	**22**	**2**

Condition of Driver

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	20	22	2
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**23**	**22**	**2**

ADT: 38,308 **Length:** 0.03

Project Information

Project Name: US 287 / 19th St Intersection Improvements

Project Description: Hazard Elimination, New Traffic Signal with Dilemma Prevention

CDOT Region: 4 Project Def: 16380 County: Larimer

Location: SH 287 Mile Points: 331.65 Length: N/A

Schedule: Work Start Date: est 7/2009 Completion Date: est 1/2010

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the crash history showed a higher than expected proportion of broadside crashes at the unsignalized T intersection of 19th St SW with US 287. There were 11 of these crashes during the two-year (2002 – 2003) time period (after construction of a new, 4-lane alignment of US 287) considered in the HSIP application.

Improvement Description: In late 2009 a signal was installed. The cost of construction was $388,123.

The HSIP application anticipated that broadside crashes would be impacted by this improvement. It was anticipated that there would be approximately a 25% crash reduction for these crashes. The expected benefit/cost ratio was estimated to be 1.66.

Summary and Findings

The analysis of safety before and after a traffic signal with dilemma prevention was installed at the intersection of US 287 and 19th Street SW showed safety improved by elimination of broadside crashes. For this intersection, there were 19 total crashes during the five-year period before the improvement (2004 – 2008). In the five years after construction (2010 – 2014), the number of crashes decreased to 2.

The new signal was apparently responsible for the elimination of broadside crashes at the intersection, but it also was apparently responsible for introducing 2 rear end crashes at the intersection in the after period, compared to none in the before period. The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 15.12 to one, showing that the improvement was justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 19 during the five-year period (2004 to 2008) before the eastbound left-turn lane and southbound to westbound acceleration lanes were extended (see **Table 1** and **Exhibit 1**) to 2 during the five-year after period (2010 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes also decreased in the five-year period after the improvements:

- Before (2004 – 2008) – no fatal crashes and 12 injury crashes with 24 injuries
- After (2010 – 2014) – no fatal crashes and 1 injury crash with 1 injury

Despite an increase in traffic volumes at the intersection, the crash rates at the intersection still decreased:

- Before (2004 – 2008): 0.58 crashes per million entering vehicles (cpmev)
- After (2010 – 2014): 0.06 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
AADT (SH 287/19th St SW)	14,950 / 2,900 vpd	17,083 / 2,900 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**19**	**2**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	12 (24)	1 (1)
Property Damage Only	7	1
Crash Types: # (%) [significance]		
Rear-End	0 (0.0%)	2 (100.0%)
Broadside	18 (94.7%)[100.00%]	0 (0.0%)

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

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

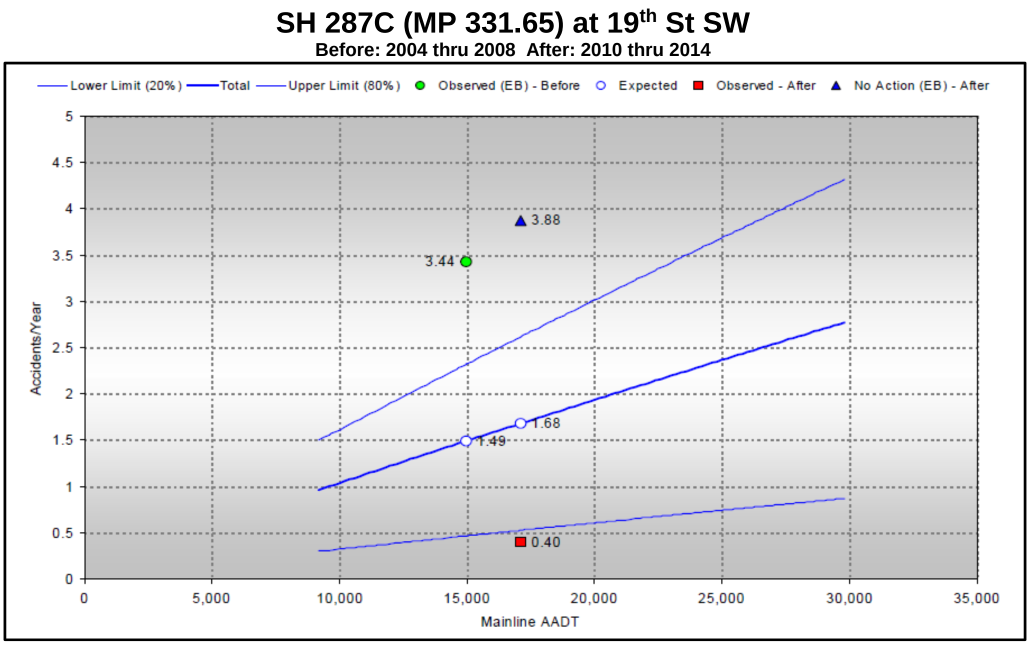
level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

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

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

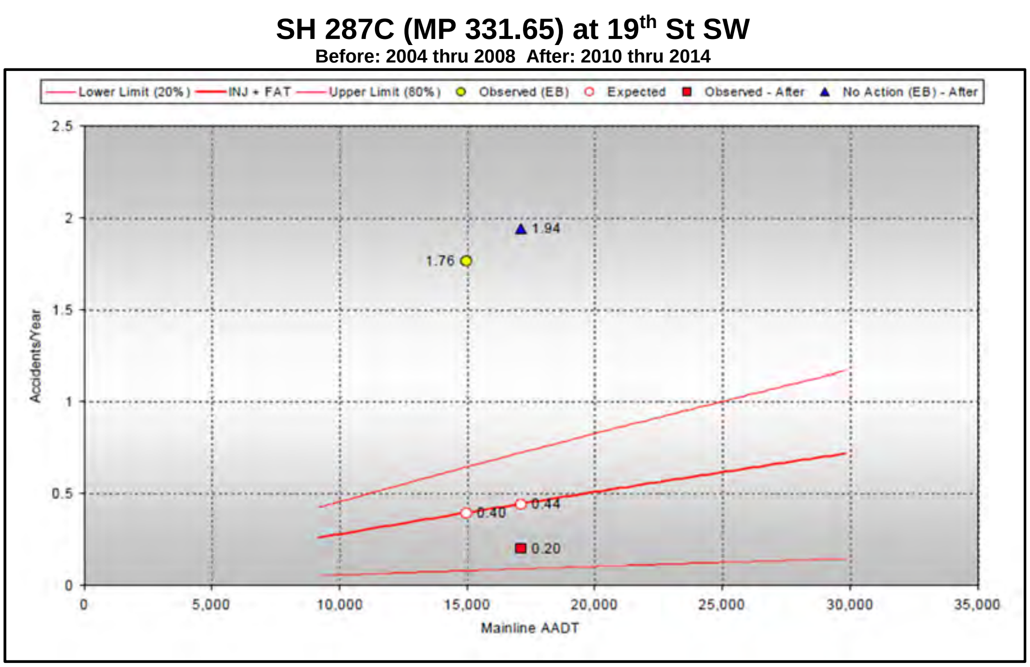
SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. The frequency of crashes remained in the LOSS IV category for the before and after period, while the severity of crashes remained in the LOSS III category. However, both showed improvement within their given category in the after period (see **Table 2**).

Figure 1 - SPF for Total Crashes



Note: Safety Performance Function (SPF) Model: Colorado – Urban 4-Lane Divided Unignalized 3-Leg Intersection

Figure 2 – SPF Injury and Fatal Crashes



Note: Safety Perfromance Function (SPF) Model: Colorado – Urban 4-Lane Divided Unsignalized 3-Leg Intersection

Table 2 – Safety Performance Function (SPF)

	Before	**After**	**No Build After**
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Unignalized, 3-Leg Intersection	Urban, 4-lane, Divided, Unsignalized, 3-Leg Intersection*	Urban, 4-lane, Divided, Unsignalized, 3-Leg Intersection
Total Crashes:			
LOSS	LOSS IV	LOSS I*	LOSS IV
CPY	3.44	0.40	3.88
Mean CPY	1.49	1.68	1.68
Proportion of Mean	2.31	0.24	2.31
Fatal & Injury Crashes:			
LOSS	LOSS IV	LOSS II*	LOSS IV
CPY	1.76	0.20	1.94
Mean CPY	0.40	0.44	0.44
Proportion of Mean	4.40	0.45	4.40

**Intersection type changed by project to Signalized, so LOSS shown is not necessarily correct for the After period, but is shown for comparison only. Actual after period Total Crashes and Injury & Fatal Crashes are both in LOSS I, reflecting that signalized T intersections typically experience more crashes per year than unsignlized T intersections, at these volumes.*

A more detailed review of the before and after crash record reveals that improvement in safety can be attributed to the addition of a well-designed signal with dilemma prevention for the mainline. The signal accomplished the intended goal of reducing broadsides, and because of the dilemma prevention, it largely avoided addition of mainline rear end crashes that might be expected when a signal is added. **Table 3** shows a comparison of primary types of crashes that are most directly affected by the improvement: broadside and rear end, as well as the total intersection crashes. The No Build After crashes were estimated using the change in mean CPY found in **Table 1** (increase is 1.128 = 3.88/3.44).

Table 3 – Results of Crash Analyses

	Before	**After**	**No Build After**
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
Crash Types:			
Total Crashes	**19**	**2**	**21**
Injury (injuries)	12 (24)	1 (1)	14 (27)
PDO	7	1	8
% Reduction in Total (Injuries/PDO)		96% / 88%	
Broadsides – Total	**18**	**0**	**20**
Injury (injuries)	11 (23)	0 (0)	12 (26)
PDO	7	0	8
% Reduction in Total (Injuries/PDO)		100% / 100%	
Rear End – Total	**0**	**2**	**0**
Injury (injuries)	0 (0)	0	0 (0)
PDO	0	3	0
% Reduction in Total (Injuries/PDO)		Undefined / Undefined	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the impacted crash types. As shown, the B/C ratio for the intersection and intersection related crashes is 15.12, showing that the improvement was justified.

Figure 3 – Benefit Cost Analysis – Intersection and Intersection Related Crashes Only

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

09/28/2016

Job #: 20160928221043

Location: 287C **Begin:** 331.62 **End:** 331.68 **From:** 01/01/2004 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes				Projected Crashes and Reduction Factors			Other Information	
PDO:	7		Weighted PDO:	1.72	88% :CRF for PDO		Cost of PDO:	$ 9,300
INJ:	12	24 :Injured	Weighted INJ:	5.90	96% :CRF for INJ		Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT		Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	93% :Weighted CRF		Interest Rate:	5%
							AADT Growth Factor:	2.0%
							Service Life:	20
							Capital Recovery Factor:	0.080
							Annual Maintenance/Delay Cost:	$ 0

Cost: $ 388,123
From: 01/01/2004
To: 12/31/2008 Days: 1827

Benefit Cost Ratio: 15.12 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SIGNALS - ADD NEW SIGNAL WITH DILEMMA PREVENTION
Special Notes:

Location: 287C **Begin:** 331.62 **End:** 331.68 **From:** 01/01/2004 **To:** 12/31/2008

BEFORE

Severity

PDO:	7		
INJ:	12	24	:Injured
FAT:	0	0	:Killed
Total:	**19**		

Number of Vehicles

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

Location

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

Lighting Conditions

Daylight:	15
Dawn or Dusk:	1
Dark - Lighted:	2
Dark - Unlighted:	1
Unknown:	0
Total:	**19**

Weather Conditions

None:	18
Rain:	1
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**19**

Crash Rates

PDO:	4.27 *
INJ:	7.32 *
FAT:	0.00 **
Total:	**11.59** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	18	Embankment:	0
Head On:	0	Curb:	0
Rear End:	0	Delineator Post:	0
Sideswipe (Same):	0	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	0
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**19**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	19
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

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

Road Description

At Intersection:	18
At Driveway Access:	0
Intersection Related:	1
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**19**

Road Conditions

Dry:	18
Wet:	1
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**19**

ADT: 14,950 **Length:** 0.06

Location: 287C **Begin:** 331.62 **End:** 331.68 **From:** 01/01/2004 **To:** 12/31/2008

BEFORE

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	14	16	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	5	0	0
Pickup Truck/Utility Van w/Trl:	0	1	0
SUV:	0	1	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	1	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**19**	**19**	**0**

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

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

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	1	17	0
Slowing:	0	0	0
Stopped in Traffic:	0	0	0
Making Right Turn:	2	0	0
Making Left Turn:	16	2	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**19**	**19**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	0	1	0
Northeast:	0	0	0
East:	18	1	0
Southeast:	0	0	0
South:	1	17	0
Southwest:	0	0	0
West:	0	0	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**19**	**19**	**0**

ADT: 14,950 **Length:** 0.06

Location: 287C **Begin:** 331.62 **End:** 331.68 **From:** 01/01/2010 **To:** 12/31/2014

AFTER

Severity

PDO:	1		
INJ:	1	1	:Injured
FAT:	0	0	:Killed
Total:	**2**		

Number of Vehicles

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

Location

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

Lighting Conditions

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

Weather Conditions

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

Crash Rates

PDO:	0.53 *
INJ:	0.53 *
FAT:	0.00 **
Total:	**1.07** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	2
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**2**

Road Description

At Intersection:	2
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**2**

Road Conditions

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

ADT: 17,083 **Length:** 0.06

Location: 287C **Begin:** 331.62 **End:** 331.68 **From:** 01/01/2010 **To:** 12/31/2014

AFTER

Vehicle Type

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

Vehicle Movement

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

Contributing Factor

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

Direction

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

Condition of Driver

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

ADT: 17,083 **Length:** 0.06

Project Information

Project Name: SH 50 West of Morris/Fortino Phase 1

Project Description: Improve the median, changing several access types to right-in/right-out

CDOT Region: 2 Project Def: 16420 County: Pueblo

Location: SH 50A Mile Points: MP 312.89 to 313.83 Length: 0.94 miles

Schedule: Work Start Date: 3/16/2008 Completion Date: 5/29/2008

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history (1999 – 2003) showed that there were a total of 126 injury crashes, 226 PDO crashes, and one fatal crashes. There were two full movement, unsignalized intersections experiencing broadside crashes. Additionally, the westbound left-turn at Baltimore did not have enough storage length, resulting in the queue extending into the through lane.

Improvement Description: Between March 16, 2008 and May 29, 2008, median was replaced. This changed several unsignalized accesses into right-in/right-out only and extended turn-lanes at signalized intersections. The cost of construction was $1,835,388.59.

The HSIP application anticipated that a 50% reduction in related crashes might be realized by the improvement. The initial benefit/cost ratio was estimated to be 1.54.

Summary and Findings

The analysis of safety before and after the median was replaced along SH 50A showed a reduction in the number and severity of intersection and intersection related crashes at the intersections of SH 50 with Westroads Avenue, Baltimore Avenue, and Ridge Drive. Along this segment of 4-lane divided arterial highway, there were 132 total crashes during the five-year period before the median was replaced (2003 – 2007) at these intersections. In the five years after construction (2009 – 2013), the number of crashes decreased to 71. This decrease in crashes was accompanied by a small decrease in AADT.

A comparison of rear end, broadside, and approach turn type crashes before and after the median improvements were installed showed that there was a decrease in injury crashes (from 33 injury crashes in five years before to 19 injury crashes in the five years after). The number of PDO crashes was reduced from 88 to 42. The actual reduction in rear end, broadside, and approach turn type crashes that was realized by the project was an improvement of approximately 50%. The ratio of benefits and cost for this project shows that benefits outweighed costs as the B/C ratio is 4.06 to one. The result is an improvement that was certainly justified from an economic standpoint.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records at the impacted intersections show a decrease in the number of crashes. The total number of intersection crashes decreased from 132 during the five-year period (2003 to 2007) before the median project was constructed (see **Tables 1, 2, 3** and **Exhibits 1, 2, 3**) to 71 during the five-year after period (2009 to 2013) (see **Tables 1, 2, 3** and **4, 5, 6**). The number of severe crashes also showed a decrease in the after period:

- Before (2003 – 2007) – no fatal crashes and 36 injury crashes with 54 injuries
- After (2009 – 2013) – no fatal crashes and 23 injury crashes with 31 injuries

Table 1 - SH 50A & Westroads Avenue (MP 313.37) - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2003 to 12/31/2007 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
AADT	39,329 / 1,500 vpd	39,896 / 1,500 vpd
Filters:	Intersection & related	Intersection & related
Total Crashes	**14**	**1**
Fatal Crashes (Fatalities)	0 (0)	0
Injury Crashes (Injuries)	6 (9)	0 (0)
Property Damage Only	8	1
Crash Types: # (% of total crashes) [cumulative probability]		
Rear End	5 (35.7%)	1 (100.0%)
Approach Turn	3 (21.4%)	0 (0%)
Broadside	3 (21.4%)	0 (0%)
Sideswipe Same	2 (14.3%)	0 (0%)
Fixed Object	1 (7.2%)	0 (0%)

Table 2 - SH 50A & Baltimore Avenue (MP 313.52) - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2003 to 12/31/2007 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
AADT	39,773 / 3,500 vpd	38,690 / 3,500 vpd
Filters:	Intersection & related	Intersection & related
Total Crashes	**86**	**58**
Fatal Crashes (Fatalities)	0 (0)	0
Injury Crashes (Injuries)	21 (33)	19 (26)
Property Damage Only	65	39
Crash Types: # (% of total crashes) [cumulative probability]		
Rear End	59 (68.6%) [100.0%]	38 (65.5%) [99.9%]
Approach Turn	15 (17.4%)	10 (17.2%)
Broadside	7 (8.1%)	3 (5.2%)
Sideswipe Same	3 (3.5%)	3 (5.2%)
Fixed Object	2 (2.3%)	2 (3.4%)

Table 3 - SH 50A & Ridge Drive (MP 313.65) - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2003 to 12/31/2007 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
AADT	40,483 / 1,200 vpd	37,450 / 1,200 vpd
Filters:	Intersection & related	Intersection & related
Total Crashes	**32**	**12**
Fatal Crashes (Fatalities)	0 (0)	0
Injury Crashes (Injuries)	9 (12)	4 (5)
Property Damage Only	23	8
Crash Types: # (% of total crashes) [cumulative probability]		
Rear End	15 (46.8%)	8 (66.7%) [98.3%]
Broadside	8 (25.0%)	1 (8.3%)
Approach Turn	6 (18.8%) [95.5%]	0 (0%)
Fixed Object	1 (3.1%)	0 (0%)

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

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

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

LOSS boundaries are calibrated by computing the 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.

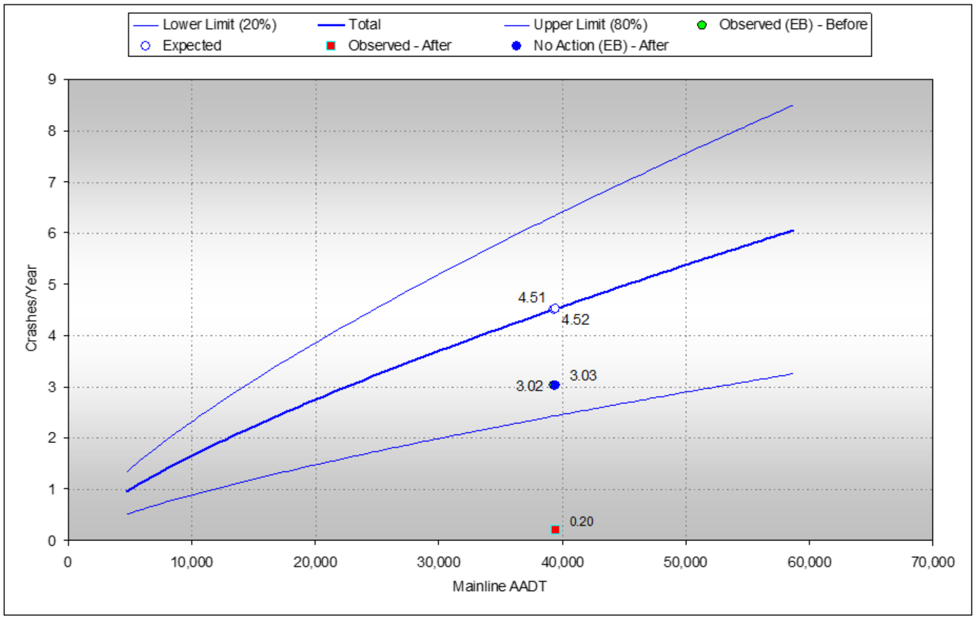
SPF plots for both total crashes and for fatal and injury crashes were created for the three intersections with the largest impacts: Westroads Avenue, Batlimore Avenue, and Ridge Drive. The SPF charts are provided in **Figures 1 through 6** as follows:

Figure 1 – Westroads Avenue Total Crashes
Figure 2 – Westroads Avenue Injury and Fatal Crashes
Figure 3 – Baltimore Avenue Total Crashes
Figure 4 – Baltimore Avenue Injury and Fatal Crashes
Figure 5 – Ridge Drive Total Crashes
Figure 6 – Ridge Drive Injury and Fatal Crashes

Tables 4, 5, and 6 provide a summary of the before and after Level of Service of Safety for each of the study intersections. As shown, each intersection improved in total crashes and all but the Baltimore Avenue intersection improved in injury and fatal crashes. The tables also show the Level of Service of Safety expected in the after period had the median not been constructed.

Figure 1 - SPF for Total Crashes

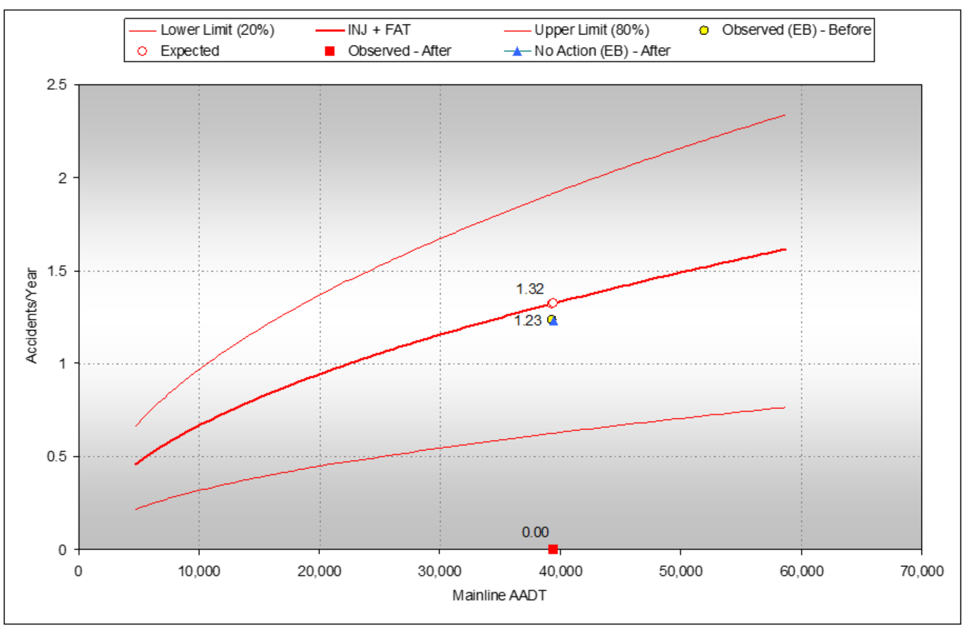
SH 50A & Westroads Ave (MP 313.37)
Before: 2003 to 2007 After: 2009 to 2013



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

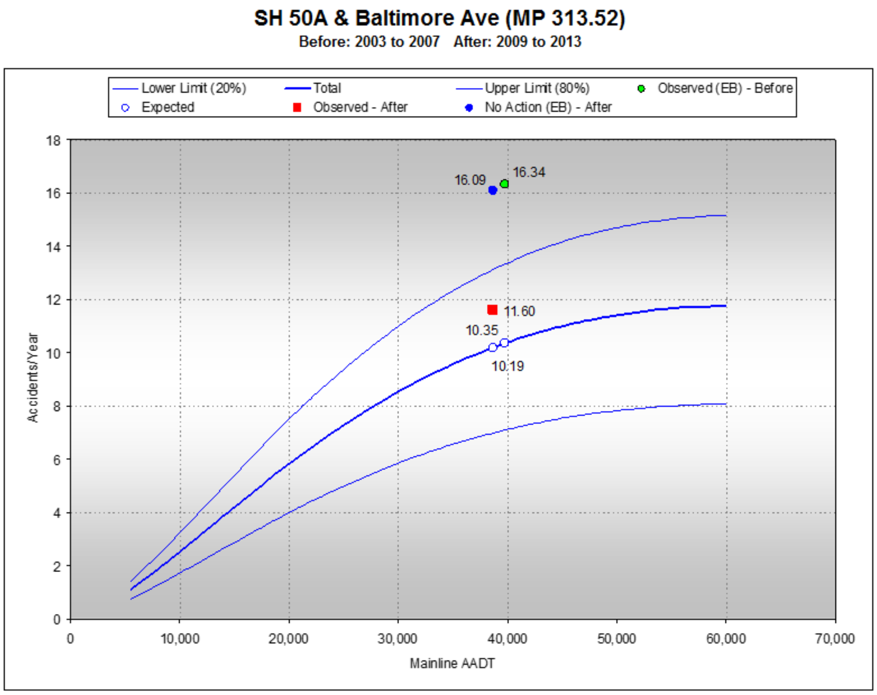
Figure 2 - SPF for Injury and Fatal Crashes

SH 50A & Westroads Ave (MP 313.37)
Before: 2003 to 2007 After: 2009 to 2013



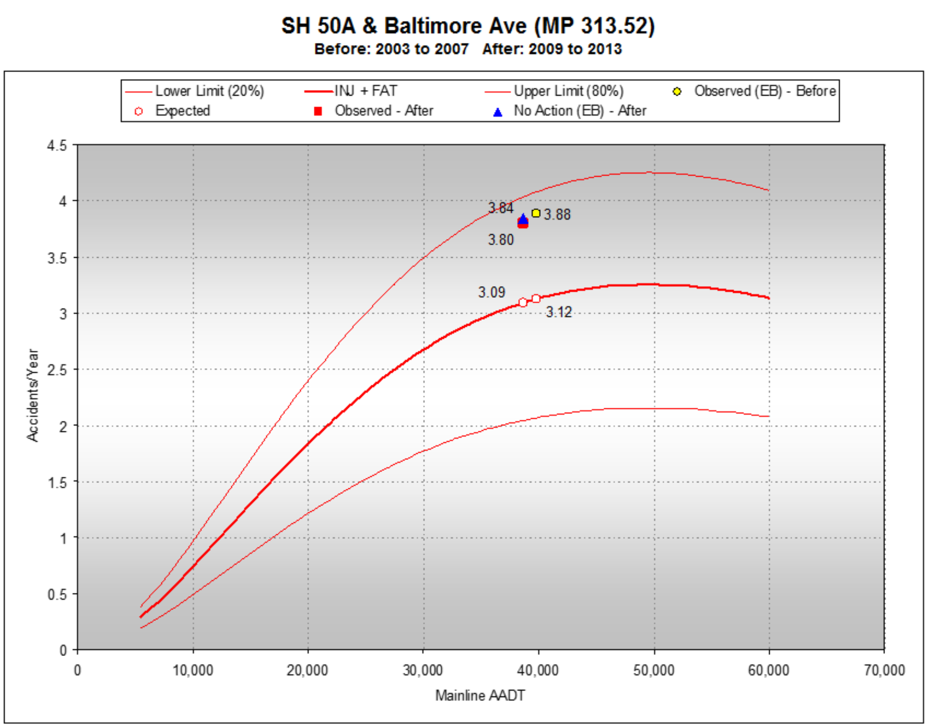
Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-Lane Divided Unsignalized 4-Leg Intersection

Figure 3 - SPF for Total Crashes



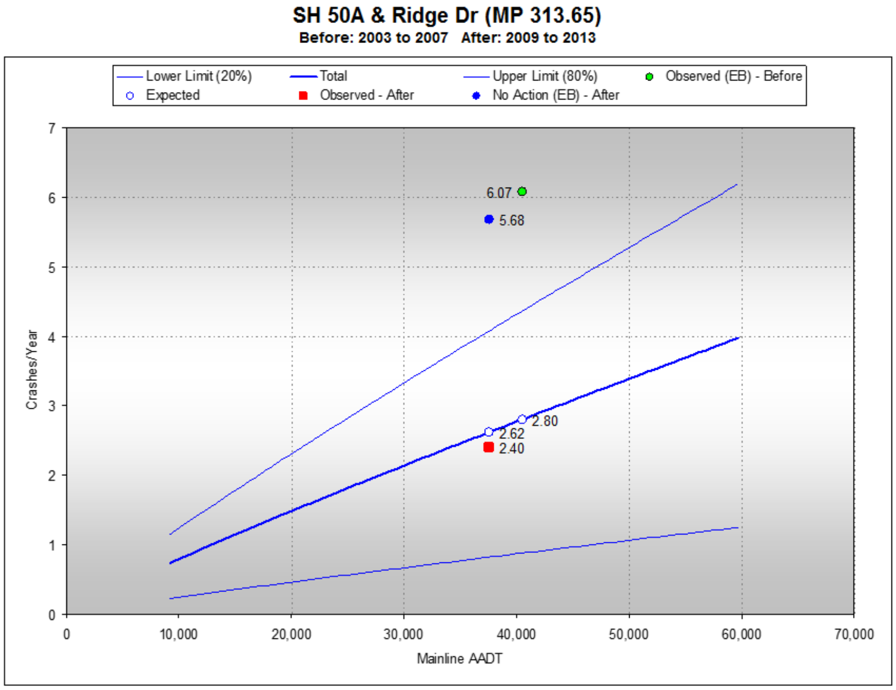
Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 4 - SPF for Injury and Fatal Crashes



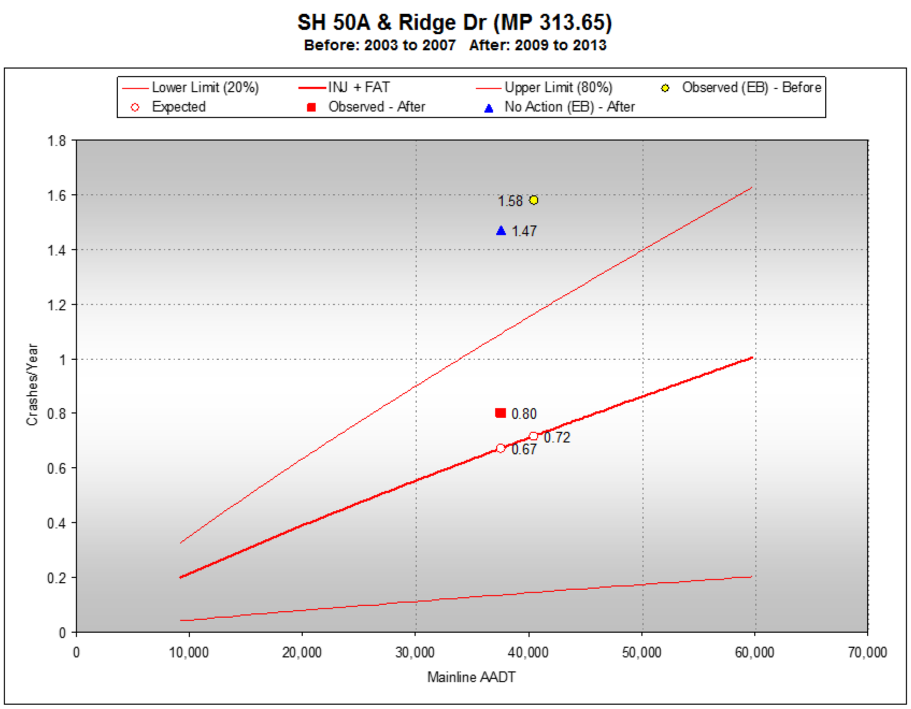
Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 5 - SPF for Total Crashes



Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-Lane Divided Unsignalized 3-Leg Intersection

Figure 6 - SPF for Injury and Fatal Crashes



Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-Lane Divided Unsignalized 3-Leg Intersection

Table 4 – SH 50A & Westroads Avenue (MP 313.37) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane Divided, Unsignalized 4-leg Intersection	Urban, 4-lane Divided, Unsignalized 4-leg Intersection	Urban, 4-lane Divided, Unsignalized 4-leg Intersection
Total Crashes:			
LOSS	LOSS II	LOSS I	LOSS II
CPMPY	3.02	0.20	3.03
Mean CPMPY	4.51	4.52	4.52
Proportion of Mean	0.670	0.044	0.670
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS I	LOSS II
CPMPY	1.23	0	1.23
Mean CPMPY	1.32	1.32	1.32
Proportion of Mean	0.932	0	0.932

Table 5 – SH 50A & Baltimore Avenue (MP 313.52) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane Divided, Signalized 4-leg Intersection	Urban, 4-lane Divided, Signalized 4-leg Intersection	Urban, 4-lane Divided, Signalized 4-leg Intersection
Total Crashes:			
LOSS	LOSS IV	LOSS III	LOSS IV
CPMPY	16.34	11.60	16.09
Mean CPMPY	10.35	10.19	10.19
Proportion of Mean	1.579	1.138	1.579
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS III	LOSS III
CPMPY	3.88	3.80	3.84
Mean CPMPY	3.12	3.09	3.09
Proportion of Mean	1.244	1.230	1.244

Table 6 – SH 50A & Ridge Dr (MP 313.65) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane Divided, Unsignalized 3-leg Intersection	Urban, 4-lane Divided, Unsignalized 3-leg Intersection	Urban, 4-lane Divided, Unsignalized 3-leg Intersection
Total Crashes:			
LOSS	LOSS IV	LOSS II	LOSS IV
CPMPY	6.07	2.40	5.68
Mean CPMPY	2.80	2.62	2.62
Proportion of Mean	2.168	0.916	2.168
Fatal & Injury Crashes:			
LOSS	LOSS IV	LOSS III	LOSS IV
CPMPY	1.58	0.80	1.47
Mean CPMPY	0.72	0.67	0.67
Proportion of Mean	2.194	1.194	2.194

A more detailed review of the before and after crash record reveals that a significant portion of the overall improvement in safety can be attributed to the replacement of the median. **Table 7** provides a comparison of the crash types affected by the median (approach turn, broadside, and rear-end). The No Build After crashes were estimated using the decrease in the median of the SPF for total crashes found in **Tables 4, 5, and 6** (e.g. for Baltimore Avenue, decrease is 0.985 = 10.19/10.35).

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Exhibit 7** for approach turn, rear end, and broadside type crashes. **Exhibit 7** shows the result of the Benefit/Cost calculation is a B/C ratio of 4.06. This result shows that the project was justified from an economic standpoint due to the significant decrease in the number and severity of crashes.

Table 7 – SH 50A - Results of Intersection Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2003 to 12/31/2007 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
US 50 & Westroads Ave (MP 313.37)			
Rear End – Total	**5**	**1**	**5**
Injury (injuries)	3 (6)	0	3 (6)
PDO	2	1	2
Broadside – Total	**3**	**0**	**3**
Injury (injuries)	1 (1)	0	1 (1)
PDO	2	0	2
Approach Turn – Total	**3**	**0**	**3**
Injury (injuries)	1 (1)	0	1 (1)
PDO	2	0	2
SH 50A & Baltimore Avenue (MP 313.52)			
Rear End – Total	**59**	**38**	**58**
Injury (injuries)	9 (14)	10 (14)	9 (14)
PDO	50	28	49
Broadside – Total	**7**	**3**	**7**
Injury (injuries)	4 (5)	2 (2)	4 (5)
PDO	3	1	3
Approach Turn – Total	**15**	**10**	**15**
Injury (injuries)	7 (14)	4 (7)	7 (14)
PDO	8	6	8
SH 50A & Ridge Dr (MP 313.65)			
Rear End – Total	**15**	**8**	**14**
Injury (injuries)	3 (4)	3 (4)	3 (4)
PDO	12	5	11
Broadside – Total	**8**	**1**	**8**
Injury (injuries)	3 (3)	0	3 (3)
PDO	5	1	5
Approach Turn – Total	**6**	**0**	**6**
Injury (injuries)	2 (4)	0	2 (4)
PDO	4	0	4
Total	**121**	**61**	**119**
Injury (injuries)	33 (52)	19 (27)	33 (52)
PDO	88	42	86
% Reduction in Total – (Injuries/ PDO)		48% / 51%	

Exhibit 7 – SH 50A - Benefit Cost Analysis

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

11/23/2016

Job #: 20161123084729

Location: 50A **Begin:** 313.35 **End:** 313.67 **From:** 01/01/2003 **To:** 12/31/2007

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	88		Weighted PDO:	21.62	51% : CRF for PDO	Cost of PDO:	$ 9,300
INJ:	33	52 : Injured	Weighted INJ:	12.78	48% : CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 : Killed	Weighted FAT:	0.00	20% : CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	50% : Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost:	$ 1,835,388
From:	01/01/2003
To:	12/31/2007
Days:	1826

Benefit Cost Ratio: 4.06 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: ROADWAY - RAISED MEDIAN
Special Notes: APPROACH TURN, BROADSIDE, & REAR-END CRASH TYPES

Location: 50A **Begin:** 313.35 **End:** 313.39 **From:** 01/01/2003 **To:** 12/31/2007

Severity

PDO:	8	
INJ:	6	9 :Injured
FAT:	0	0 :Killed
Total:	**14**	

Number of Vehicles

One Vehicle:	0
Two Vehicles:	12
Three or More:	2
Unknown:	0
Total:	**14**

Location

On Road:	13
Off Road Left:	1
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**14**

Lighting Conditions

Daylight:	13
Dawn or Dusk:	0
Dark - Lighted:	1
Dark - Unlighted:	0
Unknown:	0
Total:	**14**

Weather Conditions

None:	12
Rain:	1
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**14**

Crash Rates

PDO:	2.78 *
INJ:	2.09 *
FAT:	0.00 **
Total:	**4.87** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	14
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**14**

Road Description

At Intersection:	12
At Driveway Access:	0
Intersection Related:	2
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**14**

Road Conditions

Dry:	13
Wet:	1
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**14**

ADT: 39,329 **Length:** 0.04

Location: 50A **Begin:** 313.35 **End:** 313.39 **From:** 01/01/2003 **To:** 12/31/2007

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	8	8	2
Passenger Car/Van w/Trl:	0	1	0
Pickup Truck/Utility Van:	3	4	0
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	2	1	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**14**	**14**	**2**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	8	12	2
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	2	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	2	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	1	2	0
Total:	**14**	**14**	**2**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	13	14	2
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**14**	**14**	**2**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	5	8	0
Slowing:	0	3	1
Stopped in Traffic:	0	2	1
Making Right Turn:	1	0	0
Making Left Turn:	7	1	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**14**	**14**	**2**

Direction	Veh 1	Veh 2	Veh 3
North:	1	0	0
Northeast:	0	0	0
East:	7	8	2
Southeast:	0	0	0
South:	3	1	0
Southwest:	0	0	0
West:	3	5	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**14**	**14**	**2**

ADT: 39,329 **Length:** 0.04

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

Exhibit 2

05/20/2016

Job #: 20160520105911

Location: 50A **Begin:** 313.50 **End:** 313.54 **From:** 01/01/2003 **To:** 12/31/2007

Severity

PDO:	65		
INJ:	21	33	:Injured
FAT:	0	0	:Killed
Total:	**86**		

Number of Vehicles

One Vehicle:	2
Two Vehicles:	75
Three or More:	9
Unknown:	0
Total:	**86**

Location

On Road:	84
Off Road Left:	1
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**86**

Lighting Conditions

Daylight:	70
Dawn or Dusk:	2
Dark - Lighted:	12
Dark - Unlighted:	0
Unknown:	2
Total:	**86**

Weather Conditions

None:	78
Rain:	5
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	1
Unknown:	2
Total:	**86**

Crash Rates

PDO:	22.95 *
INJ:	7.41 *
FAT:	0.00 **
Total:	**30.36** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	7	Embankment:	0
Head On:	0	Curb:	1
Rear End:	59	Delineator Post:	0
Sideswipe (Same):	3	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	15	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	2
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**86**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	86
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**86**

Road Description

At Intersection:	65
At Driveway Access:	0
Intersection Related:	21
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**86**

Road Conditions

Dry:	80
Wet:	0
Muddy:	0
Snowy:	0
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	1
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	2
Total:	**86**

ADT: 39,773 **Length:** 0.03

Location: 50A **Begin:** 313.50 **End:** 313.54 **From:** 01/01/2003 **To:** 12/31/2007

Vehicle Type

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	52	62	4
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	21	20	4
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	4	2	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	2	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	6	0	0
Other:	0	0	0
Unknown:	0	0	1
Total:	**86**	**84**	**9**

Contributing Factor

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	59	78	6
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	6	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	8	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	11	6	3
Total:	**86**	**84**	**9**

Condition of Driver

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	79	84	9
Alcohol Involved:	7	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**86**	**84**	**9**

Vehicle Movement

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	55	31	0
Slowing:	7	6	1
Stopped in Traffic:	2	36	5
Making Right Turn:	6	3	0
Making Left Turn:	13	7	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	1
Changing Lanes:	2	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	1	1
Unknown:	0	0	1
Total:	**86**	**84**	**9**

Direction

Direction	Veh 1	Veh 2	Veh 3
North:	17	16	0
Northeast:	0	0	0
East:	39	34	5
Southeast:	0	0	0
South:	2	3	1
Southwest:	0	0	0
West:	28	31	1
Northwest:	0	0	0
Unknown:	0	0	2
Total:	**86**	**84**	**9**

ADT: 39,773 **Length:** 0.03

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

Exhibit 3

05/20/2016

Job #: 20160520114321

Location: 50A **Begin:** 313.63 **End:** 313.67 **From:** 01/01/2003 **To:** 12/31/2007

Severity

PDO:	23		
INJ:	9	12	:Injured
FAT:	0	0	:Killed
Total:	**32**		

Number of Vehicles

One Vehicle:	2
Two Vehicles:	26
Three or More:	4
Unknown:	0
Total:	**32**

Location

On Road:	32
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**32**

Lighting Conditions

Daylight:	28
Dawn or Dusk:	0
Dark - Lighted:	2
Dark - Unlighted:	2
Unknown:	0
Total:	**32**

Weather Conditions

None:	26
Rain:	2
Snow/Sleet/Hail:	3
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**32**

Crash Rates

PDO:	7.78	*
INJ:	3.04	*
FAT:	0.00	**
Total:	**10.82**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	8	Embankment:	0
Head On:	0	Curb:	0
Rear End:	15	Delineator Post:	0
Sideswipe (Same):	1	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	6	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**32**
Concrete Barrier:	1		

Mainline/Ramps/Frontage Roads

Mainline:	32
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**32**

Road Description

At Intersection:	26
At Driveway Access:	0
Intersection Related:	6
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**32**

Road Conditions

Dry:	26
Wet:	3
Muddy:	0
Snowy:	1
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	1
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**32**

ADT: 40,483 **Length:** 0.04

Location: 50A **Begin:** 313.63 **End:** 313.67 **From:** 01/01/2003 **To:** 12/31/2007

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	15	22	3
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	11	7	1
Pickup Truck/Utility Van w/Trl:	1	1	0
SUV:	2	0	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	2	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**32**	**30**	**4**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	25	29	3
Asleep at the Wheel:	1	0	0
Illness:	1	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	3	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	0	1	1
Total:	**32**	**30**	**4**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	32	30	4
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**32**	**30**	**4**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	17	16	0
Slowing:	1	6	2
Stopped in Traffic:	1	8	2
Making Right Turn:	4	0	0
Making Left Turn:	9	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**32**	**30**	**4**

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	19	12	4
Southeast:	0	0	0
South:	11	3	0
Southwest:	0	0	0
West:	2	15	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**32**	**30**	**4**

ADT: 40,483 **Length:** 0.04

Location: 50A **Begin:** 313.35 **End:** 313.39 **From:** 01/01/2009 **To:** 12/31/2013

Severity

PDO:	1	
INJ:	0	0 :Injured
FAT:	0	0 :Killed
Total:	**1**	

Number of Vehicles

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

Location

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

Lighting Conditions

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

Weather Conditions

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

Crash Rates

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

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	1
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**1**

Road Description

At Intersection:	1
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**1**

Road Conditions

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

ADT: 39,440 **Length:** 0.03

Location: 50A **Begin:** 313.35 **End:** 313.39 **From:** 01/01/2009 **To:** 12/31/2013

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

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

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

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

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

ADT: 39,440 **Length:** 0.03

Location: 50A **Begin:** 313.50 **End:** 313.54 **From:** 01/01/2009 **To:** 12/31/2013

Severity

PDO:	39		
INJ:	19	26	:Injured
FAT:	0	0	:Killed
Total:	**58**		

Number of Vehicles

One Vehicle:	3
Two Vehicles:	49
Three or More:	6
Unknown:	0
Total:	**58**

Location

On Road:	55
Off Road Left:	1
Off Road Right:	2
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**58**

Lighting Conditions

Daylight:	49
Dawn or Dusk:	1
Dark - Lighted:	8
Dark - Unlighted:	0
Unknown:	0
Total:	**58**

Weather Conditions

None:	53
Rain:	3
Snow/Sleet/Hail:	2
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**58**

Crash Rates

PDO:	14.53 *
INJ:	7.08 *
FAT:	0.00 **
Total:	**21.60** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	1	Culvert/Headwall:	0
Broadside:	3	Embankment:	0
Head On:	0	Curb:	0
Rear End:	38	Delineator Post:	0
Sideswipe (Same):	3	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	10	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	2
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	1	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**58**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	58
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**58**

Road Description

At Intersection:	35
At Driveway Access:	0
Intersection Related:	23
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**58**

Road Conditions

Dry:	52
Wet:	3
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	2
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**58**

ADT: 38,690 **Length:** 0.03

Location: 50A **Begin:** 313.50 **End:** 313.54 **From:** 01/01/2009 **To:** 12/31/2013

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	26	31	1
Passenger Car/Van w/Trl:	1	1	0
Pickup Truck/Utility Van:	7	10	1
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	17	11	4
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	3	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	3	0	0
Other:	0	1	0
Unknown:	0	0	0
Total:	**58**	**55**	**6**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	43	55	6
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	4	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	2	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	7	0	0
Total:	**58**	**55**	**6**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	58	55	6
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**58**	**55**	**6**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	41	24	1
Slowing:	2	8	0
Stopped in Traffic:	0	18	5
Making Right Turn:	0	1	0
Making Left Turn:	12	4	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**58**	**55**	**6**

Direction	Veh 1	Veh 2	Veh 3
North:	2	6	1
Northeast:	0	0	0
East:	30	27	3
Southeast:	0	0	0
South:	3	2	1
Southwest:	0	0	0
West:	23	20	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**58**	**55**	**6**

ADT: 38,690 **Length:** 0.03

Location: 50A **Begin:** 313.63 **End:** 313.67 **From:** 01/01/2009 **To:** 12/31/2013

Severity

PDO:	8		
INJ:	4	5	:Injured
FAT:	0	0	:Killed
Total:	**12**		

Number of Vehicles

One Vehicle:	0
Two Vehicles:	12
Three or More:	0
Unknown:	0
Total:	**12**

Location

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

Lighting Conditions

Daylight:	11
Dawn or Dusk:	0
Dark - Lighted:	1
Dark - Unlighted:	0
Unknown:	0
Total:	**12**

Weather Conditions

None:	11
Rain:	0
Snow/Sleet/Hail:	1
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**12**

Crash Rates

PDO:	2.92	*
INJ:	1.46	*
FAT:	0.00	**
Total:	**4.38**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	1	Embankment:	0
Head On:	0	Curb:	0
Rear End:	8	Delineator Post:	0
Sideswipe (Same):	3	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	0
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**12**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	12
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**12**

Road Description

At Intersection:	7
At Driveway Access:	0
Intersection Related:	5
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**12**

Road Conditions

Dry:	11
Wet:	1
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**12**

ADT: 37,540 **Length:** 0.04

Location: 50A **Begin:** 313.63 **End:** 313.67 **From:** 01/01/2009 **To:** 12/31/2013

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

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	7	5	0
Slowing:	1	3	0
Stopped in Traffic:	0	4	0
Making Right Turn:	2	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**12**	**12**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	5	5	0
Southeast:	0	0	0
South:	1	0	0
Southwest:	0	0	0
West:	6	7	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**12**	**12**	**0**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	8	12	0
Asleep at the Wheel:	1	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	1	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	1	0	0
Total:	**12**	**12**	**0**

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

ADT: 37,540 **Length:** 0.04

Project Information

Project Name: I-76 Burlington Canal to Bromley Lane

Project Description: Install Median Cable Barrier to Avoid Cross Over Accidents

CDOT Region: 6 Project Def: 16495 County: Adams

Location: I-76 Mile Points: 17.08 – 22.38 Length: 5.33 miles

Schedule: Work Start Date: 7/7/2008 Completion Date: 5/12/2009

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history (1999 – 2003) showed that there was a total of 27 crashes that were head-on, sideswipe opposite direction, or off-road in the median, which is higher than expected for this roadway. Of these 27 crashes, two resulted in fatalities.

Improvement Description: Between July 7, 2008 and May 12, 2009, a cable rail was installed in the median on I-76 between MP 17.08 and MP 22.38. The cost of construction was $1,182,490.

The HSIP application anticipated that a 20% reduction in property damage only crashes, a 40% reduction in injury crashes, and a 60% reduction in fatal crashes might be realized by the improvement. The initial benefit/cost ratio was estimated to be 1.78.

Summary and Findings

The analysis of safety before and after the cable rail on I-76 showed a reduction in the crashes occurring in the median or crossing the median into oncoming traffic. However, there also was an increase in fixed object crashes due to the cable rail.

Along the study segment of 4-lane divided highway on I-76, there were 157 total crashes during the five-year period before the cable rail was installed (2003 to 2007). In the five years after construction (2010 to 2014), the number of crashes increased to 276. A comparison of overturning, head-on, and sideswipe opposite direction type crashes before and after the installation of the cable rail showed that there was a decrease in injuries and fatalities. The ratio of benefits and cost for this project shows that benefits were very close to the costs as the B/C ratio was 1.03 to one. The result is the improvement was possibly justified from an economic standpoint.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records shows an increase in the number of crashes on the study corridor. On I-76 the total number of mainline crashes increased from 157 during the five-year period (2003 to 2007) before the cable rail was installed (see **Table 1** and **Exhibit 1**) to 276 during the five-year after period (2010 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes also increased on I-76:

- Before (2003 to 2007) – 2 fatal crash with 2 fatalities and 33 injury crashes with 56 injuries
- After (2010 to 2014) –2 fatal crashes with 2 fatalities and 65 injury crashes with 93 injuries

The cable rail crash type contributed to the increase in number of crashes with 84 cable rail crashes in the after period. There were no cable rail crashes in the before period. It is likely the cable rail prevented more severe crashes by keeping vehicles from traveling into oncoming traffic. However, the increase in crashes in the after period and the increase in injuries was not solely due to the installation of the cable rail.

Table 1 – I-76 (MP 17.08 to MP 22.38) - Results of Overall Crash Analyses

	Before	After
Time Period:	2003 to 2007 (5 yr.)	2010 to 2014 (5 yr.)
AADT	25,229 vpd	29,364 vpd
Filters:	Mainline	Mainline
Total Crashes	**157**	**276**
Fatal Crashes (Fatalities)	2 (2)	2 (2)
Injury Crashes (Injuries)	33 (56)	65 (93)
Property Damage Only	122	209
Crash Types: # (% of total crashes) [cumulative probability]		
Fixed Object	60 (38.2%) [95.57%]	143 (51.8%) [100.00%]
Overturning	29 (18.5%) [97.88%]	26 (9.4%)
Sideswipe Same	19 (12.1%) [96.17%]	41 (14.9%) [95.77%]
Rear-end	16 (10.2%)	30 (10.9%)
Head-on	4 (2.5%)	0
Sideswipe Opposite	1 (0.6%)	0
Fixed Object Crashes: # (% of FO) [cumulative probability]		
Guardrail	26 (43.3%) [99.93%]	28 (19.6%) [98.41%]
Sign	10 (16.7%)	6 (4.2%)
Cable Rail	0	84 (58.7%) [100.00%]

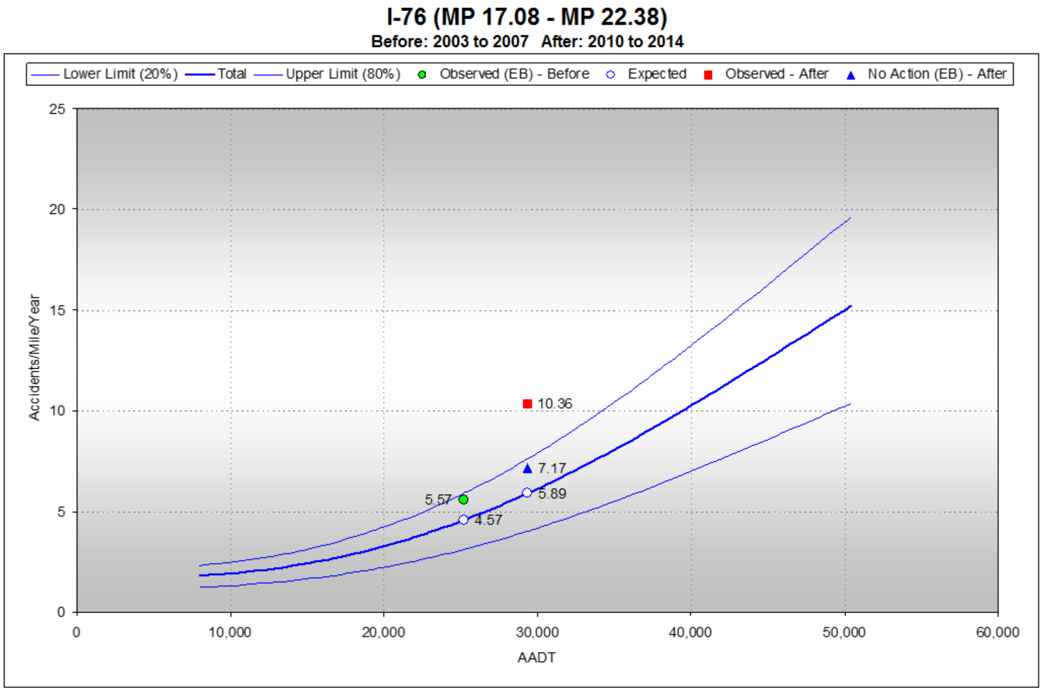
The magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. A SPF reflects the complex relationship between exposure (measured in ADT) and the crash count for a section of roadway measured in crashes per mile per year (CPMPY) or for an intersection, measured in crashes per year. The SPF models provide an estimate for the expected crash frequency and severity for a range of ADT among similar facilities. This allows for an assessment of the magnitude of the safety problem from a frequency standpoint. Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

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

LOSS boundaries are calibrated by computing the 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.

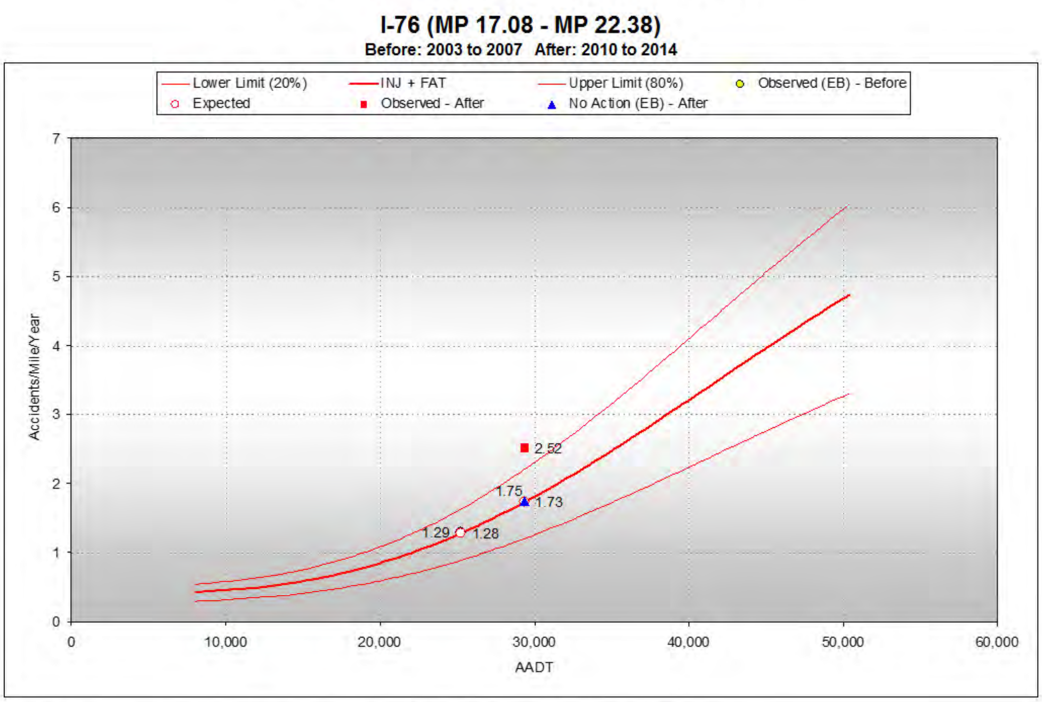
I-76 SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) reflect the increase in crashes and severity of crashes. The frequency of crashes increased from the LOSS III category to the LOSS IV category. For the severity of crashes, LOSS was at the LOSS II/LOSS III boundary line in the before period and increased to the LOSS IV category for the after periods. **Table 2** provides the results of the I-76 SPF analysis.

Figure 1 - SPF for Total Crashes



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

Figure 2 - SPF for Injury and Fatal Crashes



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

Table 2 – I-76 (MP 17.08 to MP 22.38) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, Flat Rolling Mountainous, 4-lane Divided Freeway	Urban, Flat Rolling Mountainous, 4-lane Divided Freeway	Urban, Flat Rolling Mountainous, 4-lane Divided Freeway
Total Crashes:			
LOSS	LOSS III	LOSS IV	LOSS III
CPMPY	5.57	10.36	7.19
Mean CPMPY	4.57	5.89	5.89
Proportion of Mean	1.22	1.76	1.22
Fatal & Injury Crashes:			
LOSS	LOSS II/III	LOSS IV	LOSS II/III
CPMPY	1.29	2.52	1.75
Mean CPMPY	1.28	1.73	1.73
Proportion of Mean	1.01	1.46	1.01

A more detailed review of the before and after crash record on I-76 reveals that the reduction in head-on, sideswipe opposite direction, and overturning crashes can be attributed to the installation of the cable rail. **Table 3** provides a comparison of the sideswipe opposite direction, overturning, and head-on crashes. The No Build After crashes were estimated using the increase in the mean of the SPF for total crashes found in **Table 2** (increase is 1.29 = 5.89/4.57). **Table 3** shows a decrease in head-on, sideswipe opposite direction, and overturning crashes prevented by cable rail. However, there was a large number of cable rail crashes in the after period. It is likely that the cable rail crashes prevented more severe crash types.

Table 3 – I-76 (MP 17.08 to MP 22.38) - Results of Cable Rail Crash Analyses

	Before	**After**	**No Build After**
Time Period:	2003 to 2007 (5 yr.)	2010 to 2014 (5 yr)	2003 to 2007 (5 yr)
Crash Types:			
Head-On – Total	**4**	**0**	**5**
Fatal (fatalities)	1 (1)	0	1 (1)
Injury (injuries)	2 (7)	0	3 (9)
PDO	1	0	1
% Reduction in Total		100%	
Overturning – Total (off-left/off-median only)	**12**	**5**	**16**
Injury (injuries)	6 (12)	1 (1)	8 (15)
PDO	6	4	8
% Reduction in Total – (Injuries/ PDO)		93% / 50%	
Sideswipe Opposite – Total	**1**	**0**	**1**
Injury (injuries)	1 (2)	0	1 (2)
PDO	0	0	0
% Reduction in Total –		100%	
Cable Rail – Total (off-left/off-median only)	**0**	**80**	**0**
Injury (injuries)	0	17 (22)	0
PDO	0	63	0

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the cable rail improvement on I-76. Cable rail causes new crashes since it creates a barrier in the median. The increase in cable rail crashes was factored into the analysis by increasing the cost of construction for the cable rail. During the five-year after period, there were 17 injury (22 injuries) and 63 property damage only cable rail crashes. Over the design life of 20 years for the cable rail system, the increased cost of crashes would be $9,445,200 (252 PDO = $2,343,600 and 88 injuries = $7,101,600). As shown in **Figure 3**, the B/C ratio is 1.03 for the cable rail showing the improvement may have been justified.

Figure 3 – I-76 ((MP 17.08 to MP 22.38) - Benefit Cost Analysis – Overturning, Sideswipe Opposite Direction, and Head-on Crash Types Only

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

08/29/2016

Job #: 20160829121526

Location: 76A **Begin:** 17.08 **End:** 22.38 **From:** 01/01/2003 **To:** 12/31/2007

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors				Other Information	
PDO:	9		Weighted PDO:	2.21	56%	:CRF for PDO	Cost of PDO:	$ 9,300
INJ:	12	26 :Injured	Weighted INJ:	6.39	96%	:CRF for INJ	Cost of INJ:	$ 80,700
FAT:	1	1 :Killed	Weighted FAT:	0.25	100%	:CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	79%	:Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
							Service Life:	20
							Capital Recovery Factor:	0.080
							Annual Maintenance/Delay Cost:	$ 0

Cost: $ 10,627,690
From: 01/01/2003
To: 12/31/2007 Days: 1826

Benefit Cost Ratio: 1.03 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: CABLE RAIL - HEAD-ON, SIDESWIPE OD, OVERTURNING MEDIAN CRASHES ONLY
Special Notes: COST OF CABLE RAIL CRASHES ADDED TO CONSTRUCTION

Location: 76A **Begin:** 17.08 **End:** 22.38 **From:**01/01/2003 **To:**12/31/2007

Severity

PDO:	122	
INJ:	33	56 :Injured
FAT:	2	2 :Killed
Total:	**157**	

Number of Vehicles

One Vehicle:	102
Two Vehicles:	45
Three or More:	10
Unknown:	0
Total:	**157**

Location

On Road:	64
Off Road Left:	31
Off Road Right:	53
Off Road at Tee:	0
Off in Median:	8
Unknown:	1
Total:	**157**

Lighting Conditions

Daylight:	70
Dawn or Dusk:	17
Dark - Lighted:	32
Dark - Unlighted:	38
Unknown:	0
Total:	**157**

Weather Conditions

None:	104
Rain:	7
Snow/Sleet/Hail:	45
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**157**

Crash Rates

PDO:	0.50 *
INJ:	0.13 *
FAT:	0.81 **
Total:	**0.64** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	29	Bridge Abutment:	0
Other Non Collision:	6	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	1
Broadside:	2	Embankment:	5
Head On:	4	Curb:	0
Rear End:	16	Delineator Post:	6
Sideswipe (Same):	19	Fence:	2
Sideswipe (Opposite):	1	Tree:	3
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	4	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	2
Domestic Animal:	0	Total Fixed Objects:	60
Wild Animal:	6	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	10	Involving Other Object:	10
Bridge Rail:	1	Total Other Objects:	10
Guard Rail:	26	Unknown:	0
Cable Rail:	0	**Total:**	**157**
Concrete Barrier:	4		

Mainline/Ramps/Frontage Roads

Mainline:	157
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**157**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	157
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**157**

Road Conditions

Dry:	87
Wet:	12
Muddy:	0
Snowy:	5
Icy:	45
Slushy:	4
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	1
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	1
Unknown:	0
Total:	**157**

ADT: 25,229 **Length:** 5.33

Location: 76A **Begin:** 17.08 **End:** 22.38 **From:** 01/01/2003 **To:** 12/31/2007

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	92	26	6
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	37	18	3
Pickup Truck/Utility Van w/Trl:	4	1	0
SUV:	9	1	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	8	8	1
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	5	0	0
Other:	1	1	0
Unknown:	0	0	0
Total:	**157**	**55**	**10**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	83	52	8
Asleep at the Wheel:	17	0	0
Illness:	1	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	17	1	2
Driver Fatigue:	1	0	0
Driver Preoccupied:	3	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	1	0	0
Physical Disability:	0	0	0
Unknown:	31	2	0
Total:	**157**	**55**	**10**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	150	54	10
Alcohol Involved:	6	1	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**157**	**55**	**10**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	109	43	8
Slowing:	4	5	0
Stopped in Traffic:	0	1	1
Making Right Turn:	1	0	0
Making Left Turn:	0	0	0
Making U-Turn:	2	0	0
Passing:	6	1	0
Backing:	0	0	0
Enter/Leave Parked Position:	1	0	0
Starting in Traffic:	0	0	0
Parked:	0	3	1
Changing Lanes:	5	1	0
Avoiding Object/Veh in Road:	3	0	0
Weaving:	4	0	0
Other:	21	1	0
Unknown:	1	0	0
Total:	**157**	**55**	**10**

Direction	Veh 1	Veh 2	Veh 3
North:	3	1	0
Northeast:	12	4	0
East:	68	19	2
Southeast:	0	0	0
South:	3	1	0
Southwest:	5	0	0
West:	66	30	8
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**157**	**55**	**10**

ADT: 25,229 **Length:** 5.33

Location: 76A **Begin:** 17.08 **End:** 22.38 **From:** 01/01/2010 **To:** 12/31/2014

Severity

PDO:	209		
INJ:	65	93	:Injured
FAT:	2	2	:Killed
Total:	**276**		

Number of Vehicles

One Vehicle:	185
Two Vehicles:	84
Three or More:	7
Unknown:	0
Total:	**276**

Location

On Road:	104
Off Road Left:	105
Off Road Right:	67
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**276**

Lighting Conditions

Daylight:	147
Dawn or Dusk:	26
Dark - Lighted:	59
Dark - Unlighted:	44
Unknown:	0
Total:	**276**

Weather Conditions

None:	181
Rain:	6
Snow/Sleet/Hail:	86
Fog:	1
Dust:	0
Wind:	2
Unknown:	0
Total:	**276**

Crash Rates

PDO:	0.73 *
INJ:	0.23 *
FAT:	0.70 **
Total:	**0.97** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	26	Bridge Abutment:	0
Other Non Collision:	5	Column/Pier:	0
Pedestrians:	1	Culvert/Headwall:	1
Broadside:	0	Embankment:	3
Head On:	0	Curb:	0
Rear End:	30	Delineator Post:	2
Sideswipe (Same):	41	Fence:	3
Sideswipe (Opposite):	0	Tree:	6
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	1
Parked Motor Vehicle:	1	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	1
Domestic Animal:	2	Total Fixed Objects:	143
Wild Animal:	11	Rocks in Roadway:	0
Light/Utility Pole:	3	Vehicle Cargo/Debris:	10
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	6	Involving Other Object:	6
Bridge Rail:	2	Total Other Objects:	16
Guard Rail:	28	Unknown:	0
Cable Rail:	84	**Total:**	**276**
Concrete Barrier:	3		

Mainline/Ramps/Frontage Roads

Mainline:	276
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**276**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	276
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**276**

Road Conditions

Dry:	169
Wet:	10
Muddy:	0
Snowy:	13
Icy:	67
Slushy:	5
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	4
Icy w/Icy Road Treatment:	6
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**276**

ADT: 29,364 **Length:** 5.32

Location: 76A **Begin:** 17.08 **End:** 22.38 **From:** 01/01/2010 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	127	43	3
Passenger Car/Van w/Trl:	2	0	0
Pickup Truck/Utility Van:	61	18	0
Pickup Truck/Utility Van w/Trl:	5	2	0
SUV:	57	13	3
SUV w/Trl:	1	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	16	11	1
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	1	0
Motorhome:	1	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	5	0	0
Other:	1	3	0
Unknown:	0	0	0
Total:	**276**	**91**	**7**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	87	88	7
Asleep at the Wheel:	17	0	0
Illness:	3	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	10	0	0
Driver Fatigue:	8	0	0
Driver Preoccupied:	14	0	0
Driver Unfamilar with Area:	5	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	130	3	0
Total:	**276**	**91**	**7**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	259	91	7
Alcohol Involved:	13	0	0
RX, Medication, or Drugs Involved:	2	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	2	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**276**	**91**	**7**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	173	63	5
Slowing:	8	10	0
Stopped in Traffic:	2	6	0
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	1	0	0
Passing:	4	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	1
Changing Lanes:	25	1	0
Avoiding Object/Veh in Road:	8	6	1
Weaving:	4	0	0
Other:	51	4	0
Unknown:	0	0	0
Total:	**276**	**91**	**7**

Direction	Veh 1	Veh 2	Veh 3
North:	12	2	0
Northeast:	5	0	0
East:	134	42	1
Southeast:	0	0	0
South:	3	1	0
Southwest:	4	1	0
West:	118	45	6
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**276**	**91**	**7**

ADT: 29,364 **Length:** 5.32

Project Information

Project Name: US 287 / 37th Street - Loveland

Project Description: Signal Upgrade and Geometric Improvements

CDOT Region: 4 Project Def: 16498 County: Larimer (Loveland)

Location: US 287C Mile Points: 335.75 Length: N/A

Schedule: Work Start Date: 4/12/2010 Completion Date: 5/27/2010

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the crash history showed a higher than expected number of rear-end and approach turn type crashes.

Improvement Description: In 2010, the intersection east/west approaches were realigned to improve sight distance. The signal was reconstructed to improve visibility. Additionally, modifications were made to the medians on all approaches. The cost of construction was $320,153.

The HSIP application anticipated that four crash types would be impacted by this improvement: rear-end, approach turn, broadside, and pedestrian type crashes. It was anticipated that there would be approximately a 40% crash reduction for these crash types. The initial benefit/cost ratio was estimated to be 2.69.

Summary and Findings

The analysis of safety before and after the geometry and signal was upgraded at US 287 and 37th Street showed safety improved for the affected crash types, but not overall. For this intersection, there were 25 total crashes during the four-year period before the upgrades (2006 – 2009). In the four years after construction (2011 – 2014), the number of crashes increased to 26 while the traffic volumes also increased slightly.

The signal and geometry upgrade was responsible for a slight decrease in the number and severity of approach turn crashes, while the severity of broadsides actually increased. The ratio of benefits and cost for this project shows that benefits were less than costs by a ratio of 0.57 to one, showing that the improvement was likely not justified from a safety standpoint. The high severity and approach turn crash patterns remain despite the improvements.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows approximately the same number of crashes; the total number of crashes increased from 25 during the four-year period (2006 to 2009) before the signal was upgraded (see **Table 1** and **Exhibit 1**) to 26 during the four-year after period (2011 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes slightly increased while the number of injuries was unchanged:

- Before (2006 – 2009) – no fatal crashes and 14 injury crashes with 23 injuries
- After (2011 – 2014) – no fatal crashes and 16 injury crashes with 23 injuries

The number of crashes increased slightly along with a slight increase in traffic volumes at the intersection. This resulted in a small increase in the crash rates:

- Before (2006 – 2009): 0.49 crashes per million entering vehicles (cpmev)
- After (2011 – 2014): 0.50 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2006 to 12/31/2009 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT (US 287/37th St)	27,050/7,700 vpd	27,900/7,700 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**25**	**26**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	14 (23)	16 (23)
Property Damage Only	11	10
Crash Types: # (%) [significance]		
Approach Turn	12 (48.0%) [99.97%]	11 (42.3%) [99.82%]
Rear-End	7 (28.0%)	7 (26.9%)
Broadside	4 (16.0%)	3 (11.5%)
Pedestrian	1 (4.0%)	1 (3.8%)

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

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

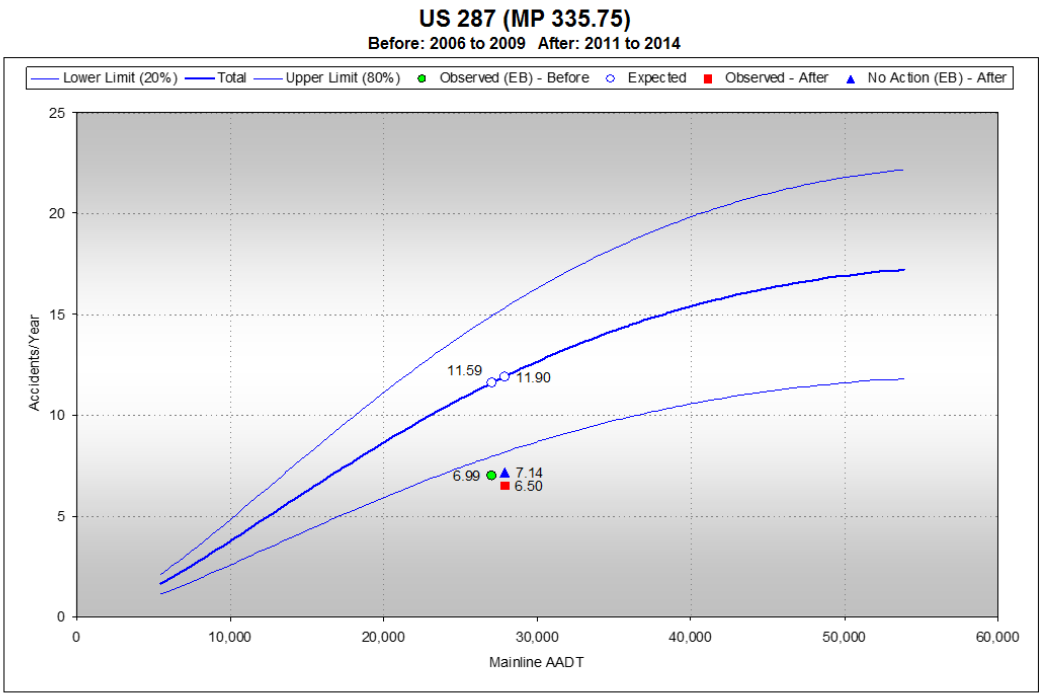
level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

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

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

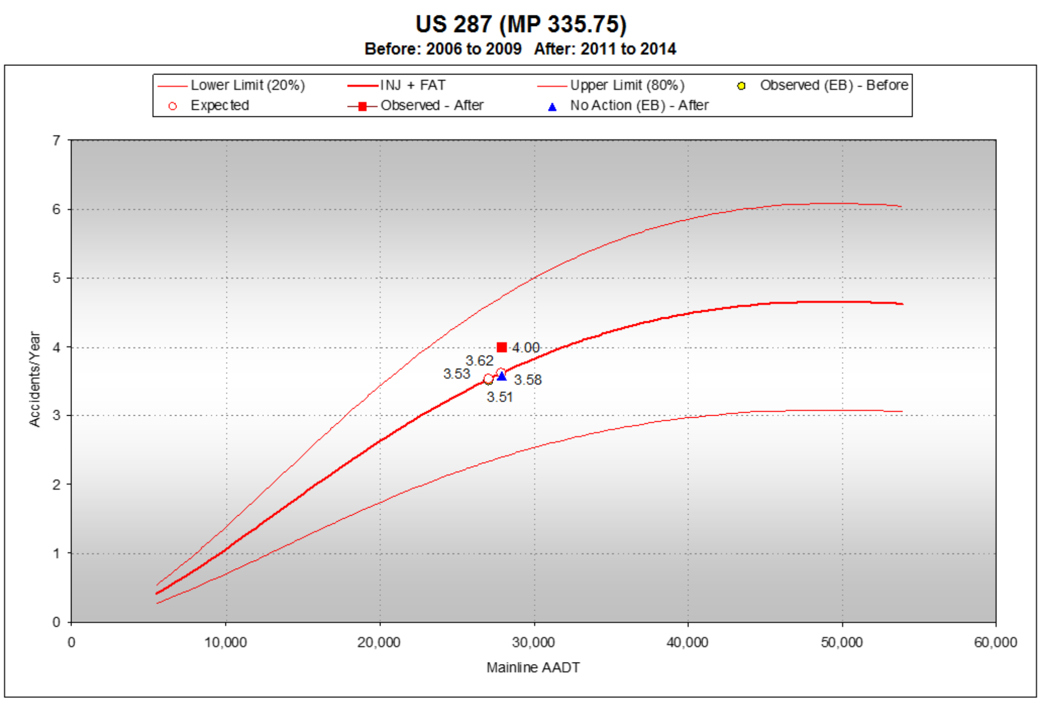
SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. The frequency of crashes remained in the LOSS I range for the before and after period. The severity of crashes was on the LOSS II / LOSS III boundary in the before period and changed to LOSS III in the after period (see **Table 2**).

Figure 1 - SPF for Total Crashes



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

Figure 2 - SPF for Injury and Fatal Crashes



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

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS I	LOSS I	LOSS I
CPY	6.99	6.50	7.14
Mean CPY	11.59	11.90	11.90
Proportion of Mean	0.60	0.55	0.60
Fatal & Injury Crashes:			
LOSS	LOSS II/III	LOSS III	LOSS II/III
CPY	3.51	4.00	3.58
Mean CPY	3.53	3.62	3.62
Proportion of Mean	0.99	1.10	0.99

A more detailed review of the before and after crash record reveals that only a minor improvement in safety can be attributed to the upgrade of the signal. **Table 3** shows a comparison of four types of crashes that are most directly affected by the improvement: rear end, approach turn, pedestrian, and broadside. As shown, there is little to no improvement in among the crash types impacted by the improvements. The No Build After crashes were estimated using the increase in the mean of the SPF for total crashes found in **Table 2** (increase is 1.03 = 11.90/11.59).

Table 3 – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2006 to 12/31/2009 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:			
Rear Ends – Total	**25**	**26**	**26**
Injury (injuries)	14 (23)	16 (23)	15 (24)
PDO	11	10	11
% Reduction in Total (Injuries/PDO)		4% / 9%	
Rear Ends – Total	**7**	**7**	**7**
Injury (injuries)	3 (6)	4 (4)	3 (6)
PDO	4	3	4
% Reduction in Total (Injuries/PDO)		33% / 25%	
Pedestrian – Total	**1**	**1**	**1**
Injury (injuries)	1 (1)	1 (1)	1 (1)
PDO	0	0	0
% Reduction in Total (Injuries/PDO)		0% / 0%	
Broadsides – Total	**4**	**3**	**4**
Injury (injuries)	1 (1)	3 (6)	1 (1)
PDO	3	0	3
% Reduction in Total (Injuries/PDO)		-500% / 100%	
Approach Turns – Total	**12**	**11**	**12**
Injury (injuries)	8 (14)	5 (8)	8 (14)
PDO	4	6	4
% Reduction in Total (Injuries/PDO)		43% / -50%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the impacted crash types. As shown, the B/C ratio for rear-end, approach turn, pedestrian, and broadside crashes is 0.57, showing that the improvement was likely not justified from a safety standpoint. The high severity and approach turn crash patterns remain despite the improvements.

Figure 3 – Benefit Cost Analysis – Intersection Crashes Only

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

11/22/2016

Job #: 20161122150630

Location: 287C **Begin:** 335.66 **End:** 335.83 **From:** 01/01/2006 **To:** 12/31/2009

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	11		Weighted PDO:	3.02	9% : CRF for PDO	Cost of PDO:	$ 9,300
INJ:	15	24 : Injured	Weighted INJ:	6.59	4% : CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 : Killed	Weighted FAT:	0.00	0% : CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	6% : Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
		Cost: $ 320,163				Service Life:	10
		From: 01/01/2006				Capital Recovery Factor:	0.129
		To: 12/31/2009	Days: 1461			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: 0.57 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SIGNAL IMPROVEMENTS
Special Notes: INTERSECTION AND INTERSECTION RELATED CRASHES ONLY

Location: 287C **Begin:** 335.66 **End:** 335.83 **From:** 01/01/2006 **To:** 12/31/2009

Severity

PDO:	11		
INJ:	14	23	:Injured
FAT:	0	0	:Killed
Total:	**25**		

Number of Vehicles

One Vehicle:	0
Two Vehicles:	20
Three or More:	5
Unknown:	0
Total:	**25**

Location

On Road:	24
Off Road Left:	1
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**25**

Lighting Conditions

Daylight:	19
Dawn or Dusk:	0
Dark - Lighted:	5
Dark - Unlighted:	1
Unknown:	0
Total:	**25**

Weather Conditions

None:	21
Rain:	2
Snow/Sleet/Hail:	1
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**25**

Crash Rates

PDO:	1.62	*
INJ:	2.06	*
FAT:	0.00	**
Total:	**3.68**	*

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	25
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**25**

Road Description

At Intersection:	21
At Driveway Access:	0
Intersection Related:	4
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**25**

Road Conditions

Dry:	21
Wet:	1
Muddy:	0
Snowy:	0
Icy:	2
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**25**

ADT: 27,066 **Length:** 0.17

Location: 287C **Begin:** 335.66 **End:** 335.83 **From:** 01/01/2006 **To:** 12/31/2009

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	11	14	4
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	6	3	1
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	4	4	0
SUV w/Trl:	1	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	2	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	1	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**25**	**25**	**5**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	9	14	1
Slowing:	3	2	0
Stopped in Traffic:	0	5	4
Making Right Turn:	0	1	0
Making Left Turn:	12	3	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**25**	**25**	**5**

Direction	Veh 1	Veh 2	Veh 3
North:	10	7	1
Northeast:	0	0	0
East:	4	2	2
Southeast:	0	0	0
South:	11	13	1
Southwest:	0	0	0
West:	0	3	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**25**	**25**	**5**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	14	22	5
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	4	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	1	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	6	3	0
Total:	**25**	**25**	**5**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	24	24	5
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	1	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**25**	**25**	**5**

ADT: 27,066 **Length:** 0.17

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

Exhibit 2

08/21/2016

Job #: 20160821204250

Location: 287C **Begin:** 335.66 **End:** 335.83 **From:** 01/01/2011 **To:** 12/31/2014

Severity

PDO:	10		
INJ:	16	23	:Injured
FAT:	0	0	:Killed
Total:	**26**		

Number of Vehicles

One Vehicle:	1
Two Vehicles:	22
Three or More:	3
Unknown:	0
Total:	**26**

Location

On Road:	25
Off Road Left:	0
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**26**

Lighting Conditions

Daylight:	16
Dawn or Dusk:	3
Dark - Lighted:	7
Dark - Unlighted:	0
Unknown:	0
Total:	**26**

Weather Conditions

None:	23
Rain:	2
Snow/Sleet/Hail:	1
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**26**

Crash Rates

PDO:	1.44	*
INJ:	2.30	*
FAT:	0.00	**
Total:	**3.73**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	1	Culvert/Headwall:	0
Broadside:	3	Embankment:	0
Head On:	0	Curb:	0
Rear End:	7	Delineator Post:	0
Sideswipe (Same):	0	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	11	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	3	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	1
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**26**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	26
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**26**

Road Description

At Intersection:	22
At Driveway Access:	0
Intersection Related:	4
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**26**

Road Conditions

Dry:	20
Wet:	3
Muddy:	0
Snowy:	1
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**26**

ADT: 27,893 **Length:** 0.17

Location: 287C **Begin:** 335.66 **End:** 335.83 **From:** 01/01/2011 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	14	14	1
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	7	5	1
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	4	3	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	1	2	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	1	0
Unknown:	0	0	0
Total:	**26**	**25**	**3**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	13	25	3
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	0	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	12	0	0
Total:	**26**	**25**	**3**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	20	25	3
Alcohol Involved:	5	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**26**	**25**	**3**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	12	17	0
Slowing:	0	0	0
Stopped in Traffic:	0	4	2
Making Right Turn:	2	0	0
Making Left Turn:	12	3	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	1
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	1	0
Total:	**26**	**25**	**3**

Direction	Veh 1	Veh 2	Veh 3
North:	13	6	0
Northeast:	1	1	0
East:	3	3	1
Southeast:	0	0	0
South:	8	13	2
Southwest:	0	0	0
West:	1	1	0
Northwest:	0	0	0
Unknown:	0	1	0
Total:	**26**	**25**	**3**

ADT: 27,893 **Length:** 0.17

Project Information

Project Name: Bakerville to Silver Plume

Project Description: Median Guardrail Safety Improvements

CDOT Region: 1	Project Def: 16563	County: Clear Creek
Location: I-70	Mile Points: 221.2 – 224.7	Length: 3.51 miles
Schedule:	Work Start Date: 6/16/2008	Completion Date: 12/12/2008

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history (1999 – 2003) showed that there was a total of 51 median crashes, which is higher than expected for this roadway type. Of these 51 crashes, one resulted in a fatality.

Improvement Description: Between June 16, 2008 and December 12, 2008, guardrail was installed in the median on I-70 between MP 221.2 and MP 224.7. The cost of construction was $1,441,676.

The HSIP application anticipated that a 40% reduction in injury crashes and a 60% reduction in fatal crashes might be realized by the improvement. The initial benefit/cost ratio was estimated to be 2.36.

Summary and Findings

The analysis of safety before and after the median guardrail on I-70 showed a reduction in the crashes occurring in the median or crossing the median into oncoming traffic. However, there also was an increase in fixed object crashes due to the guardrail.

Along the study segment of 4-lane divided highway on I-70, there were 268 total crashes during the five-year period before the guardrail was installed (2003 to 2007). In the five years after construction (2009 to 2013), the number of crashes decreased to 212. A comparison of overturning, head-on, and sideswipe opposite direction type crashes before and after the installation of the guardrail showed that there was a decrease in injuries. The ratio of benefits and cost for this project shows that benefits were greater than the costs as the B/C ratio was 5.12 to one. The result is the improvement was likely justified from an economic standpoint.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records shows a decrease in the number of crashes on the study corridor. On I-70 the total number of mainline crashes decreased from 268 during the five-year period (2003 to 2007) before the guardrail was installed (see **Table 1** and **Exhibit 1**) to 212 during the five-year after period (2009 to 2013) (see **Table 1** and **Exhibit 2**). The number of injury crashes also decreased on I-70, although there was an increase in fatalities:

- Before (2003 to 2007) – no fatal crashes and 71 injury crashes with 103 injuries
- After (2009 to 2013) –2 fatal crashes with 2 fatalities and 46 injury crashes with 73 injuries

The guardrail crash type contributed to the increase in number of crashes with 17 guardrail crashes in the before period and 56 guardrail crashes in the after period. It is likely the median guardrail prevented more severe crashes by keeping vehicles from traveling into oncoming traffic.

Table 1 – I-70 (MP 221.2 to MP 224.7) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	2003 to 2007 (5 yr.)	2009 to 2013 (5 yr.)
AADT	27,423 vpd	27,700 vpd
Filters:	Mainline	Mainline
Total Crashes	**268**	**212**
Fatal Crashes (Fatalities)	0	2 (2)
Injury Crashes (Injuries)	71 (103)	46 (73)
Property Damage Only	197	164
Crash Types: # (% of total crashes) [cumulative probability]		
Fixed Object	91 (34.0%)	107 (50.5%) [99.96%]
Rear-end	63 (23.5%) [100.00%]	52 (24.5%) [100.00%]
Overturning	54 (20.1%) [100.00%]	22 (10.4%) [97.50%]
Sideswipe Same	26 (9.7%) [97.68%]	18 (8.5%)
Head-on	2 (0.7%)	0
Sideswipe Opposite	2 (0.7%)	0
Fixed Object Crashes: # (% of FO) [cumulative probability]		
Embankment	18 (19.8%)	7 (6.5%)
Guardrail	17 (18.7%) [98.11%]	56 (52.3%) [100.00%]
Concrete Barrier	17 (18.7%) [98.82%]	11 (10.3%) [95.67%]
Tree	14(15.4%) [99.98%]	16 (15.0%) [100.00%]

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

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

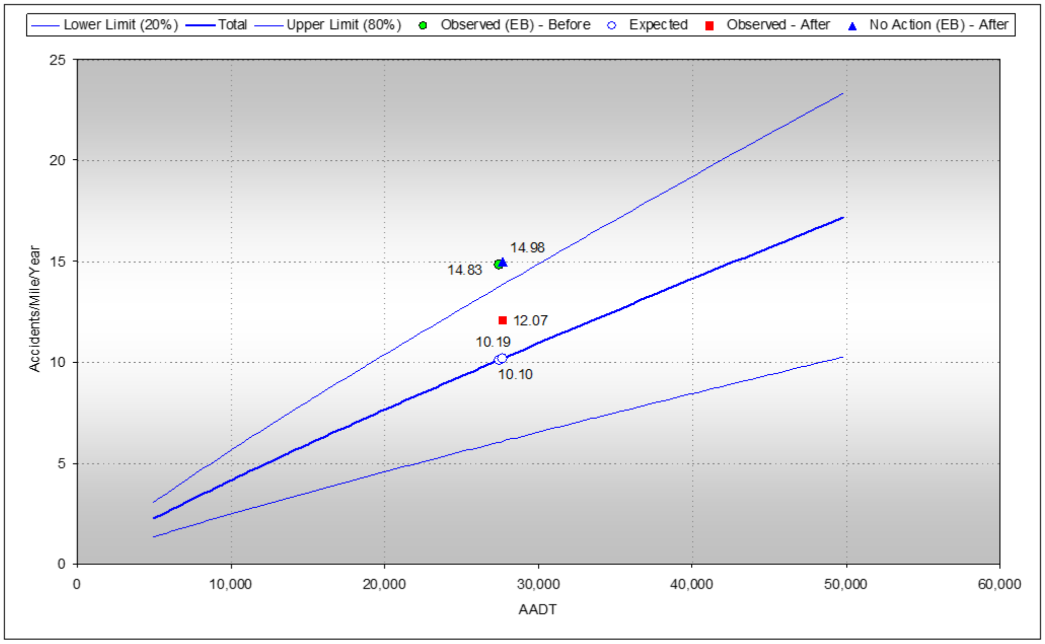
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

LOSS boundaries are calibrated by computing the 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.

The I-70 SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) reflect the decrease in crashes and severity of crashes. Both the frequency and severity of crashes decreased from the LOSS IV category to the LOSS III category. **Table 2** provides the results of the I-70 SPF analysis.

Figure 1 - SPF for Total Crashes

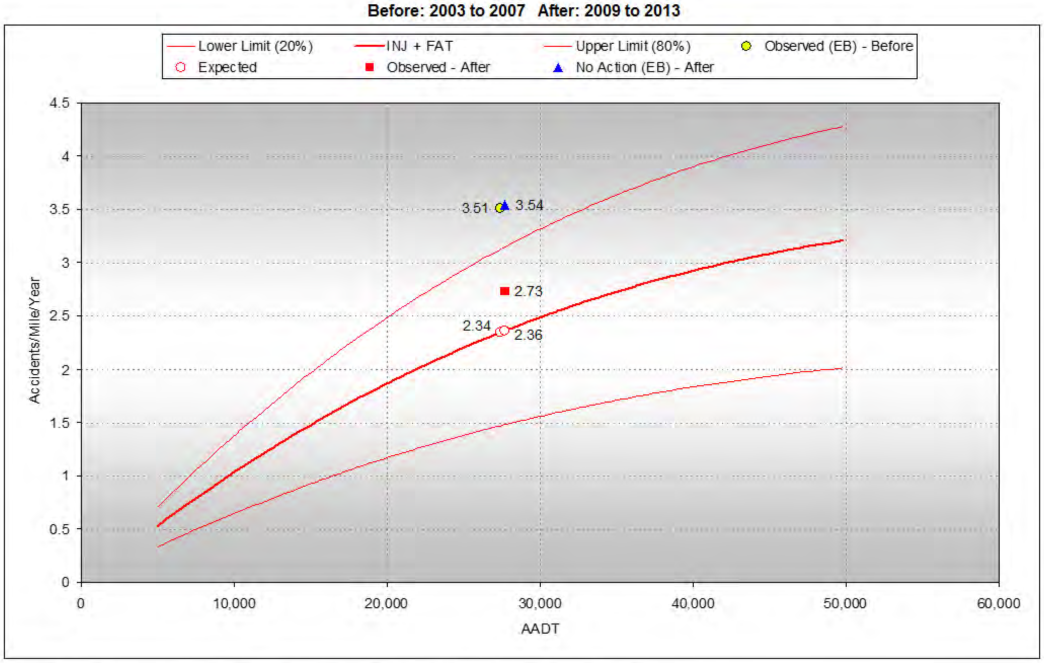
I-70 (MP 221.2 - MP 224.7)
Before: 2003 to 2007 After: 2009 to 2013



Note: Safety Performance Function (SPF) Model: Colorado - Rural, Mountainous, 4-Lane Divided Freeway

Figure 2 - SPF for Injury and Fatal Crashes

I-70 (MP 221.2 - MP 224.7)
Before: 2003 to 2007 After: 2009 to 2013



Note: Safety Performance Function (SPF) Model: Colorado - Rural, Mountainous, 4-Lane Divided Freeway

Table 2 – I-70 (MP 221.2 to MP 224.7) - Safety Performance Function (SPF)

	Before	**After**	**No Build 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 III	LOSS IV
CPMPY	14.83	12.07	14.98
Mean CPMPY	10.10	10.19	10.19
Proportion of Mean	1.47	1.18	1.47
Fatal & Injury Crashes:			
LOSS	LOSS IV	LOSS III	LOSS IV
CPMPY	3.51	2.73	3.54
Mean CPMPY	2.34	2.36	2.36
Proportion of Mean	1.5	1.16	1.5

A more detailed review of the before and after crash record on I-70 reveals that the reduction in head-on, sideswipe opposite direction, and overturning crashes can be attributed to the installation of the guardrail. **Table 3** provides a comparison of the sideswipe opposite direction, overturning, and head-on crashes. The No Build After crashes were estimated using the increase in the mean of the SPF for total crashes found in **Table 2** (increase is 1.01 = 10.19/10.10). **Table 3** shows a decrease in head-on, sideswipe opposite direction, and overturning crashes prevented by guardrail. However, there was a large number of guardrail crashes in the after period. Although, it is likely that the guardrail crashes prevented more severe crash types.

Table 3 – I-70 (MP 221.2 to MP 224.7) - Results of Guardrail Crash Analyses

	Before	**After**	**No Build After**
Time Period:	2003 to 2007 (5 yr.)	2009 to 2013 (5 yr)	2003 to 2007 (5 yr)
Crash Types:			
Head-On – Total	**2**	**0**	**2**
Injury (injuries)	2 (5)	0	2 (5)
PDO	0	0	0
% Reduction in Total		100%	
Overturning – Total (off-left/off-median only)	**36**	**9**	**36**
Fatal (fatalities)	0	1 (1)	0
Injury (injuries)	12 (16)	1 (1)	12 (16)
PDO	24	7	24
% Reduction in Total – (Fatalities/Injuries/ PDO)		NA / 94% / 71%	
Sideswipe Opposite – Total	**2**	**0**	**2**
Injury (injuries)	2 (4)	0	2 (4)
PDO	0	0	0
% Reduction in Total –		100%	
Guardail – Total (off-left/off-median only)	**3**	**42**	**3**
Injury (injuries)	1 (1)	8 (8)	1 (1)
PDO	2	34	2

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the guardrail improvement on I-70. Guardrail causes new crashes since it creates a barrier in the median. But, the overall crashes and injuries in the corridor were reduced, suggesting the presence of additional guardrail had a moderating influence on speed and crashes thru the corridor. The two fatal crashes in the after period were not related to the guardrail, but were related to not wearing a seatbelt (ejected). Therefore, the B/C analysis did not include the fatal crashes in the after period. As shown in **Figure 3**, the B/C ratio is 5.12 for the guardrail showing the improvement was likely justified.

Figure 3 – I-70 ((MP 221.2 to MP 224.7) - Benefit Cost Analysis

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

09/25/2016

Job #: 20160925160733

Location: 70A **Begin:** 221.20 **End:** 224.70 **From:** 01/01/2003 **To:** 12/31/2007

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	197		Weighted PDO:	48.40	17% :CRF for PDO	Cost of PDO:	$ 6
INJ:	71	103 :Injured	Weighted INJ:	25.31	29% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	20% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 1,441,676
From: 01/01/2003
To: 12/31/2007 Days: 1826

Benefit Cost Ratio: 5.12 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: median guardrail
Special Notes:

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

Exhibit 1

08/29/2016

Job #: 20160829124305

Location: 70A **Begin:** 221.20 **End:** 224.70 **From:** 01/01/2003 **To:** 12/31/2007

Severity

PDO:	197		
INJ:	71	103	:Injured
FAT:	0	0	:Killed
Total:	**268**		

Number of Vehicles

One Vehicle:	157
Two Vehicles:	92
Three or More:	19
Unknown:	0
Total:	**268**

Location

On Road:	112
Off Road Left:	80
Off Road Right:	72
Off Road at Tee:	0
Off in Median:	4
Unknown:	0
Total:	**268**

Lighting Conditions

Daylight:	174
Dawn or Dusk:	22
Dark - Lighted:	2
Dark - Unlighted:	70
Unknown:	0
Total:	**268**

Weather Conditions

None:	105
Rain:	16
Snow/Sleet/Hail:	133
Fog:	1
Dust:	0
Wind:	13
Unknown:	0
Total:	**268**

Crash Rates

PDO:	1.12 *
INJ:	0.40 *
FAT:	0.00 **
Total:	**1.52** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	54	Bridge Abutment:	0
Other Non Collision:	5	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	2
Broadside:	0	Embankment:	18
Head On:	2	Curb:	0
Rear End:	63	Delineator Post:	5
Sideswipe (Same):	26	Fence:	0
Sideswipe (Opposite):	2	Tree:	14
Approach Turn:	0	Large Boulders or Rocks:	5
Overtaking Turn:	1	Barricade:	0
Parked Motor Vehicle:	8	Wall/Building:	1
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	2
Domestic Animal:	0	Total Fixed Objects:	91
Wild Animal:	10	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	1
Sign:	8	Involving Other Object:	5
Bridge Rail:	1	Total Other Objects:	6
Guard Rail:	17	Unknown:	0
Cable Rail:	0	**Total:**	**268**
Concrete Barrier:	17		

Mainline/Ramps/Frontage Roads

Mainline:	268
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**268**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	268
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**268**

Road Conditions

Dry:	88
Wet:	37
Muddy:	0
Snowy:	38
Icy:	61
Slushy:	20
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	10
Icy w/Icy Road Treatment:	11
Slushy w/Icy Road Treatment:	1
Unknown:	0
Total:	**268**

ADT: 27,423 **Length:** 3.51

Location: 70A **Begin:** 221.20 **End:** 224.70 **From:** 01/01/2003 **To:** 12/31/2007

Vehicle Type

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	166	63	13
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	67	18	2
Pickup Truck/Utility Van w/Trl:	4	5	0
SUV:	21	6	1
SUV w/Trl:	1	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	7	13	1
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	2	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	1	1
Other:	0	2	1
Unknown:	1	1	0
Total:	**268**	**111**	**19**

Contributing Factor

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	234	109	19
Asleep at the Wheel:	8	0	0
Illness:	1	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	11	1	0
Driver Fatigue:	2	0	0
Driver Preoccupied:	4	0	0
Driver Unfamilar with Area:	3	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	3	1	0
Total:	**268**	**111**	**19**

Condition of Driver

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	261	111	19
Alcohol Involved:	6	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**268**	**111**	**19**

Vehicle Movement

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	208	48	3
Slowing:	13	26	5
Stopped in Traffic:	3	24	9
Making Right Turn:	0	0	0
Making Left Turn:	1	0	0
Making U-Turn:	0	0	0
Passing:	4	1	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	1	9	2
Changing Lanes:	6	0	0
Avoiding Object/Veh in Road:	3	3	0
Weaving:	1	0	0
Other:	28	0	0
Unknown:	0	0	0
Total:	**268**	**111**	**19**

Direction

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	140	76	17
Southeast:	0	0	0
South:	0	0	0
Southwest:	0	0	0
West:	128	35	2
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**268**	**111**	**19**

ADT: 27,423 **Length:** 3.51

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

Exhibit 2

08/29/2016

Job #: 20160829130121

Location: 70A **Begin:** 221.20 **End:** 224.70 **From:** 01/01/2009 **To:** 12/31/2013

Severity

PDO:	164		
INJ:	46	73	:Injured
FAT:	2	2	:Killed
Total:	**212**		

Number of Vehicles

One Vehicle:	131
Two Vehicles:	67
Three or More:	14
Unknown:	0
Total:	**212**

Location

On Road:	80
Off Road Left:	68
Off Road Right:	64
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**212**

Lighting Conditions

Daylight:	131
Dawn or Dusk:	18
Dark - Lighted:	1
Dark - Unlighted:	62
Unknown:	0
Total:	**212**

Weather Conditions

None:	90
Rain:	7
Snow/Sleet/Hail:	109
Fog:	0
Dust:	0
Wind:	6
Unknown:	0
Total:	**212**

Crash Rates

* MVMT
** 100 MVMT

PDO:	0.92 *
INJ:	0.26 *
FAT:	1.13 **
Total:	**1.19** *

Crash Type

Overturning:	22	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	1
Broadside:	0	Embankment:	7
Head On:	0	Curb:	0
Rear End:	52	Delineator Post:	4
Sideswipe (Same):	18	Fence:	0
Sideswipe (Opposite):	0	Tree:	16
Approach Turn:	0	Large Boulders or Rocks:	6
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	4	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	107
Wild Animal:	7	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	1
Sign:	3	Involving Other Object:	1
Bridge Rail:	0	Total Other Objects:	2
Guard Rail:	56	Unknown:	0
Cable Rail:	3	**Total:**	**212**
Concrete Barrier:	11		

Mainline/Ramps/Frontage Roads

Mainline:	212
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**212**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	212
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**212**

Road Conditions

Dry:	64
Wet:	19
Muddy:	0
Snowy:	46
Icy:	59
Slushy:	8
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	9
Icy w/Icy Road Treatment:	4
Slushy w/Icy Road Treatment:	2
Unknown:	0
Total:	**212**

ADT: 27,700 **Length:** 3.51

Location: 70A **Begin:** 221.20 **End:** 224.70 **From:** 01/01/2009 **To:** 12/31/2013

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	74	18	7
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	48	13	4
Pickup Truck/Utility Van w/Trl:	1	2	0
SUV:	79	35	3
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	8	12	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	1	0
Unknown:	0	0	0
Total:	**212**	**81**	**14**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	94	19	2
Slowing:	10	32	6
Stopped in Traffic:	0	22	5
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	3	1	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	1	4	0
Changing Lanes:	10	0	1
Avoiding Object/Veh in Road:	5	1	0
Weaving:	4	0	0
Other:	84	2	0
Unknown:	0	0	0
Total:	**212**	**81**	**14**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	125	81	13
Asleep at the Wheel:	6	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	28	0	1
Driver Fatigue:	2	0	0
Driver Preoccupied:	10	0	0
Driver Unfamilar with Area:	22	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	18	0	0
Total:	**212**	**81**	**14**

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	97	51	9
Southeast:	1	0	0
South:	0	0	0
Southwest:	0	0	0
West:	114	30	5
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**212**	**81**	**14**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	205	81	14
Alcohol Involved:	4	0	0
RX, Medication, or Drugs Involved:	2	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**212**	**81**	**14**

ADT: 27,700 **Length:** 3.51

Project Information

Project Name: US 50 / 28 ½ Road Intersection Improvements

Project Description: Hazard Elimination, New Traffic Signal with Dilemma Prevention

CDOT Region: 4 Project Def: 16595 County: Mesa

Location: SH 50A Mile Points: 35.38 Length: N/A

Schedule: Work Start Date: 5/21/2008 Completion Date: 8/26/2008

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the crash history showed a higher than expected proportion of broadside crashes at the unsignalized intersection of 28 ½ Road with US 50. There were 16 of these crashes during the five-year (1999 – 2003) time period considered in the HSIP application.

Improvement Description: In summer 2008 a signal was installed and deceleration lanes for right and left turns from US-50 were lengthened to meet standards. The new signal included advance detection for dilemma prevention and fully protected left turns from US 50. The cost of construction was $681,725.

The HSIP application anticipated that broadside, approach turn and rear end crashes would be impacted by this improvement. It was anticipated that there would be approximately a 25% crash reduction for these crashes. The expected benefit/cost ratio was estimated to be 1.23.

Summary and Findings

The analysis of safety before and after a traffic signal with dilemma prevention and fully protected left turns from US 50 was installed at the intersection of US 50 and 28 ½ Road showed safety improved by reduction of broadside and approach turn crashes. For this intersection, there were 14 total crashes during the five-year period before the improvement (2003 – 2007). In the five years after construction (2009 – 2013), the number of crashes decreased to 9.

The new signal was apparently responsible for the elimination of broadside crashes at the intersection, but it also was apparently responsible for introducing 5 rear end crashes at the intersection in the after period, compared to 1 in the before period. The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 23.89 to one, showing that the improvement was justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 14 during the five-year period (2003 to 2007) before the new signal, with dilemma prevention and fully protected left turns for US 50, was installed (see **Table 1** and **Exhibit 1**) to 9 during the five-year after period (2009 to 2013) (see **Table 1** and **Exhibit 2**). The number of severe crashes also decreased in the five-year period after the improvements:

- Before (2003 – 2007) – 2 fatal crashes with 3 fatalities and 7 injury crashes with 17 injuries
- After (2009 – 2013) – no fatal crashes and 6 injury crashes with 8 injuries

Despite an increase in traffic volumes at the intersection, the crash rates at the intersection still decreased:

- Before (2003 – 2007): 0.52 crashes per million entering vehicles (cpmev)
- After (2009 – 2013): 0.28 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2003 to 12/31/2007 (5 yr.)	1/1/2009 to 12/31/2013(5 yr.)
AADT (SH 50/28 ½ Rd)	13,833 / 870 vpd	16,460 / 870 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**14**	**9**
Fatal Crashes (Fatalities)	2 (3)	0
Injury Crashes (Injuries)	7 (17)	6 (8)
Property Damage Only	5	3
Crash Types: # (%) [significance]		
Broadside	11 (78.6%) [100.0]	1 (11.1%)
Approach Turn	2 (14.3%)	1 (11.1%)
Rear End	1 (7.1%)	5 (55.6%)

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

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level

of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

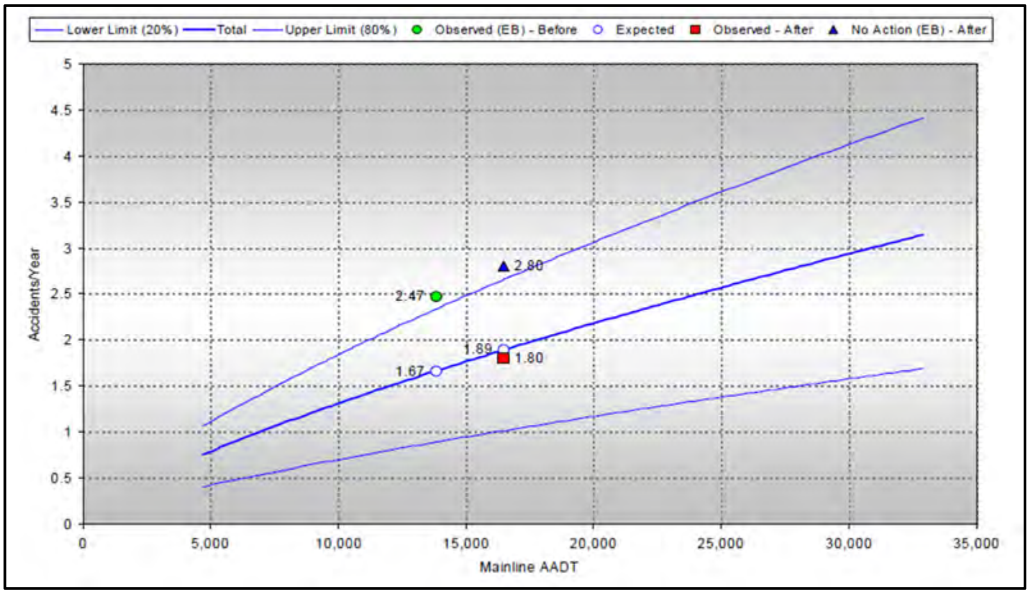
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. The frequency of crashes improved from LOSS IV category for the before period to LOSS II for the after period, while the severity of crashes remained in the LOSS IV category for both periods. However, severity showed improvement within the LOSS IV category in the after period (see **Table 2**).

Figure 1 - SPF for Total Crashes

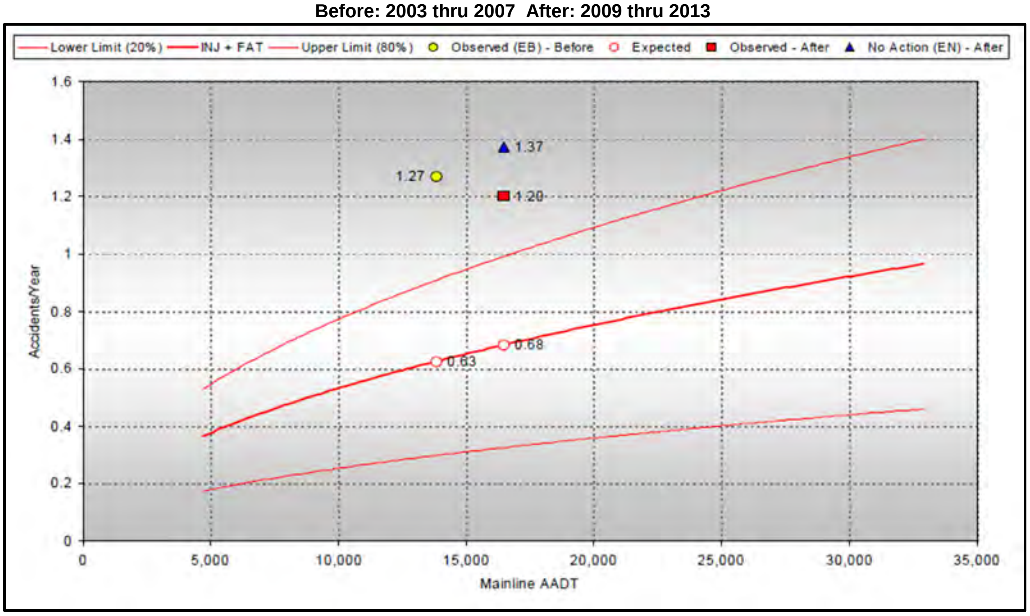
SH 287C (MP 331.65) at 19th St SW
Before: 2003 thru 2007 After: 2009 thru 2013



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

Figure 2 – SPF Injury and Fatal Crashes

SH 287C (MP 331.65) at 19th St SW
Before: 2003 thru 2007 After: 2009 thru 2013



Note: Safety Perfromance Function (SPF) Model: Colorado – Urban 4-Lane Divided Unsignalized 4-Leg Intersection

Table 2 – Safety Performance Function (SPF)

	Before	**After**	**No Build After**
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Unignalized, 4-Leg Intersection	Urban, 4-lane, Divided, Unsignalized, 4-Leg Intersection*	Urban, 4-lane, Divided, Unsignalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS IV	LOSS II*	LOSS IV
CPY	2.47	1.80	2.80
Mean CPY	1.67	1.89	1.89
Proportion of Mean	1.48	0.95	1.48
Fatal & Injury Crashes:			
LOSS	LOSS IV	LOSS IV*	LOSS IV
CPY	1.27	1.20	1.37
Mean CPY	0.63	0.68	0.68
Proportion of Mean	2.02	1.76	2.02

**Intersection type changed by project to Signalized, so LOSS shown is not necessarily correct for the After period, but is shown for comparison only. Actual after period Total Crashes are also in LOSS II, and Injury & Fatal Crashes are also in LOSS IV for Urban, 4-lane, Divided, Signalized, 4-Leg Intersection.*

A more detailed review of the before and after crash record reveals that improvement in safety can be attributed to the addition of a well-designed signal with dilemma prevention and fully protected left turns for the mainline. The signal accomplished the intended goals of reducing broadsides and approach turns, but despite the dilemma prevention, it experienced additional mainline rear end crashes that might be expected when a signal is added. **Table 3** shows a comparison of primary types of crashes that are most directly affected by the improvement: broadside, approach turn and rear end, as well as the total intersection crashes. The No Build After crashes were estimated using the change in mean CPY found in **Table 2** (increase is 1.134 = 2.80/2.47).

Table 3 – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2003 to 12/31/2007 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
Crash Types:			
Total Crashes	**14**	**9**	**21**
Fatal (fatalities)	2 (3)	0 (0)	2 (3)
Injury (injuries)	7 (17)	6 (8)	8 (19)
PDO	5	3	6
% Reduction in Total (Fatalities/Injuries/PDO)		100% / 58% / 50%	
Broadsides – Total	**11**	**1**	**20**
Fatal (fatalities)	2 (3)	0 (0)	2 (3)
Injury (injuries)	6 (14)	1 (2)	7 (16)
PDO	3	0	3
% Reduction in Total (Fatalities/Injuries/PDO)		100% / 88% / 100%	
Approach Turns - Total	**2**	**0**	**2**
Injury (injuries)	1 (3)	1 (1)	1 (3)
PDO	1	0	1
% Reduction in Total (Injuries/PDO)		67% / 100%	
Rear Ends – Total	**1**	**5**	**1**
Injury (injuries)	0 (0)	2 (2)	0 (0)
PDO	1	3	1
% Reduction in Total (Injuries/PDO)		Undefined / -300%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the impacted crash types. As shown, the B/C ratio for the intersection and intersection related crashes is 23.89, showing that the improvement was justified.

Figure 3 – Benefit Cost Analysis – Intersection and Intersection Related Crashes Only

COLORADO Department of Transportation

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

09/30/2016

Job #: 20160930232137

Location: 50A **Begin:** 35.33 **End:** 35.43 **From:** 01/01/2003 **To:** 12/31/2007

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	5		Weighted PDO:	1.23	50% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	7	17 :Injured	Weighted INJ:	4.18	58% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	2	3 :Killed	Weighted FAT:	0.74	100% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	61% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 681,725
From: 01/01/2003
To: 12/31/2007 Days: 1826

Benefit Cost Ratio: 23.89 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SIGNALS - ADD NEW SIGNALS WITH DILEMMA PREVENTION AND PROTECTED LEFT TURNS
Special Notes:

Location: 50A **Begin:** 35.35 **End:** 35.41 **From:** 01/01/2003 **To:** 12/31/2007

BEFORE

Severity

PDO:	5		
INJ:	7	17	:Injured
FAT:	2	3	:Killed
Total:	**14**		

Number of Vehicles

One Vehicle:	0
Two Vehicles:	13
Three or More:	1
Unknown:	0
Total:	**14**

Location

On Road:	14
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**14**

Lighting Conditions

Daylight:	11
Dawn or Dusk:	1
Dark - Lighted:	0
Dark - Unlighted:	2
Unknown:	0
Total:	**14**

Weather Conditions

None:	12
Rain:	1
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**14**

Crash Rates

PDO:	3.30 *
INJ:	4.62 *
FAT:	131.97 **
Total:	**9.24** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	11	Embankment:	0
Head On:	0	Curb:	0
Rear End:	1	Delineator Post:	0
Sideswipe (Same):	0	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	2	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	0
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**14**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	14
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**14**

Road Description

At Intersection:	14
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**14**

Road Conditions

Dry:	13
Wet:	1
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**14**

ADT: 13,833 **Length:** 0.06

Location: 50A **Begin:** 35.35 **End:** 35.41 **From:** 01/01/2003 **To:** 12/31/2007

BEFORE

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	9	9	1
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	2	4	0
Pickup Truck/Utility Van w/Trl:	0	1	0
SUV:	0	0	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	3	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**14**	**14**	**1**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	9	12	0
Slowing:	0	0	0
Stopped in Traffic:	1	2	1
Making Right Turn:	1	0	0
Making Left Turn:	2	0	0
Making U-Turn:	1	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**14**	**14**	**1**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	3	13	1
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	9	1	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	0	0	0
Total:	**14**	**14**	**1**

Direction	Veh 1	Veh 2	Veh 3
North:	7	0	0
Northeast:	0	0	0
East:	3	2	0
Southeast:	0	0	0
South:	4	2	0
Southwest:	0	0	0
West:	0	10	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**14**	**14**	**1**

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

ADT: 13,833 **Length:** 0.06

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

Exhibit 2

10/10/2016

Job #: 20161010092833

Location: 50A **Begin:** 35.35 **End:** 35.41 **From:** 01/01/2009 **To:** 12/31/2013

AFTER

Severity

PDO:	3		
INJ:	6	8	:Injured
FAT:	0	0	:Killed
Total:	**9**		

Number of Vehicles

One Vehicle:	1
Two Vehicles:	5
Three or More:	3
Unknown:	0
Total:	**9**

Location

On Road:	8
Off Road Left:	1
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**9**

Lighting Conditions

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

Weather Conditions

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

Crash Rates

PDO:	1.54	*
INJ:	3.07	*
FAT:	0.00	**
Total:	**4.61**	*

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	9
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**9**

Road Description

At Intersection:	4
At Driveway Access:	0
Intersection Related:	5
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**9**

Road Conditions

Dry:	9
Wet:	0
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**9**

ADT: 16,460 **Length:** 0.06

Location: 50A **Begin:** 35.35 **End:** 35.41 **From:** 01/01/2009 **To:** 12/31/2013

AFTER

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	3	5	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	1	2	1
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	3	1	2
SUV w/Trl:	1	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**9**	**8**	**3**

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

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	1
Northeast:	0	0	0
East:	5	3	1
Southeast:	0	0	0
South:	1	1	0
Southwest:	0	0	0
West:	3	4	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**9**	**8**	**3**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	3	8	3
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	2	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	0	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	3	0	0
Total:	**9**	**8**	**3**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	8	8	3
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**9**	**8**	**3**

ADT: 16,460 **Length:** 0.06

Project Information

Project Name: SH 285D / Brady Court

Project Description: Upgrade signal

CDOT Region: 6 Project Def: 16600 County: Arapahoe

Location: SH 285 Mile Points: 258.69 Length: N/A

Schedule: Work Start Date: 7/14/2008 Completion Date: 12/3/2008

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the three-year crash history showed a higher than expected number of rear-end and broadside type crashes. This is due to the signals being mounted on a span wire.

Improvement Description: In 2008, the signal installation was replaced with new mast arms, LED type signal heads, backplates and a new detection system with dilemma zone preemption. New pavement markings were installed to better delineate lanes, crosswalks, and stop lines. The cost of construction was $270,891.44.

The HSIP application anticipated that four crash types would be impacted by this improvement: rear-end, approach turn, broadside, and pedestrian type crashes. It was anticipated that there would be a 15% crash reduction for these crash types. The initial benefit/cost ratio was estimated to be 1.98.

Summary and Findings

The analysis of safety before and after the signal was upgraded at SH 285 and Brady Court showed safety improvements. For this intersection, there were 149 total crashes during the five-year period before the upgrade (2003 – 2007). In the five years after construction (2009 – 2013), the number of crashes was decreased to 101. Despite the fact that daily volumes decreased throughout the study period, the crash rate also was reduced. In addition, the number of injuries also diminished.

The signal upgrade was responsible for decreases in the number and severity of rear end, broadside and sideswipe (same) type crashes. The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 7.26 to one, showing that this improvement was certainly justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes (intersection and intersection-related) decreased from 149 during the five-year period (2003 to 2007) before the signal was upgraded (see **Table 1** and **Exhibit 1**) to 101 during the five-year after period (2009 to 2013) (see **Table 1** and **Exhibit 2**). The number of severe crashes showed only a decrease along with the number injuries:

- Before (2003 – 2007) – no fatal crashes and 32 injury crashes with 43 injuries
- After (2009 – 2013) – no fatal crashes and 24 injury crashes with 32 injuries

This decrease in injury occurred along with a modest decrease in traffic volumes at the intersection. This combination of decreased traffic and decreased number of crashes also resulted in a decrease in the accident rates:

- Before (2003 – 2007): 31.23 crashes per million entering vehicles (cpmev)
- After (2009 – 2013): 23.48 (cpmev)

Table 1 - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2003 to 12/31/2007 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
AADT	65,330 vpd	63,660 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**149**	**101**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	32 (43)	24 (32)
Property Damage Only	117	77
Crash Types: # (%) [cumulative probability]		
Rear End	108 (72.5%) [100.0%]	83 (82.2%) [100.0%]
Broadside	19 (12.8%)	7 (6.9%)
Sideswipe Same	14 (9.4%)	6 (5.9%)

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

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

level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

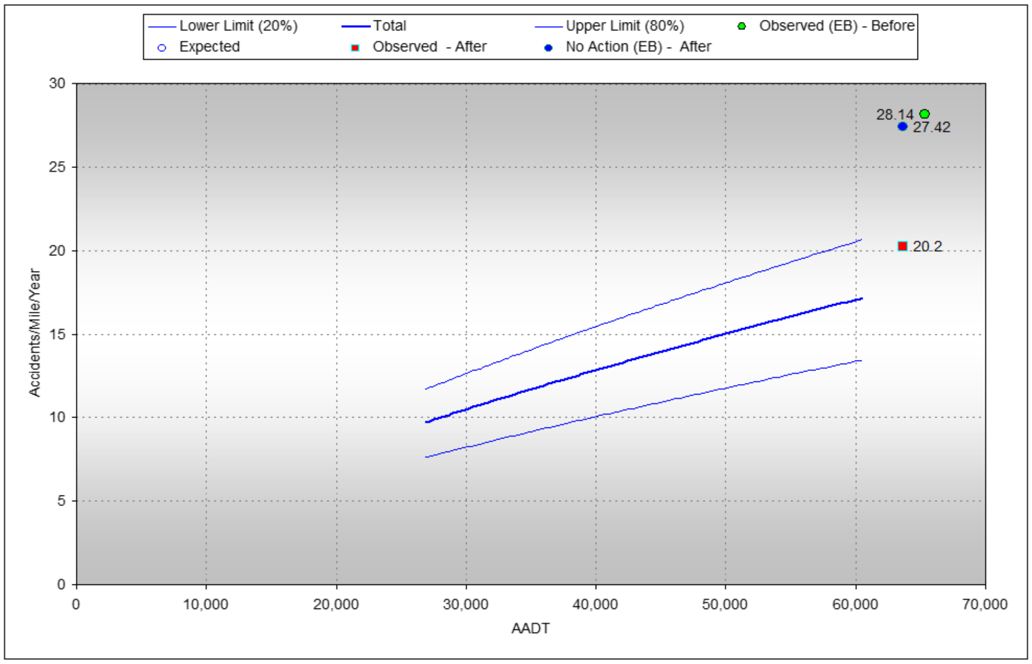
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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

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

Figure 1 - SPF for Total Crashes

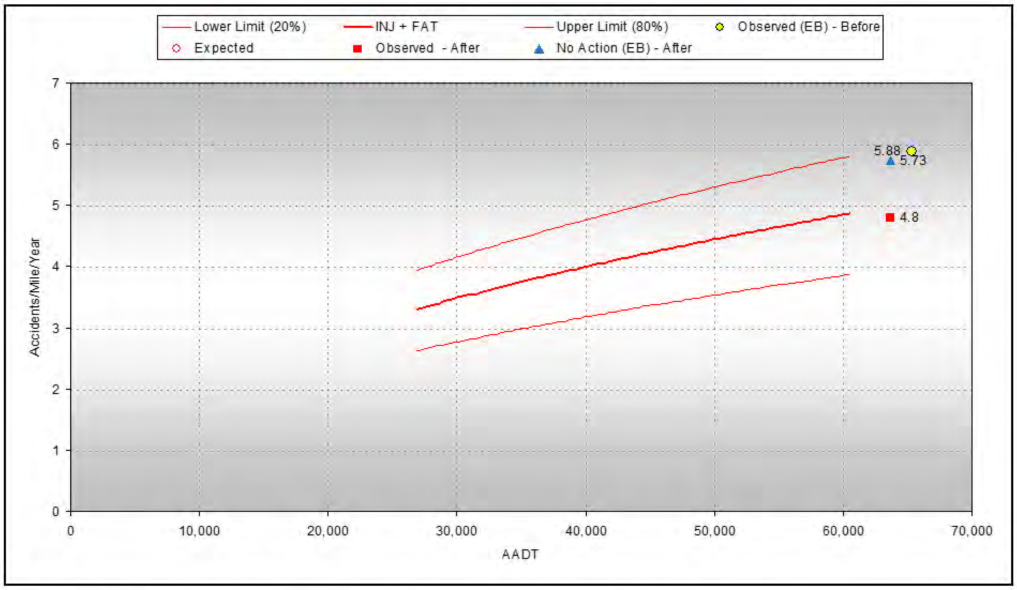
SH 285D @ Brady Court
Before: 2003 to 2007 After: 2009 to 2013



Note: Safety Performance Function (SPF) Model: Colorado - Urban 6-lane Divided Signalized 4-Leg Intersection

Figure 2 - SPF for Injury and Fatal Crashes

SH 285D @ Brady Court
Before: 2003 to 2007 After: 2009 to 2013



Note: Safety Performance Function (SPF) Model: Colorado - Urban 6-lane Divided Signalized 4-Leg Intersection

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 6-lane, Divided, Signalized, 4-Leg Intersection	Urban, 6-lane, Divided, Signalized, 4-Leg Intersection	Urban, 6-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS IV	LOSS III	LOSS IV
CPY	28.14	20.20	27.42
Mean CPY	N/A	N/A	N/A
Proportion of Mean	N/A	N/A	N/A
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS II	LOSS III
CPY	5.88	4.8	5.73
Mean CPY	N/A	N/A	N/A
Proportion of Mean	N/A	N/A	N/A

A more detailed review of the before and after crash record reveals that a significant improvement in safety can be attributed to the upgrade of the signal. **Table 3** shows a comparison of three types of crashes that are most directly affected by the improvement: rear end, approach turn, and broadside. The No Build After crashes were estimated using the proportional decrease in the AADT found in **Table 1** (decrease is 0.974 = 63,660/65,330).

Table 3 – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2003 to 12/31/2007 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
Crash Types:			
Rear Ends – Total	**108**	**83**	**105**
Injury (injuries)	19 (27)	19 (24)	18 (23)
PDO	89	64	87
% Reduction in Total		21%	
Broadsides – Total	**19**	**7**	**19**
Injury (injuries)	8 (10)	2 (5)	8 (10)
PDO	11	5	11
% Reduction in Total		63%	
Sideswipe same – Total	**14**	**6**	**14**
Injury (injuries)	0	1 (1)	0
PDO	14	5	14
% Reduction in Total		57%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the impacted crash types. As shown, the B/C ratio for rear end, broadside, and sideswipe (same) type crashes is 7.26, showing that the improvement was certainly justified.

Figure 3 – Benefit Cost Analysis – Rear End, Broadside, Sideswipe (same) Crashes Only

COLORADO Department of Transportation

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

05/25/2016

Job #: 20160525145044

Location: 285D **Begin:** 258.67 **End:** 258.71 **From:** 01/01/2003 **To:** 12/31/2007

SH 285D - Brady Court - RE, BS, & SSS crashes

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	112		Weighted PDO:	25.98	34% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	26	36 :Injured	Weighted INJ:	8.35	17% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	100% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	30% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	15
	Cost:	$ 270,891				Capital Recovery Factor:	0.096
	From:	01/01/2003				Annual Maintenance/Delay Cost:	$ 1,000
	To:	12/31/2007	Days:	1826			

Benefit Cost Ratio: 7.26 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Reducitons in rear end, broadside, and sideswipe (same) crashes

Special Notes:

Exhibit 1 05/25/2016

Job #: 20160525093955

Location: 285D **Begin:** 258.67 **End:** 258.71 **From:** 01/01/2003 **To:** 12/31/2007

SH 285D - Brady Court - intersection & related crashes

Severity

PDO:	117		
INJ:	32	43	:Injured
FAT:	0	0	:Killed
Total:	**149**		

Number of Vehicles

One Vehicle:	4
Two Vehicles:	127
Three or More:	18
Unknown:	0
Total:	**149**

Location

On Road:	147
Off Road Left:	0
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	1
Unknown:	0
Total:	**149**

Lighting Conditions

Daylight:	133
Dawn or Dusk:	2
Dark - Lighted:	14
Dark - Unlighted:	0
Unknown:	0
Total:	**149**

Weather Conditions

None:	140
Rain:	5
Snow/Sleet/Hail:	3
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**149**

Crash Rates

PDO:	24.52 *
INJ:	6.71 *
FAT:	0.00 **
Total:	**31.23** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	2	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	19	Embankment:	0
Head On:	0	Curb:	0
Rear End:	108	Delineator Post:	0
Sideswipe (Same):	14	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	2	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	1	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	2
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	1	Unknown:	0
Cable Rail:	0	**Total:**	**149**
Concrete Barrier:	1		

Mainline/Ramps/Frontage Roads

Mainline:	148
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	1
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**149**

Road Description

At Intersection:	130
At Driveway Access:	0
Intersection Related:	19
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**149**

Road Conditions

Dry:	136
Wet:	10
Muddy:	0
Snowy:	1
Icy:	2
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**149**

ADT: 65,330 **Length:** 0.04

Location: 285D **Begin:** 258.67 **End:** 258.71 **From:** 01/01/2003 **To:** 12/31/2007

SH 285D - Brady Court - intersection & related crashes

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	97	104	14
Passenger Car/Van w/Trl:	1	1	0
Pickup Truck/Utility Van:	28	22	4
Pickup Truck/Utility Van w/Trl:	4	2	0
SUV:	5	8	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	7	3	0
School Bus < 15 People:	0	1	0
Non School Bus < 15 People:	0	0	0
Motorhome:	1	0	0
Motorcycle:	2	3	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	3	1	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**149**	**145**	**18**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	84	135	18
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	5	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	37	6	0
Driver Unfamilar with Area:	4	0	0
Driver Emotionally Upset:	1	1	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	1	0	0
Unknown:	15	3	0
Total:	**149**	**145**	**18**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	141	145	18
Alcohol Involved:	7	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**149**	**145**	**18**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	93	11	2
Slowing:	25	28	4
Stopped in Traffic:	4	77	10
Making Right Turn:	2	0	0
Making Left Turn:	9	25	2
Making U-Turn:	0	0	0
Passing:	0	1	0
Backing:	4	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	0
Changing Lanes:	8	0	0
Avoiding Object/Veh in Road:	2	2	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	1	0	0
Total:	**149**	**145**	**18**

Direction	Veh 1	Veh 2	Veh 3
North:	7	10	0
Northeast:	0	0	0
East:	81	74	11
Southeast:	0	0	0
South:	8	22	2
Southwest:	0	0	0
West:	51	39	5
Northwest:	0	0	0
Unknown:	2	0	0
Total:	**149**	**145**	**18**

ADT: 65,330 **Length:** 0.04

Location: 285D **Begin:** 258.67 **End:** 258.71 **From:** 01/01/2009 **To:** 12/31/2013

SH 285D - Brady Court - After - intersection & related crashes

Severity

PDO:	77	
INJ:	24	32 :Injured
FAT:	0	0 :Killed
Total:	**101**	

Number of Vehicles

One Vehicle:	2
Two Vehicles:	93
Three or More:	6
Unknown:	0
Total:	**101**

Location

On Road:	98
Off Road Left:	1
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	1
Unknown:	0
Total:	**101**

Lighting Conditions

Daylight:	89
Dawn or Dusk:	0
Dark - Lighted:	11
Dark - Unlighted:	1
Unknown:	0
Total:	**101**

Weather Conditions

None:	95
Rain:	2
Snow/Sleet/Hail:	3
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**101**

Crash Rates

PDO:	17.90 *
INJ:	5.58 *
FAT:	0.00 **
Total:	**23.48** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	7	Embankment:	0
Head On:	1	Curb:	2
Rear End:	83	Delineator Post:	0
Sideswipe (Same):	6	Fence:	0
Sideswipe (Opposite):	1	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	1	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	2
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**101**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	101
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**101**

Road Description

At Intersection:	81
At Driveway Access:	0
Intersection Related:	20
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**101**

Road Conditions

Dry:	96
Wet:	2
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	1
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**101**

ADT: 63,660 **Length:** 0.03

Location: 285D **Begin:** 258.67 **End:** 258.71 **From:** 01/01/2009 **To:** 12/31/2013

SH 285D - Brady Court - After - intersection & related crashes

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	49	47	4
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	21	16	0
Pickup Truck/Utility Van w/Trl:	3	2	0
SUV:	20	30	2
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	4	2	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	1	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	3	0	0
Other:	0	0	0
Unknown:	0	1	0
Total:	**101**	**99**	**6**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	28	96	6
Asleep at the Wheel:	1	0	0
Illness:	3	0	0
Distracted by Passenger:	3	0	0
Driver Inexperience:	6	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	26	1	0
Driver Unfamilar with Area:	2	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	1	0	0
Physical Disability:	0	0	0
Unknown:	31	2	0
Total:	**101**	**99**	**6**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	95	99	6
Alcohol Involved:	3	0	0
RX, Medication, or Drugs Involved:	2	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**101**	**99**	**6**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	49	14	2
Slowing:	30	14	0
Stopped in Traffic:	1	63	3
Making Right Turn:	8	5	1
Making Left Turn:	4	3	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	3	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	4	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	2	0	0
Unknown:	0	0	0
Total:	**101**	**99**	**6**

Direction	Veh 1	Veh 2	Veh 3
North:	10	11	1
Northeast:	1	1	0
East:	57	53	1
Southeast:	0	0	0
South:	7	7	1
Southwest:	0	0	0
West:	26	27	2
Northwest:	0	0	1
Unknown:	0	0	0
Total:	**101**	**99**	**6**

ADT: 63,660 **Length:** 0.03

Project Information

Project Name: Upgrade Signal at SH 7 / County Line Road

Project Description: Construct New Signal and Minor Widening for Auxiliary Lanes

CDOT Region: 6 Project Def: 16601 County: Boulder

Location: SH 7 Mile Points: 64.14 Length: N/A

Schedule: Work Start Date: 6/1/2009 Completion Date: 5/28/2010

Problem Description: The three-year crash history (2001 – 2003) had 21 crashes with 4 injury crashes and no fatalities. There was a fatal crash at this intersection in 1999. The intersection has a skew from the north and is offset from Flagg Drive by 150 to the south. The intersection met signal warrants.

Improvement Description: Between June 2009 and May 2010, the intersection with County Line Road was signalized, the roadway to the north was re-aligned to reduce the skew, and turn lanes were constructed. Additionally, Flagg Drive to the south of SH 7 was reconstructed to limit turning movements to right-in/right-out. The cost of construction was $627,786.

It was anticipated that the primary crash types impacted by this improvement would be rear-end, approach turn, broadside, and head-on type crashes. It was anticipated that there would be a 30% crash reduction for these crash types. The initial benefit/cost ratio was estimated to be 2.06.

Summary and Findings

The analysis of safety before and after the intersection of SH 7 and County Line Road was signalized and the intersection of SH 7 with Flagg Drive was restricted to right-in/right-out showed the total crashes at the intersections decreased, but the severity of crashes increased.

At the intersection of SH 7 with County Line Road, there were 38 total crashes during the four-year period before the upgrades (2005 – 2008). In the four years after construction (2011 – 2014), the number of crashes decrease to 28. Injury crashes at this intersection increased from 6 to 14 between the two periods. At the intersection of SH 7 with Flagg Drive, there were five crashes in the before period and four crashes in the after period. There were no injury crashes during the before period and two injury crashes during the after period at this intersection.

The ratio of benefits and cost for this project shows that cost outweighed the benefits as the B/C ratio was 0.17 to one. The result is the improvement was probably not justified from an economic standpoint.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes at each of the intersections in this section of SH 7. At the intersection of SH 7 with County Line Road, the total number of mainline crashes decreased from 38 during the four-year period (2005 to 2008) before the intersection was improved (see **Table 1** and **Exhibit 1**) to 28 during the four-year after period (2011 to 2014) (see **Table 1** and **Exhibit 3**). However, the number of severe crashes increased:

- Before (2005 – 2008) – no fatal crashes and 6 injury crashes with 9 injuries
- After (2011 – 2014) – no fatal crashes and 14 injury crashes with 22 injuries

The number of crashes decreased slightly despite an increase in traffic volumes at the intersection. This resulted in a decrease in the crash rates:

- Before (2005 – 2008): 1.04 crashes per million entering vehicles (cpmev)
- After (2011 – 2014): 0.74 cpmev

Table 1 – SH 7 / County Line Road (MP 6.14) – Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT (SH 7/County Line Rd)	17,350/7,750 vpd	18,300/7,750 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**38**	**28**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	6 (9)	14 (22)
Property Damage Only	32	14
Crash Types: # (%) [significance]		
Rear-End	15 (39.5%)	14 (50.0%)
Broadside	15 (39.5%) [99.99%]	4 (14.3%)
Sideswipe Same Direction	5 (13.2%) [99.54%]	0
Approach Turn	3 (7.9%)	5 (17.9%)

At the intersection of SH 7 with Flagg Drive, the total number of mainline crashes decreased slightly from 5 during the four-year before period (see **Table 2** and **Exhibit 2**) to 4 during the four-year after period (see **Table 2** and **Exhibit 4**). However, the number of severe crashes increased:

- Before (2005 – 2008) – no fatal crashes and no injury crashes
- After (2011 – 2014) – no fatal crashes and 2 injury crashes with 2 injuries

The number of crashes decreased slightly despite an increase in traffic volumes at the intersection. This resulted in a decrease in the crash rates:

- Before (2005 – 2008): 0.19 cpmev
- After (2011 – 2014): 0.13 cpmev

Table 2 – SH 7 / Flagg Drive (MP 6.17) – Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT (SH 7/Flagg Dr)	17,700/525 vpd	20,000/525 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**5**	**4**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	0	2 (2)
Property Damage Only	5	2
Crash Types: # (%)		
Rear-End	4 (80.0%)	3 (75.0%)
Broadside	1 (20.0%)	0

Typically, the magnitude of safety problems on select highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. However, there are no SPFs available matching the study intersections, so this analysis could not be completed.

A more detailed review of the before and after crash record reveals a large reduction in broadside type crashes with the intersection improvements. **Table 3** shows a comparison of total crashes in addition to crash types that are most directly affected by the improvements: approach turn, broadside, and rear-end. The safety improvement did not seem to have any impact on approach turns or rear-end as both these crash types experienced very little change in the number of crashes, but both saw severity of crashes increase. The No Build After crashes were estimated using the increase in the volume found in **Table 1** (increase is 1.05 = 17,350/18,300).

Table 3 – SH 7 / County Line Road (MP 6.14) – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:			
Total Crashes	**38**	**28**	**40**
Injury (injuries)	6 (9)	14 (22)	6 (9)
PDO	32	14	34
% Reduction in Total (Injuries/PDO)		-144% / 59%	
Approach Turns – Total	**3**	**5**	**3**
Injury (injuries)	1 (1)	3 (5)	1 (1)
PDO	2	2	2
% Reduction in Total (Injuries/PDO)		-400% / 0%	
Broadsides – Total	**15**	**4**	**16**
Injury (injuries)	3 (4)	0	3 (4)
PDO	12	4	13
% Reduction in Total (Injuries/PDO)		100% / 69%	
Rear-Ends – Total	**15**	**14**	**16**
Injury (injuries)	2 (4)	9 (12)	2 (4)
PDO	13	5	14
% Reduction in Total (Injuries/PDO)		-200% / 64%	

A review of the before and after crash record at the intersection of SH 7 with Flagg Drive reveals a reduction in total crashes after the intersection improvements. **Table 4** shows a comparison of total crashes in addition to crash types that are most directly affected by the improvement: broadside and rear-end. The safety improvement did not seem to have much impact on rear-end as the number of crashes decreased while the severity of crashes increased. The No Build After crashes were estimated using the increase in the volume found in **Table 2** (increase is 1.13 = 20,000/17,700).

Table 4 – SH 7 / Flagg (MP 6.17) – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:			
Total Crashes	**5**	**4**	**6**
Injury (injuries)	0	2 (2)	0
PDO	5	2	6
% Reduction in Total (Injuries/PDO)		N/A / 66%	
Broadsides – Total	**1**	**0**	**1**
PDO	1	0	1
% Reduction in Total		100%	
Rear-Ends – Total	**4**	**3**	**5**
Injury (injuries)	0	2 (2)	0
PDO	4	1	5
% Reduction in Total (Injuries/PDO)		N/A / 80%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of this B/C analysis are shown in **Figure 1** for the intersection crashes at the intersection of SH 7 and County Line Road. While the total crashes decreased, there was an increase in injuries and injury crashes. The increase in injuries was factored into the analysis by increasing the cost of construction for the signal. During the four-year after period, there were 13 additional injuries at the intersection. Over the design life of 10 years for the signal, the increased cost of crashes would be $2,622,750 (32.5 INJ = $2,622,750). As shown, the B/C ratio for the improvements at the intersection of SH 7 and County Line Road is 0.11.

Figure 2 provides the B/C analysis for the intersection of SH 7 with Flagg Drive. Similar to the intersection with County Line Road, the total crashes decreased while there was an increase in injuries and injury crashes. The increase in injuries was factored into the analysis by increasing the cost of construction for the improvements. During the four-year after period, there were two additional injuries at the intersection. Over the design life of 10 years for the improvements, the increased cost of crashes would be $403,500 (5 INJ = $403,500). As shown in **Figure 2**, the B/C ratio for the improvements at the intersection of SH 7 and Flagg Drive is 0.06.

When the results of the two intersections are combined, the resulting B/C ratio for the safety project is 0.17 (0.11 + 0.06), showing that the improvement was likely not justified from a safety standpoint.

This project produced an isolated signal with high severity rear-end collisions. Dilemma Zone Preemption should be considered here as an immediate countermeasure and a roundabout as a long term solution.

Figure 1 – SH 7 / County Line Road (MP 6.14) –Intersection and Intersection Related Crashes Only

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

09/21/2016

Job #: 20160921141148

Location: 7D **Begin:** 64.11 **End:** 64.15 **From:** 01/01/2005 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	32		Weighted PDO:	8.78	59% : CRF for PDO	Cost of PDO:	$ 9,300
INJ:	6	9 : Injured	Weighted INJ:	2.47	0% : CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 : Killed	Weighted FAT:	0.00	0% : CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	49% : Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
Cost:	$ 3,250,536					Service Life:	10
From:	01/01/2005					Capital Recovery Factor:	0.129
To:	12/31/2008		Days: 1461			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: 0.11 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: NEW SIGNAL WITH INTERSECTION IMPROVEMENTS
Special Notes: INTERSECTION CRASHES ONLY

Figure 2 – SH 7 / Flagg (MP 6.17) –Intersection and Intersection Related Crashes Only

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

09/21/2016

Job #: 20160921142347

Location: 7D **Begin:** 64.16 **End:** 64.18 **From:** 01/01/2005 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	5		Weighted PDO:	1.37	66% : CRF for PDO	Cost of PDO:	$ 9,300
INJ:	0	0 : Injured	Weighted INJ:	0.00	0% : CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 : Killed	Weighted FAT:	0.00	0% : CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	66% : Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
Cost:	$ 1,031,286					Service Life:	10
From:	01/01/2005					Capital Recovery Factor:	0.129
To:	12/31/2008		Days: 1461			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: 0.06 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: NEW SIGNAL WITH INTERSECTION IMPROVEMENTS
Special Notes: INTERSECTION CRASHES ONLY

Location: 7D **Begin:** 64.11 **End:** 64.15 **From:** 01/01/2005 **To:** 12/31/2008

Severity

PDO:	32		
INJ:	6	9	:Injured
FAT:	0	0	:Killed
Total:	**38**		

Number of Vehicles

One Vehicle:	1
Two Vehicles:	34
Three or More:	3
Unknown:	0
Total:	**38**

Location

On Road:	38
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**38**

Lighting Conditions

Daylight:	34
Dawn or Dusk:	0
Dark - Lighted:	3
Dark - Unlighted:	1
Unknown:	0
Total:	**38**

Weather Conditions

None:	37
Rain:	0
Snow/Sleet/Hail:	1
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**38**

Crash Rates

PDO:	31.60 *
INJ:	5.92 *
FAT:	0.00 **
Total:	**37.52** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	15	Embankment:	0
Head On:	0	Curb:	0
Rear End:	15	Delineator Post:	0
Sideswipe (Same):	5	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	3	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	0
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**38**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	38
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**38**

Road Description

At Intersection:	35
At Driveway Access:	0
Intersection Related:	3
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**38**

Road Conditions

Dry:	35
Wet:	1
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**38**

ADT: 17,329 **Length:** 0.04

Location: 7D **Begin:** 64.11 **End:** 64.15 **From:** 01/01/2005 **To:** 12/31/2008

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	23	26	2
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	11	4	0
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	3	6	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**38**	**37**	**3**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	13	18	1
Slowing:	1	0	0
Stopped in Traffic:	0	11	1
Making Right Turn:	7	2	0
Making Left Turn:	13	6	1
Making U-Turn:	0	0	0
Passing:	2	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**38**	**37**	**3**

Direction	Veh 1	Veh 2	Veh 3
North:	0	1	0
Northeast:	0	0	0
East:	12	10	2
Southeast:	0	0	0
South:	21	9	0
Southwest:	0	0	0
West:	5	17	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**38**	**37**	**3**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	23	35	3
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	2	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	10	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	2	2	0
Total:	**38**	**37**	**3**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	37	37	3
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**38**	**37**	**3**

ADT: 17,329 **Length:** 0.04

Location: 7D **Begin:** 64.16 **End:** 64.18 **From:** 01/01/2005 **To:** 12/31/2008

Severity

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

Number of Vehicles

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

Location

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

Lighting Conditions

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

Weather Conditions

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

Crash Rates

PDO:	8.79 *
INJ:	0.00 *
FAT:	0.00 **
Total:	**8.79** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	5
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

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

Road Description

At Intersection:	4
At Driveway Access:	0
Intersection Related:	1
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**5**

Road Conditions

Dry:	4
Wet:	0
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**5**

ADT: 17,700 **Length:** 0.02

Location: 7D **Begin:** 64.16 **End:** 64.18 **From:** 01/01/2005 **To:** 12/31/2008

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

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

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

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

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

ADT: 17,700 **Length:** 0.02

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

Exhibit 3

09/08/2016

Job #: 20160908094918

Location: 7D **Begin:** 64.11 **End:** 64.15 **From:** 01/01/2011 **To:** 12/31/2014

Severity

PDO:	14	
INJ:	14	22 :Injured
FAT:	0	0 :Killed
Total:	**28**	

Number of Vehicles

One Vehicle:	3
Two Vehicles:	23
Three or More:	2
Unknown:	0
Total:	**28**

Location

On Road:	25
Off Road Left:	1
Off Road Right:	2
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**28**

Lighting Conditions

Daylight:	20
Dawn or Dusk:	0
Dark - Lighted:	7
Dark - Unlighted:	1
Unknown:	0
Total:	**28**

Weather Conditions

None:	26
Rain:	0
Snow/Sleet/Hail:	1
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**28**

Crash Rates

PDO:	13.41 *
INJ:	13.41 *
FAT:	0.00 **
Total:	**26.83** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	4	Embankment:	0
Head On:	2	Curb:	0
Rear End:	14	Delineator Post:	2
Sideswipe (Same):	0	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	5	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	3
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**28**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	28
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

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

Road Description

At Intersection:	20
At Driveway Access:	0
Intersection Related:	8
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**28**

Road Conditions

Dry:	27
Wet:	0
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**28**

ADT: 18,318 **Length:** 0.03

Location: 7D **Begin:** 64.11 **End:** 64.15 **From:** 01/01/2011 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	18	16	2
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	3	2	0
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	5	7	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**28**	**25**	**2**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	14	7	0
Slowing:	1	2	0
Stopped in Traffic:	0	10	2
Making Right Turn:	4	0	0
Making Left Turn:	6	5	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	1	1	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**28**	**25**	**2**

Direction	Veh 1	Veh 2	Veh 3
North:	1	0	0
Northeast:	0	0	0
East:	12	11	1
Southeast:	0	0	0
South:	6	4	1
Southwest:	1	2	0
West:	8	8	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**28**	**25**	**2**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	9	24	2
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	6	0	0
Driver Unfamilar with Area:	0	1	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	10	0	0
Total:	**28**	**25**	**2**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	26	25	2
Alcohol Involved:	2	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**28**	**25**	**2**

ADT: 18,318 **Length:** 0.03

Location: 7D **Begin:** 64.16 **End:** 64.18 **From:** 01/01/2011 **To:** 12/31/2014

Severity

PDO:	2	
INJ:	2	2 :Injured
FAT:	0	0 :Killed
Total:	**4**	

Number of Vehicles

One Vehicle:	1
Two Vehicles:	3
Three or More:	0
Unknown:	0
Total:	**4**

Location

On Road:	3
Off Road Left:	0
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**4**

Lighting Conditions

Daylight:	3
Dawn or Dusk:	0
Dark - Lighted:	0
Dark - Unlighted:	0
Unknown:	1
Total:	**4**

Weather Conditions

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

Crash Rates

PDO:	3.42 *
INJ:	3.42 *
FAT:	0.00 **
Total:	**6.84** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	4
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**4**

Road Description

At Intersection:	1
At Driveway Access:	0
Intersection Related:	3
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**4**

Road Conditions

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

ADT: 20,000 **Length:** 0.02

Location: 7D **Begin:** 64.16 **End:** 64.18 **From:**01/01/2011 **To:**12/31/2014

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

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

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

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

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

ADT: 20,000 **Length:** 0.02

Project Information

Project Name: SH 392 and Weld CR 31 Intersection Improvements

Project Description: Hazard Elimination, Add Left Turn Lanes on SH 392

CDOT Region: 4 Project Def: 16623 County: Weld

Location: SH 392B Mile Points: 11.54 Length: N/A

Schedule: Work Start Date: 7/30/2008 Completion Date: 11/5/2008

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the crash history showed rear end, broadside and approach turn crashes occurred at the unsignalized intersection of Weld County Road 31with SH 392. There were 5 of these crashes during the three-year (2001 – 2003) time period considered in the HSIP application.

Improvement Description: In summer 2008 deceleration lanes for right and left turns from SH 392 were added to the intersection. The cost of construction was $ 464,242.

The HSIP application anticipated that broadside, approach turn and rear end crashes would be impacted by this improvement. It was anticipated that there would be approximately a 35% crash reduction for these crashes. The expected benefit/cost ratio was estimated to be 1.44.

Summary and Findings

The analysis of safety before and after right and left turn deceleration lanes were installed at the intersection of SH 392 and Weld County Rd 31 showed safety improved by reduction of broadside and reduced severity of approach turn and rear end crashes. Fixed object crashes were eliminated in the after period. The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 9.02 to one, showing that the improvement was justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 22 during the three-year period (2005 to 2007) before the improvements (see **Table 1** and **Exhibit 1**) to 11 during the three-year after period (2009 to 20111) (see **Table 1** and **Exhibit 2**). The number of serious crashes also decreased in the three-year period after the improvements:

- Before (2005 – 2007) – no fatal crashes and 12 injury crashes with 18 injuries
- After (2009 – 2011) – no fatal crashes and 6 injury crashes with 9 injuries

Despite an increase in traffic volumes at the intersection, the crash rates at the intersection still decreased:

- Before (2003 – 2007): 2.19 crashes per million entering vehicles (cpmev)
- After (2009 – 2013): 1.01 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2005 to 12/31/2007 (3 yr.)	1/1/2009 to 12/31/2011(3 yr.)
AADT (SH 392/WCR 31)	5,060 / 4,100 vpd	5,863 / 4,100 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**22**	**11**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	12 (18)	6 (9)
Property Damage Only	10	5
Crash Types: # (%) [significance]		
Broadside	13 (59.1%) [99.99%]	3 (27.3%)
Approach Turn	2(9.1%)	4 (36.4%)
Rear End	4(18.2%)	4 (36.4%)

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

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

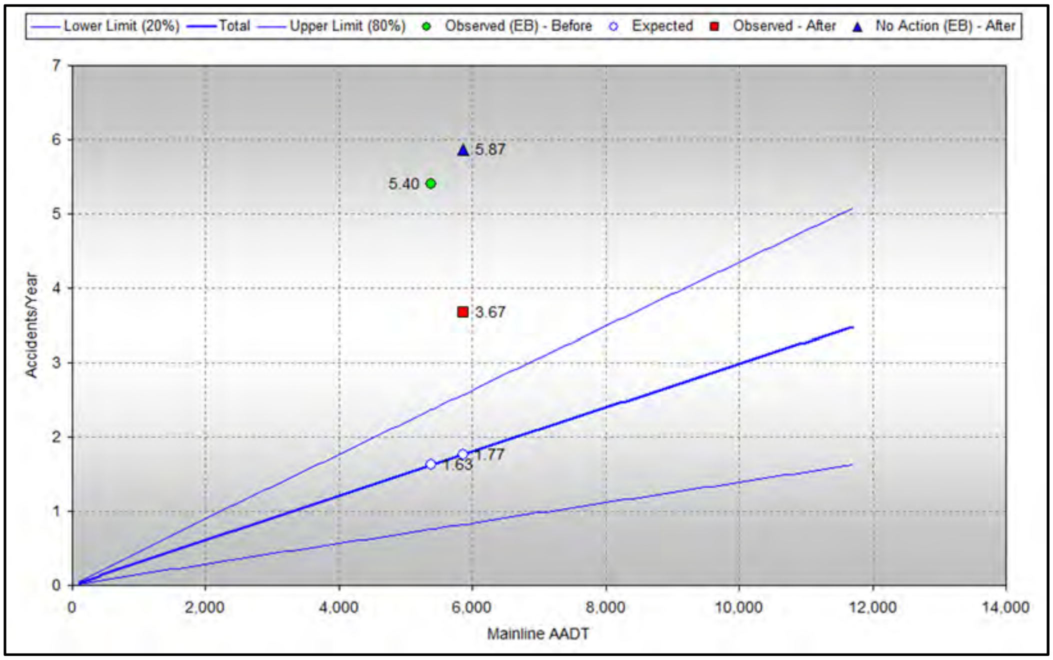
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. The frequency and severity of crashes remained in the LOSS IV category for both periods; however, both frequency and severity showed improvement within the LOSS IV category in the after period (see **Table 2**).

Figure 1 - SPF for Total Crashes SH 392B (MP 11.54) at Weld CR 31

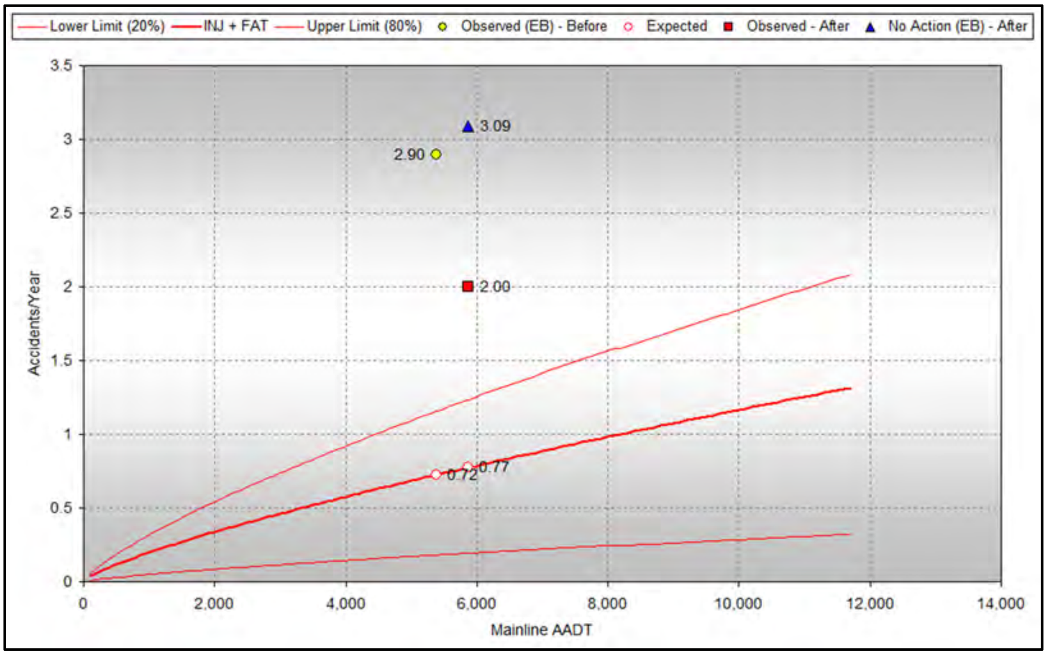
Before: 2005 thru 2007 After: 2009 thru 2011



Note: Safety Performance Function (SPF) Model: Colorado – Urban 2-Lane Univided Unignalized 4-Leg Intersection

Figure 2 – SPF Injury and Fatal Crashes SH 392B (MP 11.54) at Weld CR 31

Before: 2005 thru 2007 After: 2009 thru 2011



Note: Safety Perfromance Function (SPF) Model: Colorado – Urban 2-Lane Univided Unsignalized 4-Leg Intersection

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	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	5.40	3.67	5.87
Mean CPY	1.63	1.77	1.77
Proportion of Mean	3.31	2.09	3.31
Fatal & Injury Crashes:			
LOSS	LOSS IV	LOSS IV*	LOSS IV
CPY	2.90	2.00	3.09
Mean CPY	0.72	0.77	0.77
Proportion of Mean	4.03	2.60	4.03

**Intersection type changed by project to Divided so LOSS shown is not necessarily correct for the After period, but is shown for comparison only. Actual after period Total Crashes are also in LOSS IV, and Injury & Fatal Crashes are also in LOSS IV for Urban, 2-lane, Divided, Unsignalized, 4-Leg Intersection. Although this intersection is classified as urban it has high speed rural characteristics which partially explains elevated frequency and severity in the before and the after periods.*

A more detailed review of the before and after crash record reveals that improvement in safety can be attributed to the addition left turn and right turn deceleration lanes for the mainline. The improvements accomplished the intended goals of reducing broadsides, but it experienced additional rear end and approach turn crashes. The severity of those crashes was reduced. **Table 3** shows a comparison of primary types of crashes that are most directly affected by the improvement: broadside, approach turn and rear end, as well as the total intersection crashes. The No Build After crashes were estimated using the change in mean CPY found in **Table 2** (increase is 1.069 = 0.77/0.72).

Table 3 – Results of Crash Analyses

	Before	**After**	**No Build After**
Time Period:	1/1/2005 to 12/31/2007 (3 yr.)	1/1/2009 to 12/31/2011 (3 yr.)	1/1/2009 to 12/31/2011 (3 yr.)
Crash Types:			
Total Crashes	**22**	**11**	**24**
Injury (injuries)	12(18)	6 (9)	13(19)
PDO	10	5	11
% Reduction in Total (Injuries/PDO)		53% / 55%	
Broadsides – Total	**13**	**3**	**14**
Injury (injuries)	9 (14)	1 (2)	10 (15)
PDO	4	2	4
% Reduction in Total (Injuries/PDO)		87% / 50%	
Approach Turns - Total	**2**	**4**	**2**
Injury (injuries)	0 (0)	3(5)	0 (0)
PDO	2	1	2
% Reduction in Total (Injuries/PDO)		Undefined / 50%	
Rear Ends – Total	**2**	**4**	**2**
Injury (injuries)	2(3)	2 (2)	2 (3)
PDO	0	2	0
% Reduction in Total (Injuries/PDO)		33% / Undefined	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the impacted crash types. As shown, the B/C ratio for the intersection and intersection related crashes is 9.02, showing that the improvement was justified.

Figure 3 – Benefit Cost Analysis – Intersection and Intersection Related Crashes Only

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

11/07/2016

Job #: 20161107211857

Location: 392B **Begin:** 111.51 **End:** 111.57 **From:** 01/01/2005 **To:** 12/31/2007

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	10		Weighted PDO:	4.09	55% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	12	18 :Injured	Weighted INJ:	7.37	53% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	3.00	53% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
		Cost: $ 464,242				Service Life:	20
		From: 01/01/2005				Capital Recovery Factor:	0.080
		To: 12/31/2007	Days: 1095			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: 9.02 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: INTERSECTION IMPROVEMENTS - ADD LEFT TURN AND RIGHT TURN DECELERATION LANES
Special Notes:

Location: 392B **Begin:** 111.51 **End:** 111.57 **From:** 01/01/2005 **To:** 12/31/2007

Severity

PDO:	10		
INJ:	12	18	:Injured
FAT:	0	0	:Killed
Total:	**22**		

Number of Vehicles

One Vehicle:	2
Two Vehicles:	16
Three or More:	4
Unknown:	0
Total:	**22**

Location

On Road:	19
Off Road Left:	0
Off Road Right:	3
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**22**

Lighting Conditions

Daylight:	19
Dawn or Dusk:	1
Dark - Lighted:	0
Dark - Unlighted:	2
Unknown:	0
Total:	**22**

Weather Conditions

None:	21
Rain:	0
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**22**

Crash Rates

PDO:	28.25	*
INJ:	33.90	*
FAT:	0.00	**
Total:	**62.15**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	13	Embankment:	0
Head On:	0	Curb:	0
Rear End:	4	Delineator Post:	1
Sideswipe (Same):	0	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	2	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	3
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**22**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	22
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**22**

Road Description

At Intersection:	21
At Driveway Access:	0
Intersection Related:	1
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**22**

Road Conditions

Dry:	22
Wet:	0
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**22**

ADT: 5,388 **Length:** 0.06

Location: 392B **Begin:** 111.51 **End:** 111.57 **From:** 01/01/2005 **To:** 12/31/2007

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	15	9	3
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	5	4	0
Pickup Truck/Utility Van w/Trl:	0	1	0
SUV:	1	2	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	3	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	1	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	1	0	0
Total:	**22**	**20**	**4**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	12	20	4
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	3	0	0
Driver Unfamilar with Area:	2	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	3	0	0
Total:	**22**	**20**	**4**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	21	20	4
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**22**	**20**	**4**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	12	14	1
Slowing:	0	0	0
Stopped in Traffic:	0	4	3
Making Right Turn:	2	0	0
Making Left Turn:	6	1	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	1	1	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**22**	**20**	**4**

Direction	Veh 1	Veh 2	Veh 3
North:	11	2	2
Northeast:	0	0	0
East:	2	6	2
Southeast:	0	0	0
South:	6	2	0
Southwest:	0	0	0
West:	3	10	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**22**	**20**	**4**

ADT: 5,388 **Length:** 0.06

Location: 392B **Begin:** 111.51 **End:** 111.57 **From:** 01/01/2009 **To:** 12/31/2011

Severity

PDO:	5	
INJ:	6	9 :Injured
FAT:	0	0 :Killed
Total:	**11**	

Number of Vehicles

One Vehicle:	0
Two Vehicles:	10
Three or More:	1
Unknown:	0
Total:	**11**

Location

On Road:	11
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**11**

Lighting Conditions

Daylight:	10
Dawn or Dusk:	1
Dark - Lighted:	0
Dark - Unlighted:	0
Unknown:	0
Total:	**11**

Weather Conditions

None:	10
Rain:	0
Snow/Sleet/Hail:	0
Fog:	1
Dust:	0
Wind:	0
Unknown:	0
Total:	**11**

Crash Rates

PDO:	13.20 *
INJ:	15.84 *
FAT:	0.00 **
Total:	**29.04** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	11
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**11**

Road Description

At Intersection:	11
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**11**

Road Conditions

Dry:	11
Wet:	0
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**11**

ADT: 5,863 **Length:** 0.05

Location: 392B **Begin:** 111.51 **End:** 111.57 **From:** 01/01/2009 **To:** 12/31/2011

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

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

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

Direction	Veh 1	Veh 2	Veh 3
North:	8	5	1
Northeast:	0	0	0
East:	1	3	0
Southeast:	0	0	0
South:	0	2	0
Southwest:	0	0	0
West:	2	1	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**11**	**11**	**1**

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

ADT: 5,863 **Length:** 0.05

Project Information

Project Name: US 287 Intersections, Fort Collins

Project Description: Intersection Improvements on US 287

CDOT Region: 4 Project Def: 16625 County: Larimer

Location: US 287 Mile Points: 343.72, 344.67, Length: N/A

Schedule: Work Start Date: 7/20/2009 Completion Date: 5/21/2010

Problem Description: This project includes two signals located in Fort Collins along US 287: Swallow Road and Rutgers Lane. The crash history at the intersection of US 287 with Swallow Road indicated there was a southbound rear-end problem. While the intersection with Rutgers Lane had a higher number of approach turn, pedestrian, and sideswipe same direction type crashes.

Improvement Description: Between late 2009 and early 2010, both intersections were improved. The intersection of US 287 with Swallow Road had the existing median removed and the southbound left-turn lane was extended. In addition, signal heads were added to the signal poles. At the intersection with Rutgers Lane, the southbound right turn lane was extended and pedestrian countdown timers were installed. Additionally, a protected phase was added for the northbound left-turning movement. The cost of construction for both signals was $276,860

It was anticipated that at the intersection of US 287 with Swallow Road, there would be a 10% crash reduction for southbound rear-ends, resulting in a benefit/cost ratio of 4.63. At the intersection of US 287 with Rutgers Lane four crash types would be impacted by the improvements: approach turn, sideswipe same direction, right-turns, and pedestrian type crashes. It was anticipated that there would be a 10% crash reduction on property damage only crashes and a 40% reduction in injury crashes. The initial benefit/cost ratio at this intersection was estimated to be 1.09.

Summary and Findings

The analysis of safety before and after the signal was upgraded at US 287 and Swallow Road showed no safety improved for intersection. The number of property damage only crashes increased, as did the number of injury crashes between the before and after periods.

The intersection of US 287 and Rutgers Lane showed some safety improvements with the signal upgrade. The injury crashes decreased in the after period, although there was an overall increase in crashes. Injuries decreased from 16 during the before period to 12 in the after period. The overall ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 1.14 to one, showing that the improvement may have been justified from a safety standpoint.

Results of Safety Analyses

Using VZS, the review of before and after crash records at the intersection of US 287 and Swallow Road shows the number of crashes increased from 55 during the four-year period (2005 to 2008) before the intersection improvements (see **Table 1** and **Exhibit 1**) to 76 during the four-year after period (2011 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes increased, although the number of injuries did not increase:

- Before (2005 – 2007) – no fatal crashes and 11 injury crashes with 22 injuries
- After (2011 – 2013) – no fatal crashes and 18 injury crashes with 22 injuries

The number of crashes increased along with a slight decrease in traffic volumes at the intersection. This resulted in an increase in the crash rates:

- Before (2005 – 2008): 0.77 crashes per million entering vehicles (cpmev)
- After (2011 – 2014): 1.16 cpmev

Table 1 – US 287 / Swallow Road – Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT (US 287/Swallow Rd)	41,250/7,800 vpd	37,000/7,800 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**55**	**76**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	11 (22)	18 (22)
Property Damage Only	44	58
Crash Types: # (%) [significance]		
Rear-End	27 (49.1%)	31 (40.8%)
Approach Turn	15 (27.3%)	20 (26.3%)
Broadside	7 (12.7%)	11 (14.5%)
Sideswipe Same Direction	4 (7.3%)	9 (11.8%)

A review of before and after crash records at the intersection of US 287 and Rutgers Lane also shows an increase in crashes; the total number of crashes increased from 30 during the four-year period (2005 to 2008) before the improvements (see **Table 2** and **Exhibit 3**) to 39 during the four-year after period (2011 to 2014) (see **Table 2** and **Exhibit 4**). The number of severe crashes decreased between the two study periods:

- Before (2005 – 2008) – no fatal crashes and 11 injury crashes with 16 injuries
- After (2011 – 2014) – no fatal crashes and 7 injury crash with 12 injury

The number of crashes increased and there was a decrease in traffic volumes at the intersection. This resulted in an increase in the crash rates:

- Before (2005 – 2008): 0.43 cpmev
- After (2011 – 2014): 0.60 cpmev

Table 2 – US 287 / Rutgers Lane – Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT (US 287/Rutgers Lane)	41,075/6,400 vpd	38,250/6,400 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**30**	**39**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	11 (16)	7 (12)
Property Damage Only	19	32
Crash Types: # (%) [significance]		
Rear-End	8 (26.7%)	16 (41.0%)
Approach Turn	8 (26.7%)	12 (30.8%) [96.3%]
Broadside	6 (20.0%)	8 (20.5%)
Sideswipe Same Direction	3 (10.0%)	2 (5.1%)

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

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

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

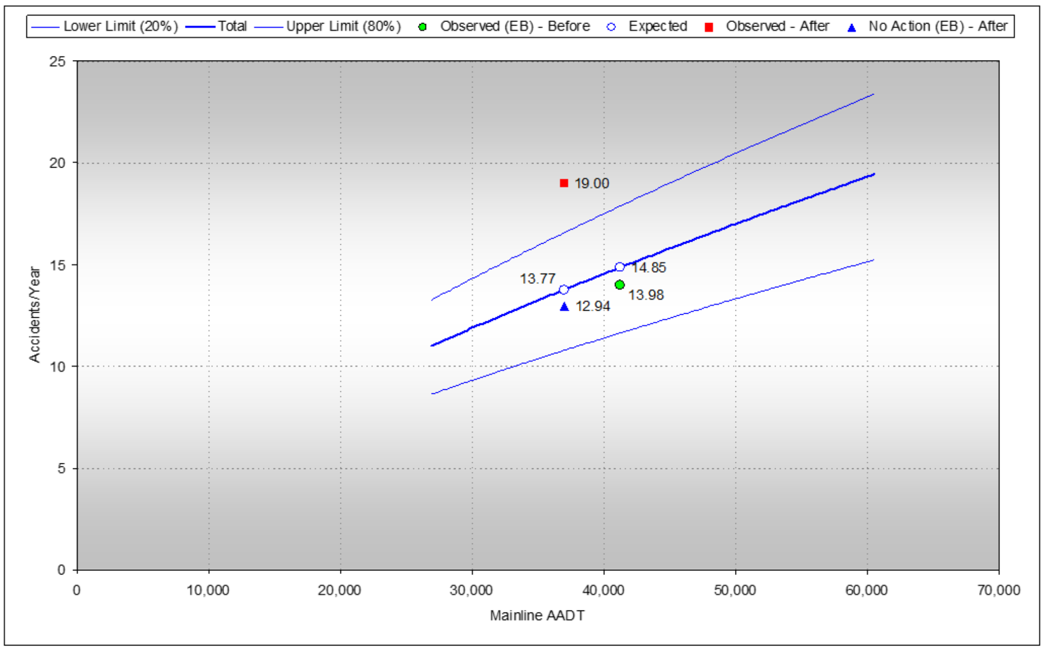
LOSS boundaries are calibrated by computing the 20th and the 80th percentiles using the Gamma Distribution Probability Density Function. Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT increases.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

SPF plots were created for the intersection of US 287 and Swallow Road for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**). The frequency of crashes increased from LOSS II in the before period to LOSS IV in the after period. The severity of crashes increased from LOSS I/LOSS II boundary in the before period to LOSS III in the after period (see **Table 3**).

For the intersection of US 287 and Rutgers Lane, SPF plots were created for both total crashes (see **Figure 3**) and for fatal and injury crashes (see **Figure 4**). The frequency of crashes remained in the LOSS II range for the before and after period. The severity of crashes improved from the LOSS II range in the before period to the LOSS I range in the after period. (see **Table 4**).

Figure 1 - SPF for Total Crashes

US 287 / Swallow Road (MP 343.72)
Before: 2005 to 2008 After: 2011 to 2014

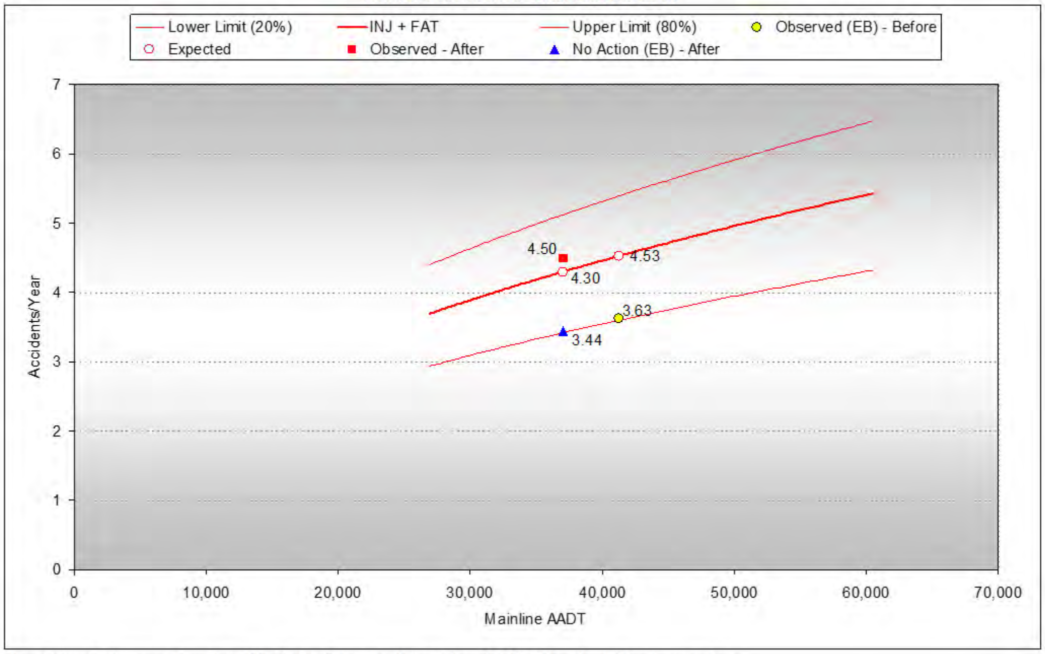


Note: Safety Performance Function (SPF) Model: Colorado - Urban 6-Lane Divided Signalized 4-Leg Intersection

Figure 2 - SPF for Injury and Fatal Crashes

US 287 / Swallow Road (MP 343.72)

Before: 2005 to 2008 After: 2011 to 2014

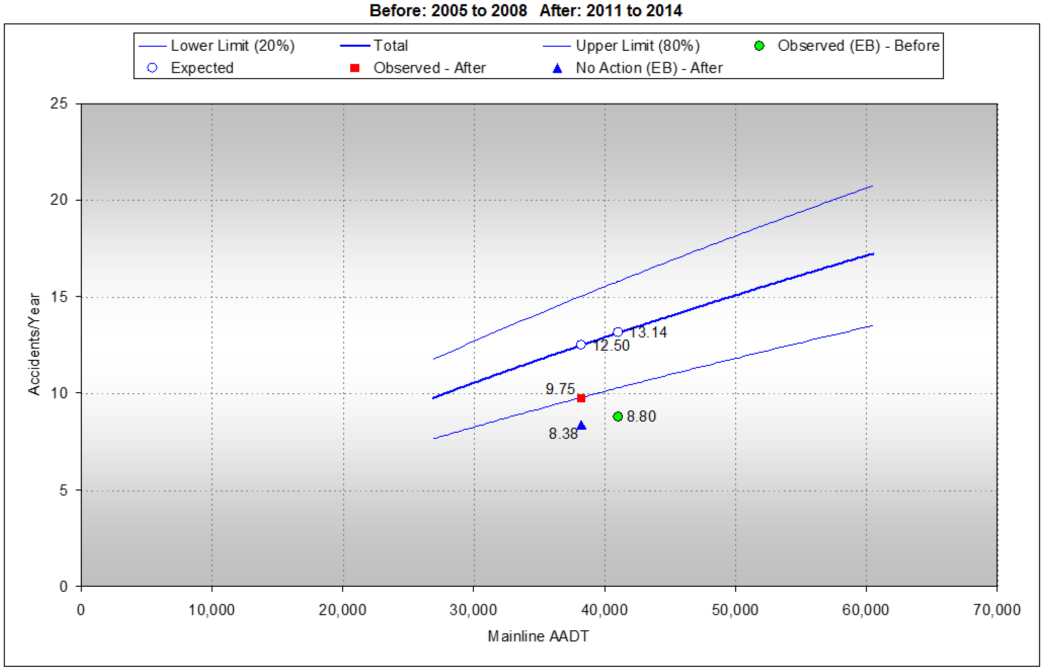


Note: Safety Performance Function (SPF) Model: Colorado - Urban 6-Lane Divided Signalized 4-Leg Intersection

Figure 3 - SPF for Total Crashes

US 287 / Rutgers Lane (MP 344.67)

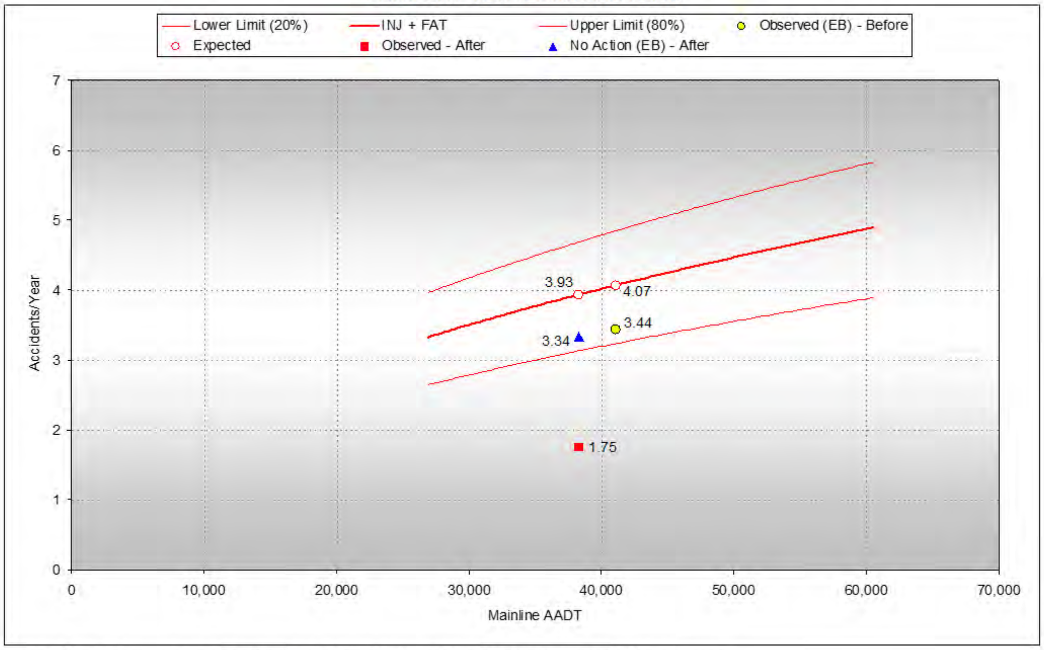
Before: 2005 to 2008 After: 2011 to 2014



Note: Safety Performance Function (SPF) Model: Colorado - Urban 6-Lane Divided Signalized 4-Leg Intersection

Figure 4 - SPF for Injury and Fatal Crashes

US 287 / Rutgers Lane (MP 344.67)
Before: 2005 to 2008 After: 2011 to 2014



Note: Safety Performance Function (SPF) Model: Colorado - Urban 6-Lane Divided Signalized 4-Leg Intersection

Table 3 – US 287 / Swallow Road – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 6-lane, Divided, Signalized, 4-Leg Intersection	Urban, 6-lane, Divided, Signalized, 4-Leg Intersection	Urban, 6-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS II	LOSS IV	LOSS II
CPY	13.98	19.00	12.94
Mean CPY	14.85	13.77	13.77
Proportion of Mean	0.94	1.38	0.94
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS III	LOSS II
CPY	3.63	4.50	3.44
Mean CPY	4.53	4.30	4.30
Proportion of Mean	0.80	1.05	0.80

Table 4 – US 287 / Rutgers Lane – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 6-lane, Divided, Signalized, 4-Leg Intersection	Urban, 6-lane, Divided, Signalized, 4-Leg Intersection	Urban, 6-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS I	LOSS II	LOSS I
CPY	8.80	9.75	8.38
Mean CPY	13.14	12.50	12.50
Proportion of Mean	0.67	0.78	0.67
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS I	LOSS II
CPY	3.44	1.75	3.34
Mean CPY	4.07	3.93	3.93
Proportion of Mean	0.85	0.45	1.08

A more detailed review of the before and after crash record reveals that no improvement in safety can be attributed to the upgrade of the signal at the intersection of US 287 and Swallow Road. **Table 5** shows a comparison of four types of crashes that are most directly affected by the improvement: rear end, approach turn, pedestrian, and broadside. Almost every crash type saw an increase in frequency of crashes. The No Build After crashes were estimated using the decrease in the mean of the SPF for total crashes found in **Table 3** (decrease is 0.93 = 13.77/14.85).

Table 5 – US 287 / Swallow Road – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2005 to 12/31/2007 (3 yr.)	1/1/2011 to 12/31/2013 (3 yr.)	1/1/2011 to 12/31/2013 (3 yr.)
Crash Types:			
Intersection Total	**55**	**76**	**51**
Injury (injuries)	11 (22)	18 (22)	10 (20)
PDO	44	58	41
% Reduction in Total (Injuries/PDO)		-10% / -41%	
Rear Ends – Total	**37**	**31**	**34**
Injury (injuries)	3 (5)	8 (8)	3 (5)
PDO	34	23	31
% Reduction in Total (Injuries/PDO)		-60% / 26%	
Approach Turns – Total	**15**	**20**	**14**
Injury (injuries)	6 (15)	4 (7)	6 (14)
PDO	9	16	8
% Reduction in Total (Injuries/PDO)		50% / -100%	
Broadsides – Total	**7**	**11**	**7**
Injury (injuries)	1 (1)	3 (3)	1 (1)
PDO	6	8	6
% Reduction in Total (Injuries/PDO)		-200% / -33%	
Sideswipe Same Direction – Total	**4**	**9**	**4**
Injury (injuries)	0	1 (1)	0
PDO	4	8	4
% Reduction in Total (Injuries/PDO)		NA / -100%	

A review of the before and after crashes at the intersection of US 287 and Rutgers Lane shows that very little improvement in safety can be attributed to the upgrade of the signal. **Table 6** shows a comparison of crash types that are most directly affected by the improvement: rear end, approach turn, and broadside. There was an increase in the number of crashes, although the number of injuries decreased. The No Build After crashes were estimated using the decrease in the mean of the SPF for total crashes found in **Table 4** (decrease is 0.95 = 12.50/13.14).

Table 6 – US 287 / Rutgers Lane – Results of Crash Analyses

	Before	**After**	**No Build After**
Time Period:	1/1/2005 to 12/31/2007 (3 yr.)	1/1/2011 to 12/31/2013 (3 yr.)	1/1/2011 to 12/31/2013 (3 yr.)
Crash Types:			
Intersection Total	**30**	**39**	**29**
Injury (injuries)	11 (16)	7 (12)	11 (16)
PDO	19	32	18
% Reduction in Total (Injuries/PDO)		25% / -78%	
Rear Ends – Total	**8**	**16**	**8**
Injury (injuries)	3 (5)	3 (4)	3 (5)
PDO	5	13	5
% Reduction in Total (Injuries/PDO)		20% / -160%	
Approach Turns – Total	**8**	**12**	**8**
Injury (injuries)	2 (2)	2 (5)	2 (2)
PDO	6	10	6
% Reduction in Total (Injuries/PDO)		0% / -66%	
Broadsides – Total	**6**	**8**	**6**
Injury (injuries)	3 (6)	2 (3)	3 (6)
PDO	3	6	3
% Reduction in Total (Injuries/PDO)		50% / -100%	
Sideswipe Same Direction – Total	**3**	**2**	**3**
PDO	3	2	3
% Reduction in Total		33%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. No B/C analysis could be run for the intersection of US 287 with Swallow Road because there was an increase in injuries and property damage only crashes. There was no benefit with which to run an analysis.

The results of the B/C analysis for the intersection of US 287 with Rutgers Lane are shown in **Figure 5**. There was an increase in property damage only crashes after the improvement. The increase in property damage only crashes was factored into the analysis by increasing the cost of construction for the improvement. During the four-year after period, there was an additional 14 property damage only crashes. Over the design life of 10 years for the improvements, the increased cost of crashes would be $325,500 (35 PDO = $325,500). The resulting B/C ratio is 1.14 (See **Figure 5**), showing the improvement may have been justified.

Figure 5 – US 287 / Rutgers Lane – Benefit Cost Analysis – Intersection Crashes Only

COLORADO Department of Transportation

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

10/08/2016

Job #: 20161008143638

Location: 287C **Begin:** 344.65 **End:** 344.69 **From:** 01/01/2005 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	18		Weighted PDO:	4.94	0% : CRF for PDO	Cost of PDO:	$ 9,300
INJ:	11	16 : Injured	Weighted INJ:	4.39	25% : CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 : Killed	Weighted FAT:	0.00	0% : CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	9% : Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	10
						Capital Recovery Factor:	0.129
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 602,360
From: 01/01/2005
To: 12/31/2008 Days: 1461

Benefit Cost Ratio: **1.14** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: PEDESTRIAN COUNTDOWN TIMERS, PROTECTED LEFT-TURN
Special Notes: INTERSECTION CRASHES ONLY

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

Exhibit 1

10/07/2016

Job #: 20161007133545

Location: 287C **Begin:** 343.70 **End:** 343.74 **From:** 01/01/2005 **To:** 12/31/2008

Severity

PDO:	44		
INJ:	11	22	:Injured
FAT:	0	0	:Killed
Total:	**55**		

Number of Vehicles

One Vehicle:	1
Two Vehicles:	42
Three or More:	12
Unknown:	0
Total:	**55**

Location

On Road:	54
Off Road Left:	1
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**55**

Lighting Conditions

Daylight:	44
Dawn or Dusk:	1
Dark - Lighted:	10
Dark - Unlighted:	0
Unknown:	0
Total:	**55**

Weather Conditions

None:	52
Rain:	3
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**55**

Crash Rates

PDO:	18.25 *
INJ:	4.56 *
FAT:	0.00 **
Total:	**22.82** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	7	Embankment:	0
Head On:	0	Curb:	0
Rear End:	27	Delineator Post:	0
Sideswipe (Same):	4	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	15	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	1	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**55**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	50
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	4
E:	0	I:	0		

Left Frontage Rd (L):	4
Rt Frontage Rd (R):	1
HOV Lanes (V):	0
Unknown:	0
Total:	**55**

Road Description

At Intersection:	41
At Driveway Access:	0
Intersection Related:	14
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**55**

Road Conditions

Dry:	49
Wet:	5
Muddy:	1
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**55**

ADT: 41,250 **Length:** 0.04

Location: 287C **Begin:** 343.70 **End:** 343.74 **From:** 01/01/2005 **To:** 12/31/2008

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	36	35	6
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	10	8	3
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	6	9	3
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	1	0
Bicycle:	0	1	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**55**	**54**	**12**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	17	45	11
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	4	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	19	4	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	2	0	0
Evading Law Enforcement Officier:	1	0	0
Physical Disability:	1	0	0
Unknown:	9	5	1
Total:	**55**	**54**	**12**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	53	54	12
Alcohol Involved:	2	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**55**	**54**	**12**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	30	23	2
Slowing:	2	3	1
Stopped in Traffic:	1	19	9
Making Right Turn:	1	2	0
Making Left Turn:	14	7	0
Making U-Turn:	0	0	0
Passing:	1	0	0
Backing:	3	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	3	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**55**	**54**	**12**

Direction	Veh 1	Veh 2	Veh 3
North:	16	20	1
Northeast:	0	0	0
East:	4	4	2
Southeast:	0	0	0
South:	27	20	5
Southwest:	0	0	0
West:	8	10	4
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**55**	**54**	**12**

ADT: 41,250 **Length:** 0.04

Location: 287C **Begin:** 343.70 **End:** 343.74 **From:** 01/01/2011 **To:** 12/31/2014

Severity

PDO:	58	
INJ:	18	22 :Injured
FAT:	0	0 :Killed
Total:	**76**	

Number of Vehicles

One Vehicle:	1
Two Vehicles:	66
Three or More:	9
Unknown:	0
Total:	**76**

Location

On Road:	76
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**76**

Lighting Conditions

Daylight:	58
Dawn or Dusk:	4
Dark - Lighted:	13
Dark - Unlighted:	0
Unknown:	1
Total:	**76**

Weather Conditions

None:	69
Rain:	3
Snow/Sleet/Hail:	4
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**76**

Crash Rates

PDO:	27.51 *
INJ:	8.54 *
FAT:	0.00 **
Total:	**36.05** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	11	Embankment:	0
Head On:	0	Curb:	0
Rear End:	31	Delineator Post:	0
Sideswipe (Same):	9	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	20	Large Boulders or Rocks:	0
Overtaking Turn:	1	Barricade:	0
Parked Motor Vehicle:	1	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	1	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	0
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	1
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	1
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**76**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	76
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**76**

Road Description

At Intersection:	61
At Driveway Access:	0
Intersection Related:	15
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**76**

Road Conditions

Dry:	60
Wet:	7
Muddy:	0
Snowy:	1
Icy:	5
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	1
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	1
Total:	**76**

ADT: 37,000 **Length:** 0.03

Location: 287C **Begin:** 343.70 **End:** 343.74 **From:** 01/01/2011 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	41	41	6
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	11	8	1
Pickup Truck/Utility Van w/Trl:	1	2	0
SUV:	14	19	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	3	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	1	0
Motorhome:	0	0	0
Motorcycle:	2	2	0
Bicycle:	1	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	3	1	1
Other:	0	0	0
Unknown:	0	0	0
Total:	**76**	**75**	**9**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	40	73	9
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	5	1	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	11	1	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	2	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	17	0	0
Total:	**76**	**75**	**9**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	74	75	9
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**76**	**75**	**9**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	34	37	0
Slowing:	6	2	0
Stopped in Traffic:	1	28	9
Making Right Turn:	6	5	0
Making Left Turn:	19	2	0
Making U-Turn:	2	0	0
Passing:	2	0	0
Backing:	2	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	0
Changing Lanes:	3	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**76**	**75**	**9**

Direction	Veh 1	Veh 2	Veh 3
North:	30	20	1
Northeast:	1	1	0
East:	3	5	3
Southeast:	0	0	0
South:	39	42	3
Southwest:	0	0	0
West:	3	7	2
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**76**	**75**	**9**

ADT: 37,000 **Length:** 0.03

Location: 287C **Begin:** 344.65 **End:** 344.69 **From:** 01/01/2005 **To:** 12/31/2008

Severity

PDO:	19		
INJ:	11	16	:Injured
FAT:	0	0	:Killed
Total:	**30**		

Number of Vehicles

One Vehicle:	2
Two Vehicles:	26
Three or More:	2
Unknown:	0
Total:	**30**

Location

On Road:	29
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	1
Unknown:	0
Total:	**30**

Lighting Conditions

Daylight:	24
Dawn or Dusk:	2
Dark - Lighted:	3
Dark - Unlighted:	1
Unknown:	0
Total:	**30**

Weather Conditions

None:	28
Rain:	2
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**30**

Crash Rates

PDO:	8.79 *
INJ:	5.09 *
FAT:	0.00 **
Total:	**13.89** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	6	Embankment:	0
Head On:	0	Curb:	0
Rear End:	8	Delineator Post:	0
Sideswipe (Same):	3	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	8	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	2	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	2
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	1	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**30**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	29
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	1
HOV Lanes (V):	0
Unknown:	0
Total:	**30**

Road Description

At Intersection:	21
At Driveway Access:	0
Intersection Related:	9
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**30**

Road Conditions

Dry:	25
Wet:	4
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**30**

ADT: 41,075 **Length:** 0.03

Location: 287C **Begin:** 344.65 **End:** 344.69 **From:** 01/01/2005 **To:** 12/31/2008

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	18	17	0
Passenger Car/Van w/Trl:	0	0	1
Pickup Truck/Utility Van:	5	6	1
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	5	4	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	1	1	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**30**	**28**	**2**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	17	15	1
Slowing:	0	1	0
Stopped in Traffic:	0	9	1
Making Right Turn:	2	0	0
Making Left Turn:	9	3	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	2	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**30**	**28**	**2**

Direction	Veh 1	Veh 2	Veh 3
North:	17	7	0
Northeast:	0	0	0
East:	0	6	2
Southeast:	0	0	0
South:	11	14	0
Southwest:	0	0	0
West:	2	1	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**30**	**28**	**2**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	14	26	2
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	3	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	10	1	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	2	1	0
Total:	**30**	**28**	**2**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	30	28	2
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**30**	**28**	**2**

ADT: 41,075 **Length:** 0.03

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

COLORADO Department of Transportation — CDOT

Exhibit 4

10/07/2016

Job #: 20161007150552

Location: 287C **Begin:** 344.65 **End:** 344.69 **From:** 01/01/2011 **To:** 12/31/2014

Severity

PDO:	32		
INJ:	7	12	:Injured
FAT:	0	0	:Killed
Total:	**39**		

Number of Vehicles

One Vehicle:	1
Two Vehicles:	35
Three or More:	3
Unknown:	0
Total:	**39**

Location

On Road:	39
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**39**

Lighting Conditions

Daylight:	29
Dawn or Dusk:	3
Dark - Lighted:	7
Dark - Unlighted:	0
Unknown:	0
Total:	**39**

Weather Conditions

None:	39
Rain:	0
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**39**

Crash Rates

PDO:	15.91	*
INJ:	3.48	*
FAT:	0.00	**
Total:	**19.39**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	8	Embankment:	0
Head On:	0	Curb:	0
Rear End:	16	Delineator Post:	0
Sideswipe (Same):	2	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	12	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	0
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	1
Bridge Rail:	0	Total Other Objects:	1
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**39**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	39
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**39**

Road Description

At Intersection:	29
At Driveway Access:	0
Intersection Related:	10
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**39**

Road Conditions

Dry:	35
Wet:	2
Muddy:	0
Snowy:	0
Icy:	1
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**39**

ADT: 38,250 **Length:** 0.03

Location: 287C **Begin:** 344.65 **End:** 344.69 **From:** 01/01/2011 **To:** 12/31/2014

Vehicle Type

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	24	23	1
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	7	6	1
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	7	9	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**39**	**38**	**3**

Vehicle Movement

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	22	15	0
Slowing:	2	3	1
Stopped in Traffic:	0	12	2
Making Right Turn:	1	0	0
Making Left Turn:	11	8	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	3	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**39**	**38**	**3**

Contributing Factor

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	18	36	3
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	4	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	11	1	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	5	1	0
Total:	**39**	**38**	**3**

Direction

Direction	Veh 1	Veh 2	Veh 3
North:	13	11	1
Northeast:	0	0	0
East:	1	5	0
Southeast:	0	0	0
South:	24	21	2
Southwest:	0	0	0
West:	1	1	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**39**	**38**	**3**

Condition of Driver

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	38	38	3
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**39**	**38**	**3**

ADT: 38,250 **Length:** 0.03

Project Information

Project Name: Queue Detection System

Project Description: Install Queue Detection System

CDOT Region: 6 Project Def: 16642 County: Arapahoe

Location: US 285 Mile Points: 257.69 – 258.06 Length: 0.37 miles

Schedule: Work Start Date: 10/13/2008 Completion Date: 8/5/2009

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history (1999 – 2003) showed that there was a total of 145 crashes with 20 injury crashes. This highway segment experiences a high number of rear-end and sideswipe same direction crashes, some of which are related to the sight distance limitations due to the westbound vertical curve at the Federal Boulevard underpass.

Improvement Description: Between October 13, 2008 and August 5, 2009, a queue detection system and blankout warning sign were installed for the westbound traffic approaching the intersection of US 285 with Knox Court. The cost of construction was $250,000.

The HSIP application anticipated that a 15% reduction in rear-end crashes might be realized by the improvement. The initial benefit/cost ratio was estimated to be 2.17.

Summary and Findings

The analysis of safety before and after the queue detectors and warning sign were installed on SH 285 showed a reduction congestion related crashes occurring in the westbound direction.

Along the study segment of 6-lane divided highway on SH 285, there were 94 non-intersection crashes during the five-year period before the system was installed (2003 to 2007). In the five years after construction (2010 to 2014), the number of crashes increased to 113. However, a comparison of westbound crashes before and after the installation of the queue detector showed that there was a decrease in rear-end crashes. At the intersection of SH 285 and Knox Court, the number of crashes decreased from 149 crashes during the before period to 66 crashes in the after period. There was a large decrease in westbound rear-end crashes at the intersection.

The ratio of benefits and cost for this project shows that benefits were very cost to the costs as the B/C ratio was 6.29 to one. The result is the improvement was likely justified from an economic standpoint.

Results of Safety Analyses

For this improvement, both non-intersection crashes to the east of the US 285 / Knox Court intersection along with crashes at the intersection were impacted. Both the non-intersection segment of highway and the intersection were analyzed to get the full picture of the impacts of the queue detection and warning system on crashes.

Using Vision Zero Suite, the review of before and after crash records shows an increase in the number of non-intersection crashes on the study corridor. On SH 285 the total number of non-intersection crashes increased from 94 during the five-year period (2003 to 2007) before the queue detector and warning system was installed (see **Table 1** and **Exhibit 1**) to 113 during the five-year after period (2010 to 2014) (see **Table 1** and **Exhibit 2**). However, the number of severe crashes decreased on SH 285 between the before and after periods:

- Before (2003 to 2007) – 1 fatal crash with 3 fatalities and 23 injury crashes with 29 injuries
- After (2010 to 2014) – no fatal crashes and 17 injury crashes with 19 injuries

Table 1 – SH 285 (MP 257.69 to MP 258.06) - Results of Overall Crash Analyses

	Before	After
Time Period:	2003 to 2007 (5 yr.)	2010 to 2014 (5 yr.)
AADT	70,945 vpd	67,200 vpd
Filters:	Mainline, Non-Intersection	Mainline, Non-Intersection
Total Crashes	**94**	**113**
Fatal Crashes (Fatalities)	1 (3)	0
Injury Crashes (Injuries)	23 (29)	17 (19)
Property Damage Only	70	96
Crash Types: # (% of total crashes)		
Rear-end	77 (81.9%)	77 (68.1%)
Fixed Object	7 (7.4%)	13 (11.5%)
Sideswipe Same	6 (6.4%)	17 (15.0%)
Fixed Object Crashes: # (% of FO)		
Guardrail	4 (57.1%)	2 (15.4%)
Concrete Barrier	2 (28.6%)	6 (46.1%)

At the intersection of SH 285 with Knox Court there was a decrease in the number of crashes. At the intersection, the number of intersection and intersection-related crashes decreased from 149 during the five-year before period (see **Table 2** and **Exhibit 3**) to 66 during the five-year after period (see **Table 2** and **Exhibit 4**). The number of severe crashes also decreased at the intersection of SH 285 and Knox Court between the before and after periods:

- Before (2003 to 2007) – no fatal crashes and 31 injury crashes with 42 injuries
- After (2010 to 2014) – no fatal crashes and 20 injury crashes with 21 injuries

The number of rear-ends significantly decreased between the before and after periods, as did the number sideswipe same direction crashes and approach turn crashes.

Table 2 – SH 285/Knox Court Intersection (MP 257.69) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	2003 to 2007 (5 yr.)	2010 to 2014 (5 yr.)
AADT (SH 285 / Knox Court)	70,945 vpd / 7,190 vpd	67,200 vpd / 7,190 vpd
Filters:	Intersection, Intersection Related	Intersection, Intersection Related
Total Crashes	**149**	**66**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	31 (42)	20 (21)
Property Damage Only	118	46
Crash Types: # (% of total crashes) [cumulative probability]		
Rear-end	104 (69.8%) [100.0%]	42 (63.6%) [99.9%]
Sideswipe Same	11 (7.4%)	2 (3.0%)
Broadside	11 (7.4%)	13 (19.7%)
Approach Turn	10 (6.7%)	2 (3.0%)

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.

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.

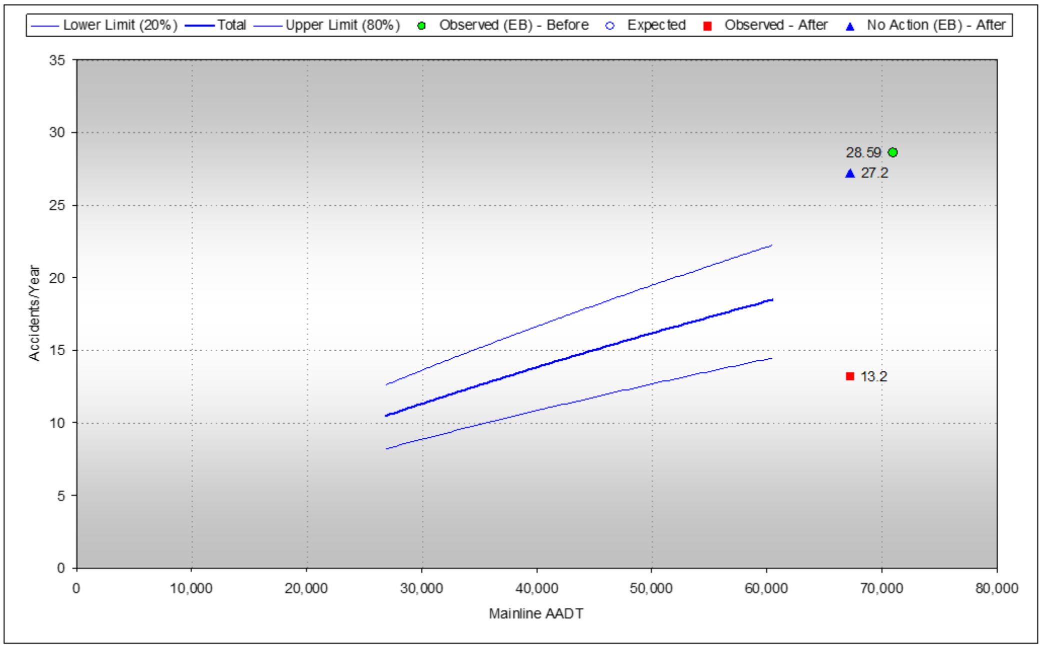
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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.

No SPFs have been created for corridors similar to SH 285, so no SPF analysis was completed for the non-intersection crashes. The SH 285 / Knox Court intersection SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) reflect the decrease in crashes and severity of crashes. The frequency of crashes decreased from the LOSS IV category to the LOSS I category. The severity of crashes decreased from the LOSS III category to the LOSS I category. **Table 3** provides the results of the intersection SPF analysis.

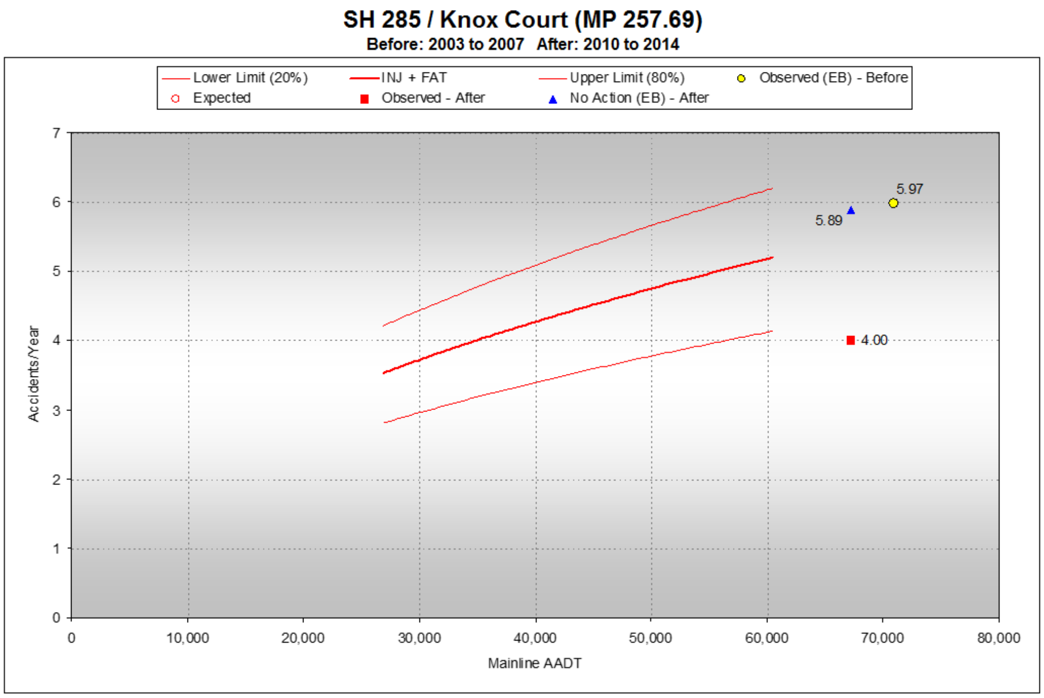
Figure 1 - SPF for Total Crashes

SH 285 / Knox Court (MP 257.69)
Before: 2003 to 2007 After: 2010 to 2014



Note: Safety Performance Function (SPF) Model: Colorado - Urban Divided Signalized 6-Lane 4-Leg Intersection

Figure 2 - SPF for Injury and Fatal Crashes



Note: Safety Performance Function (SPF) Model: Colorado - Urban Divided Signalized 6-Lane 4-Leg Intersection

Table 3 – SH 285 / Knox Court (MP 257.69) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, Divided, Signalized, 6-Lane, 4-Leg Intersection	Urban, Divided, Signalized, 6-Lane, 4-Leg Intersection	Urban, Divided, Signalized, 6-Lane, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS IV	LOSS I	LOSS IV
CPMPY	28.59	13.20	27.2
Mean CPMPY	Approx. 21	Approx. 20	Approx. 20
Proportion of Mean	1.36	0.66	1.36
Fatal & Injury Crashes:			
LOSS	LOSS IIII	LOSS I	LOSS II/III
CPMPY	5.97	4.00	5.89
Mean CPMPY	Approx. 5.5	Approx. 5.4	Approx. 5.4
Proportion of Mean	1.09	0.74	1.09

A more detailed review of the before and after crash record on SH 285 reveals that the reduction in westbound rear-end and sideswipe same direction crashes can be attributed to the installation of the queue detection and warning system. **Table 4** provides a comparison of the sideswipe opposite direction, and rear-end crashes. The No Build After crashes were estimated using the decrease in the mean of the SPF for total crashes found in **Table 3** (decrease is 0.95

= 20/21). **Table 4** shows there was a decrease in rear-end and sideswipe same direction crashes.

Table 4 – SH 285 (MP 257.69 to MP 258.06) - Results of Queue Detector Crash Analyses

	Before	**After**	**No Build After**
Time Period:	2003 to 2007 (5 yr.)	2010 to 2014 (5 yr)	2003 to 2007 (5 yr)
Crash Types: SH 285 Non-Intersection			
Rear-End – Total (westbound only)	**56**	**48**	**53**
Injury (injuries)	15 (18)	12 (14)	14 (17)
PDO	41	36	39
% Reduction in Total – (Injuries/ PDO)		18% / 8%	
Sideswipe Same Direction – Total (westbound only)	**3**	**12**	**3**
Injury (injuries)	0	1 (1)	0
PDO	3	11	3
% Reduction in Total – (Injuries/ PDO)		NA / NA	
Crash Types: SH 285 / Knox Court Intersection			
Rear-End – Total (westbound only)	**48**	**14**	**46**
Injury (injuries)	7 (12)	3 (3)	7 (12)
PDO	41	11	39
% Reduction in Total – (Injuries/ PDO)		75% / 72%	
Sideswipe Same Direction – Total (westbound only)	**3**	**0**	**3**
PDO	3	0	3
% Reduction in Total		100%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the queue detection. As shown in **Figure 3**, the B/C ratio is 6.29 for the queue detection warning system, showing the improvement was likely justified.

Figure 3 – SH 285 (MP 257.69 to MP 258.06) - Benefit Cost Analysis – Rear-End and Sideswipe Same Direction Crash Types Only

COLORADO Department of Transportation

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

08/21/2018

Job #: 20180821111658

Location: 285D **Begin:** 257.69 **End:** 258.06 **From:** 01/01/2003 **To:** 12/31/2007

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	84		Weighted PDO:	18.05	31% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	21	29 :Injured	Weighted INJ:	6.23	38% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	32% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
		Cost: $ 250,000				Service Life:	8
		From: 01/01/2003				Capital Recovery Factor:	0.154
		To: 12/31/2007	Days: 1826			Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: 6.29 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: QUEUE DETECTION SYSTEM AND WARNING SIGN
Special Notes: WESTBOUND REAR-END AND SIDESWIPE SAME ONLY

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

COLORADO Department of Transportation

Exhibit 1

09/27/2016

Job #: 20160927101314

Location: 285D **Begin:** 257.69 **End:** 258.06 **From:** 01/01/2003 **To:** 12/31/2007

Severity

PDO:	70		
INJ:	23	29	:Injured
FAT:	1	3	:Killed
Total:	**94**		

Number of Vehicles

One Vehicle:	6
Two Vehicles:	71
Three or More:	17
Unknown:	0
Total:	**94**

Location

On Road:	85
Off Road Left:	4
Off Road Right:	4
Off Road at Tee:	0
Off in Median:	1
Unknown:	0
Total:	**94**

Lighting Conditions

Daylight:	64
Dawn or Dusk:	8
Dark - Lighted:	12
Dark - Unlighted:	9
Unknown:	1
Total:	**94**

Weather Conditions

None:	87
Rain:	4
Snow/Sleet/Hail:	2
Fog:	1
Dust:	0
Wind:	0
Unknown:	0
Total:	**94**

Crash Rates

PDO:	1.46	*
INJ:	0.48	*
FAT:	2.09	**
Total:	**1.96**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	2	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	1	Embankment:	1
Head On:	1	Curb:	0
Rear End:	77	Delineator Post:	0
Sideswipe (Same):	6	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	7
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	4	Unknown:	0
Cable Rail:	0	**Total:**	**94**
Concrete Barrier:	2		

Mainline/Ramps/Frontage Roads

Mainline:	94
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**94**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	94
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**94**

Road Conditions

Dry:	87
Wet:	5
Muddy:	0
Snowy:	0
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	1
Total:	**94**

ADT: 70,945 **Length:** 0.37

Location: 285D **Begin:** 257.69 **End:** 258.06 **From:** 01/01/2003 **To:** 12/31/2007

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	60	62	12
Passenger Car/Van w/Trl:	1	1	0
Pickup Truck/Utility Van:	18	16	2
Pickup Truck/Utility Van w/Trl:	1	1	0
SUV:	3	3	0
SUV w/Trl:	0	1	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	4	3	2
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	1	0	0
Motorcycle:	3	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	2	0	1
Other:	0	0	0
Unknown:	1	1	0
Total:	**94**	**88**	**17**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	70	20	5
Slowing:	8	22	2
Stopped in Traffic:	2	42	10
Making Right Turn:	2	1	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	7	0	0
Avoiding Object/Veh in Road:	1	2	0
Weaving:	0	0	0
Other:	2	0	0
Unknown:	2	1	0
Total:	**94**	**88**	**17**

Direction	Veh 1	Veh 2	Veh 3
North:	2	2	0
Northeast:	0	0	0
East:	20	21	2
Southeast:	1	1	0
South:	4	3	0
Southwest:	0	0	0
West:	65	60	15
Northwest:	0	0	0
Unknown:	2	1	0
Total:	**94**	**88**	**17**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	60	86	15
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	24	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	5	2	2
Total:	**94**	**88**	**17**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	93	88	17
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**94**	**88**	**17**

ADT: 70,945 **Length:** 0.37

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

Exhibit 2

09/27/2016

Job #: 20160927102812

Location: 285D **Begin:** 257.69 **End:** 258.06 **From:** 01/01/2010 **To:** 12/31/2014

Severity

PDO:	96	
INJ:	17	19 :Injured
FAT:	0	0 :Killed
Total:	**113**	

Number of Vehicles

One Vehicle:	15
Two Vehicles:	76
Three or More:	22
Unknown:	0
Total:	**113**

Location

On Road:	98
Off Road Left:	3
Off Road Right:	12
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**113**

Lighting Conditions

Daylight:	77
Dawn or Dusk:	4
Dark - Lighted:	25
Dark - Unlighted:	7
Unknown:	0
Total:	**113**

Weather Conditions

None:	103
Rain:	3
Snow/Sleet/Hail:	7
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**113**

Crash Rates

PDO:	2.03 *
INJ:	0.36 *
FAT:	0.00 **
Total:	**2.39** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	1	Culvert/Headwall:	0
Broadside:	0	Embankment:	1
Head On:	0	Curb:	1
Rear End:	77	Delineator Post:	1
Sideswipe (Same):	17	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	1	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	13
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	1
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	2
Bridge Rail:	0	Total Other Objects:	3
Guard Rail:	2	Unknown:	0
Cable Rail:	0	**Total:**	**113**
Concrete Barrier:	6		

Mainline/Ramps/Frontage Roads

Mainline:	113
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**113**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	113
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**113**

Road Conditions

Dry:	99
Wet:	7
Muddy:	0
Snowy:	2
Icy:	0
Slushy:	2
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	1
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	1
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**113**

ADT: 67,200 **Length:** 0.38

Location: 285D **Begin:** 257.69 **End:** 258.06 **From:** 01/01/2010 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	57	50	10
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	19	12	1
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	31	33	10
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	2	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	4	1	1
Other:	1	0	0
Unknown:	0	0	0
Total:	**113**	**98**	**22**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	62	28	3
Slowing:	19	15	4
Stopped in Traffic:	2	52	15
Making Right Turn:	1	0	0
Making Left Turn:	2	0	0
Making U-Turn:	0	0	0
Passing:	2	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	16	2	0
Avoiding Object/Veh in Road:	0	1	0
Weaving:	3	0	0
Other:	5	0	0
Unknown:	0	0	0
Total:	**113**	**98**	**22**

Direction	Veh 1	Veh 2	Veh 3
North:	4	1	0
Northeast:	0	0	0
East:	28	25	5
Southeast:	0	0	0
South:	13	10	4
Southwest:	0	0	0
West:	68	62	13
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**113**	**98**	**22**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	43	98	22
Asleep at the Wheel:	1	0	0
Illness:	4	0	0
Distracted by Passenger:	3	0	0
Driver Inexperience:	5	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	21	0	0
Driver Unfamilar with Area:	2	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	33	0	0
Total:	**113**	**98**	**22**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	108	98	22
Alcohol Involved:	4	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**113**	**98**	**22**

ADT: 67,200 **Length:** 0.38

Exhibit 3

Location: 285D **Begin:** 257.67 **End:** 257.71 **From:** 01/01/2003 **To:** 12/31/2007

Severity

PDO:	118	
INJ:	31	42 :Injured
FAT:	0	0 :Killed
Total:	**149**	

Number of Vehicles

One Vehicle:	5
Two Vehicles:	129
Three or More:	15
Unknown:	0
Total:	**149**

Location

On Road:	140
Off Road Left:	2
Off Road Right:	7
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**149**

Lighting Conditions

Daylight:	113
Dawn or Dusk:	1
Dark - Lighted:	33
Dark - Unlighted:	0
Unknown:	2
Total:	**149**

Weather Conditions

None:	138
Rain:	6
Snow/Sleet/Hail:	4
Fog:	0
Dust:	0
Wind:	0
Unknown:	1
Total:	**149**

Crash Rates

PDO:	22.77 *
INJ:	5.98 *
FAT:	0.00 **
Total:	**28.75** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	1	Culvert/Headwall:	0
Broadside:	11	Embankment:	0
Head On:	0	Curb:	4
Rear End:	104	Delineator Post:	1
Sideswipe (Same):	11	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	10	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	1
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	2	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	8
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	2	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**149**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	149
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**149**

Road Description

At Intersection:	118
At Driveway Access:	0
Intersection Related:	31
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**149**

Road Conditions

Dry:	134
Wet:	10
Muddy:	0
Snowy:	1
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	1
Unknown:	2
Total:	**149**

ADT: 70,945 **Length:** 0.04

Location: 285D **Begin:** 257.67 **End:** 257.71 **From:** 01/01/2010 **To:** 12/31/2014

Severity

PDO:	46	
INJ:	20	21 :Injured
FAT:	0	0 :Killed
Total:	**66**	

Number of Vehicles

One Vehicle:	2
Two Vehicles:	59
Three or More:	5
Unknown:	0
Total:	**66**

Location

On Road:	63
Off Road Left:	1
Off Road Right:	1
Off Road at Tee:	1
Off in Median:	0
Unknown:	0
Total:	**66**

Lighting Conditions

Daylight:	44
Dawn or Dusk:	4
Dark - Lighted:	16
Dark - Unlighted:	2
Unknown:	0
Total:	**66**

Weather Conditions

None:	59
Rain:	2
Snow/Sleet/Hail:	5
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**66**

Crash Rates

PDO:	10.13 *
INJ:	4.41 *
FAT:	0.00 **
Total:	**14.54** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	2	Culvert/Headwall:	0
Broadside:	13	Embankment:	0
Head On:	0	Curb:	0
Rear End:	42	Delineator Post:	0
Sideswipe (Same):	2	Fence:	1
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	2	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	1	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	3
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	1	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	1	Unknown:	0
Cable Rail:	0	**Total:**	**66**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	66
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**66**

Road Description

At Intersection:	46
At Driveway Access:	0
Intersection Related:	20
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**66**

Road Conditions

Dry:	56
Wet:	6
Muddy:	0
Snowy:	3
Icy:	0
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**66**

ADT: 67,200 **Length:** 0.03

Location: 285D **Begin:** 257.67 **End:** 257.71 **From:** 01/01/2010 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	37	37	5
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	10	9	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	15	15	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	1	0	0
Motorcycle:	0	0	0
Bicycle:	0	1	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	2	0	0
Other:	1	2	0
Unknown:	0	0	0
Total:	**66**	**64**	**5**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	18	61	5
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	5	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	13	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	29	3	0
Total:	**66**	**64**	**5**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	61	63	5
Alcohol Involved:	5	1	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**66**	**64**	**5**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	32	15	0
Slowing:	17	8	1
Stopped in Traffic:	1	32	3
Making Right Turn:	1	0	0
Making Left Turn:	10	6	1
Making U-Turn:	1	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	2	1	0
Avoiding Object/Veh in Road:	0	1	0
Weaving:	0	0	0
Other:	1	1	0
Unknown:	0	0	0
Total:	**66**	**64**	**5**

Direction	Veh 1	Veh 2	Veh 3
North:	5	5	0
Northeast:	0	0	0
East:	27	26	1
Southeast:	0	0	0
South:	9	14	1
Southwest:	0	0	0
West:	24	19	3
Northwest:	1	0	0
Unknown:	0	0	0
Total:	**66**	**64**	**5**

ADT: 67,200 **Length:** 0.03

Location: 285D **Begin:** 257.67 **End:** 257.71 **From:** 01/01/2003 **To:** 12/31/2007

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	89	100	9
Passenger Car/Van w/Trl:	1	1	0
Pickup Truck/Utility Van:	30	28	2
Pickup Truck/Utility Van w/Trl:	2	2	0
SUV:	7	4	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	7	3	2
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	1	0	0
Motorcycle:	1	2	2
Bicycle:	2	0	0
Motorized Bicycle:	1	1	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	7	2	0
Other:	0	1	0
Unknown:	1	0	0
Total:	**149**	**144**	**15**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	96	137	15
Asleep at the Wheel:	1	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	6	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	27	3	0
Driver Unfamilar with Area:	2	0	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	0	1	0
Physical Disability:	1	0	0
Unknown:	14	3	0
Total:	**149**	**144**	**15**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	139	144	15
Alcohol Involved:	7	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	2	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**149**	**144**	**15**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	101	29	3
Slowing:	23	17	1
Stopped in Traffic:	0	80	10
Making Right Turn:	2	1	0
Making Left Turn:	6	15	0
Making U-Turn:	0	0	0
Passing:	2	0	0
Backing:	2	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	8	0	0
Avoiding Object/Veh in Road:	2	1	0
Weaving:	0	0	0
Other:	2	1	0
Unknown:	1	0	1
Total:	**149**	**144**	**15**

Direction	Veh 1	Veh 2	Veh 3
North:	8	9	0
Northeast:	0	0	0
East:	74	64	11
Southeast:	0	0	0
South:	5	11	1
Southwest:	0	0	0
West:	61	60	3
Northwest:	0	0	0
Unknown:	1	0	0
Total:	**149**	**144**	**15**

ADT: 70,945 **Length:** 0.04

Project Information

Project Name: 23 Road and G Road in Grand Junction

Project Description: Roundabouts

CDOT Region: 3 **Project Def**:16730 **County**: Adams

Location: 23 Rd & G Rd **Mile Points**: N/A **Length:** N/A

Schedule: Work Start Date: after 10/9/2011 Completion Date: 5/25/2012

Problem Description: As described in the Federal Hazard Elimination Project (FHEP) application for this project, this is an intersection of two two-lane roads was controlled by stop signs for the east and west approaches. Both 23 Road and G Road are very long, straight roadways with no other traffic control for at least one-half mile. Most crashes seemed to be the result of drivers either missing the stop signs, assuming a four-way stop, or misjudging the speed of approaching vehicles. The worst crashes were side impacts at fairly high speeds. In a six-year period (2000 through 2005), there were one fatal crash, 12 injury crashes, and eight PDO crashes.

Improvement Description: Between November 2011 and May 2012, a roundabout was constructed at this intersection to limit the horizon for drivers, which was anticipated to help reduce speeds and eliminate the potential for serious side impact crashes. In addition, replacing drainage facilities in and around the intersection was included in the project. The cost of construction was $901,266.

It was anticipated that the crash reduction factor for all types of crashes would be 50%. The initial benefit/cost ratio was estimated to be 2.54.

Summary and Findings

The analysis of safety before and after the intersection of 23 Road and G Road was reconstructed as a roundabout showed a significant decrease in number of crashes. For this intersection, there were nine total crashes (at intersection, intersection related) during the three-year period before the roundabouts were installed (2008 – 2010). In the three years after construction (2012 – 2015), the number of crashes decreased to one. There were no fatal crashes in the after period, and the number of injuries decrease from 13 to one. Additionally, the number of PDO accidents also decreased to zero.

The overall ratio of benefits and cost for this project was 15.36. The result is an improvement that was justified from the standpoint of safety.

Results of Safety Analyses

A review of crash records before and after construction of the roundabout shows a significant decrease in the number of crashes; the total number of crashes decreased from nine during the three-year period (2008 to 2010) before the interchange was reconstructed (see **Table 1** and **Exhibit 1**) to one during the three-year after period (7/1/2012 to 6/30/2015). The number of severe crashes also showed a decrease in the number injuries and fatalities:

- Before (2008 – 2010) – six injury crashes with 13 injuries and one fatal crash with one fatality
- After (2012 – 2015) – one injury crash with one injury

Table 1 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2008 to 12/31/2010 (3 yr.)	7/1/2012 to 6/30/2015 (3 yr.)
AADT		
Filters:	Intersection & related	Intersection & related
Total Crashes	**9**	**1**
Fatal Crashes (Fatalities)	1 (1)	0
Injury Crashes (Injuries)	6 (13)	1 (1)
Property Damage Only	2	1
Crash Types: # (%)		
Broadside	7(78%)	0
Sideswipe (Same)	1(11%)	0
Approach Turn	1 (11%)	0
Overturning	0	1 (100%)

Normally, the magnitude of safety problems on highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. However, in the case of the roundabout at the 23 Road / G Road Intersection, no SPFs have been developed.

Table 2 shows a comparison of the total number of crashes including a No Build After scenario. The No Build After crashes were estimated based on the average increase in daily volumes along 23 Road north and south of the intersection (increase is 1.23 = 4.2% per year x 5.5 years) which was multiplied by the before total crashes found in **Table 1.**

Table 2 – Results of Before & After Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2008 to 12/31/2010 (3 yr.)	7/1/2012 to 6/30/2015 (3 yr.)	7/1/2012 to 6/30/2015 (3 yr.)
AADT			
Filters:	Intersection & related	Intersection & related	Intersection & related
Total Crashes	**9**	**1**	**11**
Fatal Crashes (Fatalities)	1 (1)	0	1 (1)
Injury Crashes (Injuries)	6 (13)	1 (1)	8 (16)
Property Damage Only	2	0	2

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 1** based on before/after crashes. The B/C ratio for this project is 15.36, showing that the safety benefits justify the improvement.

Figure 1 – Benefit Cost Analysis

CDOT
COLORADO Department of Transportation

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

05/04/2016
Job #: 20160504135530

Location: Accident History for G and 23 **From:** 01/01/2008 **To:** 12/31/2010

G Road and 23 Road - Intersection & intersection related

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	2		Weighted PDO:	0.82	100% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	7	16 :Injured	Weighted INJ:	6.55	94% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	1	1 :Killed	Weighted FAT:	0.41	100% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	3.00	95% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 500

Cost: $ 901,266
From: 01/01/2008
To: 12/31/2010 Days: 1096

Benefit Cost Ratio: 15.36 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Construct new roundabout
Special Notes:

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

Exhibit 1 05/03/2016

Job #: 20160503133156

Location: Accident History for G and 23 **From:**01/01/2008 **To:**12/31/2010

G Road and 23 Road - Intersection & intersection related

Severity

PDO:	2		
INJ:	6	13	:Injured
FAT:	1	1	:Killed
Total:	**9**		

Number of Vehicles

One Vehicle:	0
Two Vehicles:	8
Three or More:	1
Unknown:	0
Total:	**9**

Location

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

Lighting Conditions

Daylight:	7
Dawn or Dusk:	1
Dark - Lighted:	0
Dark - Unlighted:	1
Unknown:	0
Total:	**9**

Weather Conditions

None:	3
Rain:	0
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	6
Total:	**9**

Crash Rates

PDO:	N/A *	* MVMT
INJ:	N/A *	** 100 MVMT
FAT:	N/A **	**Total:** **N/A** *

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	0
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	9
Total:	**9**

Road Description

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

Road Conditions

Dry:	8
Wet:	1
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**9**

Location: Accident History for G and 23 **From:** 01/01/2008 **To:** 12/31/2010

G Road and 23 Road - Intersection & intersection related

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

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	1	3	0
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	0	0	0
Driver Unfamilar with Area:	2	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	6	6	1
Total:	**9**	**9**	**1**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	7	9	1
Alcohol Involved:	2	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**9**	**9**	**1**

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

Direction	Veh 1	Veh 2	Veh 3
North:	0	4	0
Northeast:	1	0	0
East:	3	1	0
Southeast:	0	0	0
South:	1	4	0
Southwest:	0	0	0
West:	4	0	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**9**	**9**	**1**

Location: Accident History for G and 23 **From:** 07/01/2012 **To:** 12/31/2014

G Road and 23 Road - Intersection & intersection related

Severity

PDO:	0		
INJ:	1	1	:Injured
FAT:	0	0	:Killed
Total:	**1**		

Number of Vehicles

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

Location

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

Lighting Conditions

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

Weather Conditions

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

Crash Rates

PDO:	N/A *
INJ:	N/A *
FAT:	N/A **
Total:	**N/A** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	0
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	1
Total:	**1**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	0
In Alley:	0
Roundabout:	1
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**1**

Road Conditions

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

Location: Accident History for G and 23 **From:** 07/01/2012 **To:** 12/31/2014

G Road and 23 Road - Intersection & intersection related

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

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

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

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

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

Project Information

Project Name: SH 14 E/O I-25 Larimer County Signals

Project Description: Signal and Intersection Improvements

CDOT Region: 4 Project Def: 16762 County: Larimer

Location: SH 14 Mile Points: 139.21 Length: N/A

Schedule: Work Start Date: 9/19/2009 Completion Date: 4/5/2010

Problem Description: The crash history showed a high number of broadside type crashes at the unsignalized intersection of SH 14 with the I-25 east frontage road.

Improvement Description: Between September 2009 and April 2010 the intersection was signalized. The cost of construction was $1,003,714.

The HSIP application anticipated that broadside and approach turn crashes would be impacted by this improvement. It was anticipated that there would be an 80% crash reduction for these crashes. The initial benefit/cost ratio was estimated to be 1.14.

Summary and Findings

The analysis of safety before and after the intersection of SH 14 and the east I-25 frontage road was signalization showed safety improved for the affected crash types: broadside and approach turn. For this intersection, there were 21 total crashes during the four-year period before the improvement (2005 – 2008). In the four years after construction (2011 – 2014), the number of crashes increased to 27.

The signalization project was responsible for decreases in the number of broadside and approach turn crashes. However, there was an increase in the number of rear-end crashes occurring at the intersection. The rear-ends crashes were primarily property damage only. Broadside and approach turn crashes tend to be more severe, so this resulted in a lower number of severe crashes at the intersection. However, there was an approach turn fatality in the after period that had to be accounted for in the benefit/cost analysis. As a result, the ratio of benefits and cost for this project shows that costs outweigh the benefits with a B/C ratio of 0.44 to one, showing that the improvement may not have been justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records showed the number of crashes increased between the two study periods. The total number of crashes was 21 during the four-year period (2005 to 2008) before the intersection was signalized (see **Table 1** and **Exhibit 1**) and 27 during the four-year after period (2011 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes decreased in the four-year period after the improvements, however there was a fatal crash in the after period when there was no fatal crash in the before period.

- Before (2005 – 2008) – no fatal crashes and 13 injury crashes with 20 injuries
- After (2011 – 2014) – 1 fatal crash with 1 fatality and 6 injury crashes with 8 injuries

Despite a slight increase in traffic volumes at the intersection, the crash rates at the intersection increased due to the increase in crashes:

- Before (2005 – 2008): 0.76 crashes per million entering vehicles (cpmev)
- After (2011 – 2014): 0.93 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT (SH 119/Hover St)	17,225/approx. 1,750 vpd	18,000/approx. 1,800 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**21**	**27**
Fatal Crashes (Fatalities)	0	1 (1)
Injury Crashes (Injuries)	13 (20)	6 (8)
Property Damage Only	8	20
Crash Types: # (%) [significance]		
Broadside	9 (42.9%) [99.3%]	4 (14.8%)
Approach Turn	6 (26.6%) [99.6%]	5 (18.5%)
Sideswipe Same Direction	2 (9.5%)	2 (7.4%)
Rear-End	2 (4.8%)	13 (48.1%)

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

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level

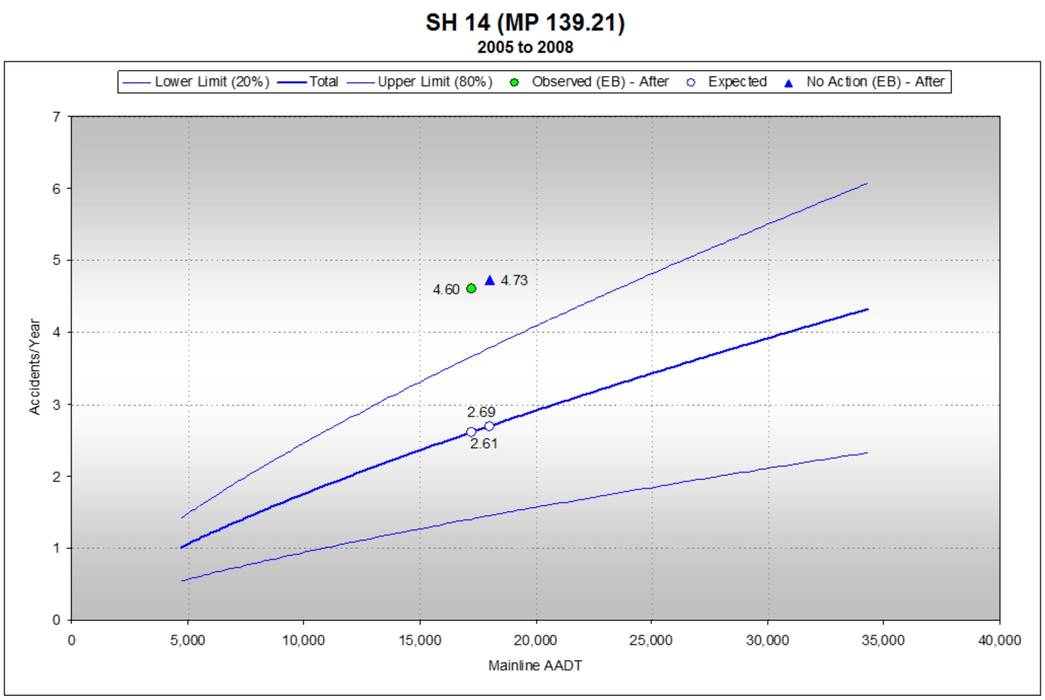
of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

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

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

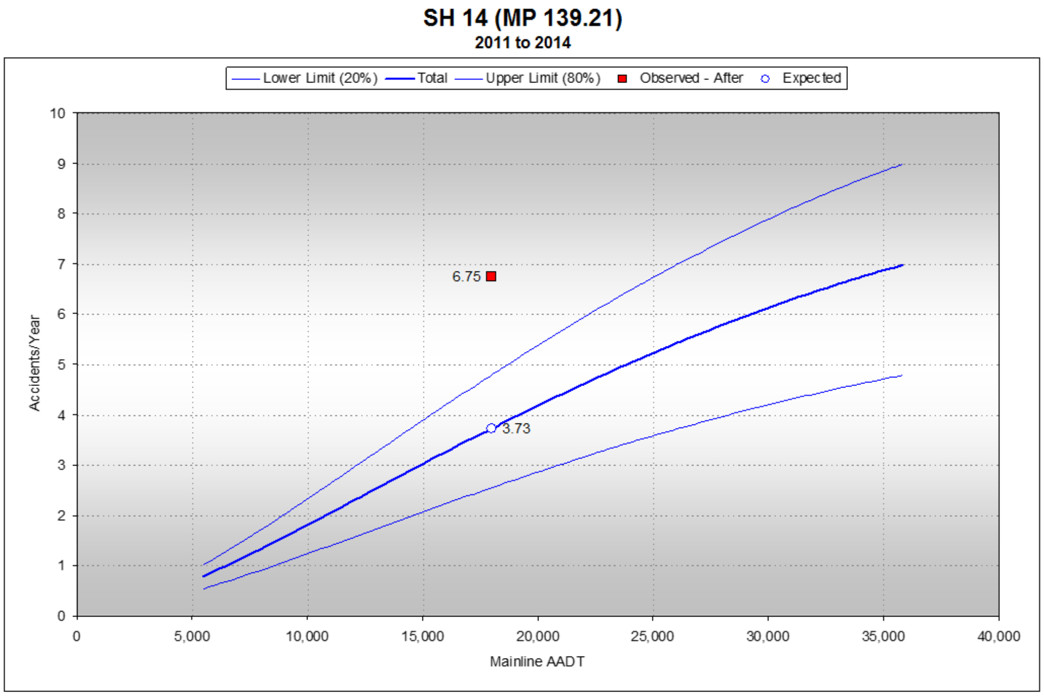
SPF plots for both total crashes (see **Figures 1** and **2**) and for fatal and injury crashes (see **Figures 3** and **4**) also reflect the change in the crash record. Both the frequency and severity of crashes remained in the LOSS IV category for the before and after periods (see **Table 2**).

Figure 1 - SPF for Total Crashes - Before/No Action After



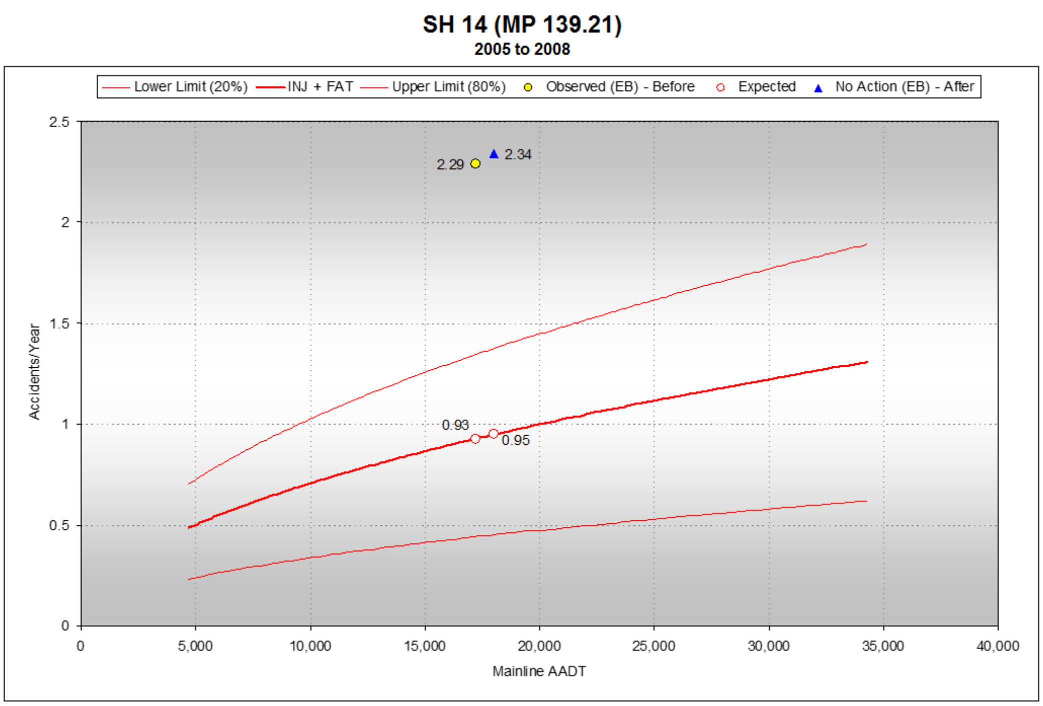
Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 2 - SPF for Total Crashes - After



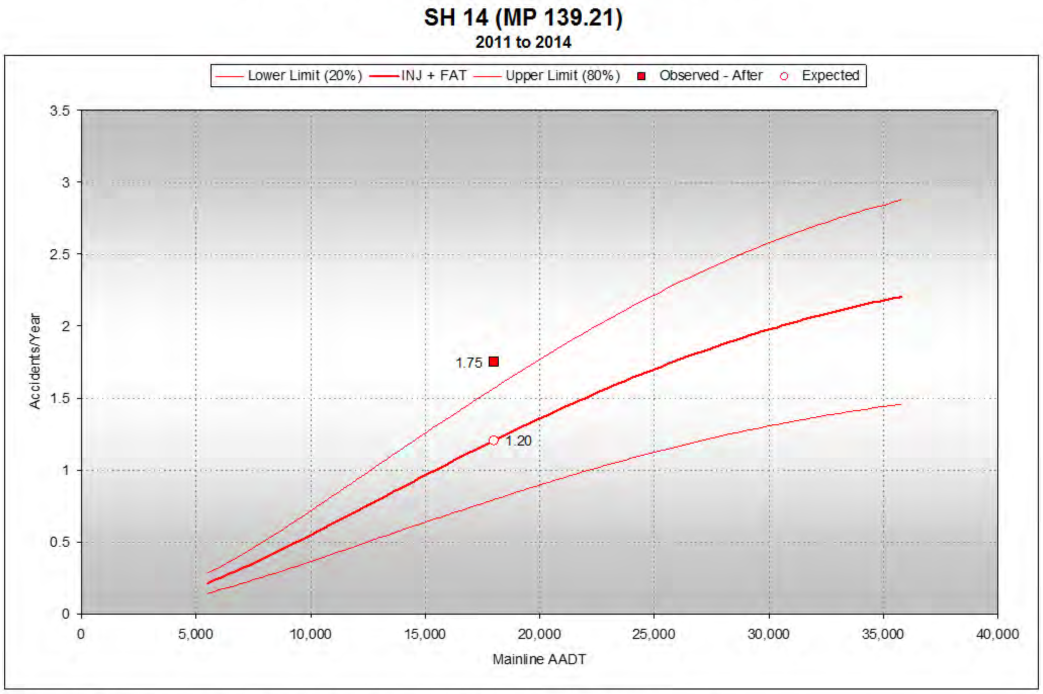
Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 3 - SPF for Injury and Fatal Crashes - Before/No Action After



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

Figure 4 - SPF for Injury and Fatal Crashes - After



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

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Unsignalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Unsignalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPY	4.60	6.75	4.73
Mean CPY	2.61	3.73	2.69
Proportion of Mean	1.76	1.81	1.76
Fatal & Injury Crashes:			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPY	2.29	1.75	2.34
Mean CPY	0.93	1.20	0.95
Proportion of Mean	2.46	1.46	2.46

A more detailed review of the before and after crash record reveals that some improvement in safety can be attributed to the signalization of the intersection of SH 14 with the east frontage road. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that are most directly affected by the improvement: broadside, approach turn, and rear-end. The installation of the signal reduced the number of broadside and approach turn crash, but increased the number of rear-ends. This is an expected outcome when signalizing an intersection. The number of crashes does not necessarily decrease, but the crash types become less severe by reducing the broadside and approach turn crashes. However, there was one approach turn fatality that occurred in the after period. The No Build After crashes were estimated using the change in SH 14 traffic volumes between the before and after period, as found in **Table 1** (increase is 1.04 = 18,000/17,225).

Table 3 – Results of Crash Analyses

	Before	**After**	**No Build After**
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:			
Total Crashes	**21**	**27**	**22**
Fatal (fatalities)	0	1 (1)	0
Injury (injuries)	13 (20)	6 (8)	14 (21)
PDO	8	20	8
% Reduction in Total (Fatalities/Injuries/PDO)		NA / 62% / -150%	
Broadside – Total	**9**	**4**	**9**
Injury (injuries)	7 (13)	0	7 (13)
PDO	2	4	2
% Reduction in Total (Injuries/PDO)		100% / -50%	
Approach Turn – Total	**6**	**5**	**6**
Fatal (fatalities)	0	1 (1)	0
Injury (injuries)	4 (5)	2 (3)	4 (5)
PDO	2	2	2
% Reduction in Total (Fatalities/Injuries/PDO)		NA / 40% / 0%	
Rear Ends – Total	**1**	**13**	**1**
Injury (injuries)	0	2 (2)	0
PDO	1	11	1
% Reduction in Total (Injuries/PDO)		N/A / -1000%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the intersection. Signalizing an intersection can cause new crashes since it forces cars on the mainline to stop for a signal, whereas they did not previously have to stop. The increase in property damage only crashes was factored into the analysis by increasing the cost of construction for the safety project along with the fatality that occurred in the after period. During the four-year after period, there was 1 new fatality and 12 new property damage only crashes. Over the design life of 10 years for the signal, the increased cost of crashes would be $4,029,000 (30 PDO = $279,000 and 2.5 fatalities = $3,750,000). As shown, the B/C ratio crashes occurring at the intersection is 0.44, showing that the improvement may not have been justified from the safety standpoint.

Figure 3 – Benefit Cost Analysis – Intersection and Intersection Related Crashes Only

CDOT
COLORADO
Department of Transportation

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

09/06/2016

Job #: 20160906111731

Location: 14C 25A **Begin:** 139.13 **End:** 139.29 **From:** 01/01/2005 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes				**Projected Crashes and Reduction Factors**				**Other Information**	
PDO:	8			Weighted PDO:	2.20	0%	:CRF for PDO	Cost of PDO:	$ 9,300
INJ:	13	21	:Injured	Weighted INJ:	5.76	62%	:CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0	:Killed	Weighted FAT:	0.00	0%	:CRF for FAT	Cost of FAT:	$ 1,500,000
				B/C Weighted Year Factor:	4.00	38%	:Weighted CRF	Interest Rate:	5%
								AADT Growth Factor:	2.0%
								Service Life:	10
								Capital Recovery Factor:	0.129
								Annual Maintenance/Delay Cost:	$ 0

Cost: $ 5,032,714
From: 01/01/2005
To: 12/31/2008 Days: 1461

Benefit Cost Ratio: 0.44 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: INSTALLING SIGNAL
Special Notes:

Location: 14C 25A **Begin:** 139.13 **End:** 139.29 **From:** 01/01/2005 **To:** 12/31/2008

Severity

PDO:	8	
INJ:	13	20 :Injured
FAT:	0	0 :Killed
Total:	**21**	

Number of Vehicles

One Vehicle:	2
Two Vehicles:	19
Three or More:	0
Unknown:	0
Total:	**21**

Location

On Road:	20
Off Road Left:	1
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**21**

Lighting Conditions

Daylight:	18
Dawn or Dusk:	2
Dark - Lighted:	0
Dark - Unlighted:	1
Unknown:	0
Total:	**21**

Weather Conditions

None:	20
Rain:	0
Snow/Sleet/Hail:	1
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**21**

Crash Rates

PDO:	1.88 *
INJ:	3.06 *
FAT:	0.00 **
Total:	**4.94** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	9	Embankment:	0
Head On:	0	Curb:	0
Rear End:	1	Delineator Post:	0
Sideswipe (Same):	2	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	6	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	1
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	1
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**21**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	18
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	0	O:	0	P:	3

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**21**

Road Description

At Intersection:	21
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**21**

Road Conditions

Dry:	19
Wet:	0
Muddy:	0
Snowy:	1
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**21**

ADT: 17,225 **Length:** 0.16

Location: 14C 25A **Begin:** 139.13 **End:** 139.29 **From:** 01/01/2005 **To:** 12/31/2008

Vehicle Type

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	15	12	0
Passenger Car/Van w/Trl:	0	1	0
Pickup Truck/Utility Van:	2	3	0
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	3	2	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	1	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**21**	**19**	**0**

Vehicle Movement

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	5	18	0
Slowing:	1	0	0
Stopped in Traffic:	0	1	0
Making Right Turn:	0	0	0
Making Left Turn:	12	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	2	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	1	0	0
Total:	**21**	**19**	**0**

Direction

Direction	Veh 1	Veh 2	Veh 3
North:	9	0	0
Northeast:	0	0	0
East:	3	14	0
Southeast:	0	0	0
South:	3	1	0
Southwest:	0	0	0
West:	5	4	0
Northwest:	0	0	0
Unknown:	1	0	0
Total:	**21**	**19**	**0**

Contributing Factor

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	16	19	0
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	2	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	2	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	0	0	0
Total:	**21**	**19**	**0**

Condition of Driver

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	20	19	0
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**21**	**19**	**0**

ADT: 17,225 **Length:** 0.16

Location: 14C 25A **Begin:** 139.20 **End:** 139.29 **From:** 01/01/2011 **To:** 12/31/2014

Severity

PDO:	20		
INJ:	6	8	:Injured
FAT:	1	1	:Killed
Total:	**27**		

Number of Vehicles

One Vehicle:	2
Two Vehicles:	24
Three or More:	1
Unknown:	0
Total:	**27**

Location

On Road:	25
Off Road Left:	0
Off Road Right:	2
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**27**

Lighting Conditions

Daylight:	20
Dawn or Dusk:	2
Dark - Lighted:	5
Dark - Unlighted:	0
Unknown:	0
Total:	**27**

Weather Conditions

None:	20
Rain:	2
Snow/Sleet/Hail:	3
Fog:	0
Dust:	0
Wind:	2
Unknown:	0
Total:	**27**

Crash Rates

PDO:	9.27 *
INJ:	2.78 *
FAT:	46.37 **
Total:	**12.52** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	1	Culvert/Headwall:	1
Broadside:	4	Embankment:	0
Head On:	0	Curb:	0
Rear End:	13	Delineator Post:	0
Sideswipe (Same):	2	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	5	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**27**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	26
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	1
HOV Lanes (V):	0
Unknown:	0
Total:	**27**

Road Description

At Intersection:	19
At Driveway Access:	0
Intersection Related:	8
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**27**

Road Conditions

Dry:	21
Wet:	3
Muddy:	0
Snowy:	1
Icy:	2
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**27**

ADT: 18,000 **Length:** 0.08

Location: 14C 25A **Begin:** 139.20 **End:** 139.29 **From:** 01/01/2011 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	13	17	1
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	6	6	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	4	2	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	3	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**27**	**25**	**1**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	9	11	0
Slowing:	3	1	0
Stopped in Traffic:	0	10	1
Making Right Turn:	4	1	0
Making Left Turn:	4	1	0
Making U-Turn:	3	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	4	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	1	0
Unknown:	0	0	0
Total:	**27**	**25**	**1**

Direction	Veh 1	Veh 2	Veh 3
North:	2	2	0
Northeast:	0	0	0
East:	11	8	1
Southeast:	0	0	0
South:	3	2	0
Southwest:	0	0	0
West:	11	13	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**27**	**25**	**1**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	16	24	1
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	2	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	5	1	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	3	0	0
Total:	**27**	**25**	**1**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	27	25	1
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**27**	**25**	**1**

ADT: 18,000 **Length:** 0.08

Project Information

Project Name: I-70B – MP 0.40 to MP 1.3

Project Description: Roadway realignment, signalization, and median channelization of 23 Road

CDOT Region: 3 Project Def: 16804 County: Mesa

Location: I-70B Mile Points: 0.40 – 1.30 Length: 0.9 miles

Schedule: Work Start Date: 5/18/2009 Completion Date: 9/29/2009

Problem Description: As described in the Federal Hazard Elimination Program (FHEP) application for this project, the three-year crash history (2001 – 2003) showed that there were a total of seven injury crashes, 19 PDO crashes, and one fatal crashes. This rapidly developing industrial area has a high and increasing percentage of trucks due to its proximity to I-70. I-70B is a seven lane highway through this section, and there are two significant county collectors that intersect with I-70B (23 Road and G Road).

Improvement Description: Between May 5, 2009 and September 29, 2009, the intersection of I-70B and 23 Road was signalized. There was a minor realignment of I-70B to allow the installation of a raised median separating eastbound left-turning vehicles from through traffic so through traffic does not normally have to stop for 23 Road traffic turning left at the intersection. In addition, some access control measures were anticipated. The cost of construction was $1,055,256.

The FHEP application anticipated that a 30% reduction in all types of crashes might be realized by the improvement. The initial benefit/cost ratio was estimated to be 1.65.

Summary and Findings

The analysis of safety before and after the new traffic signal was installed at the intersection of I-70B and 23 Road showed a reduction in the number and severity of all crash types. The decrease in broadside type crashes was particularly notable. At the two intersections (G Road and 23 Road) in this segment of 4-lane divided arterial highway, there were 32 total crashes during the five-year period before the signal was installed (2004 – 2008). In the five years after construction (2010 – 2014), the number of crashes decreased to 17. This decrease in crashes was accompanied by modest decreases/increases in AADT (depending on the intersection).

A comparison of all type crashes before and after the traffic signal improvement was installed showed that there was a decrease in fatal crashes (one fatality in five years before to none in the five years after). Injury crashes also decreased from ten INJ (20 injuries) before to six INJ (nine injuries) after. The number of PDO crashes was reduced from 21 to 11. The ratio of benefits and cost for this project shows that benefits outweighed costs as the B/C ratio is 5.63 to one. The result is an improvement that was justified from an economic standpoint.

<u>Results of Safety Analyses</u>

Using Vision Zero Suite, the review of before and after crash records at the two intersections (G Road and 23 Road) shows a decrease in the number of crashes; the total number of crashes decreased from 32 during the five-year period (2004 to 2008) before the 23 Road intersection was signalized (see **Tables 1** and **2** as well as **Exhibits 1** and **2**) to 17 during the five-year after period (2010 to 2014) (see **Table 1** and **2** as well as **Exhibits 3** and **4**). The number of severe crashes also showed a decrease in the after period:

- Before (2004 – 2008) – one fatal crash with one fatality and ten injury crashes with 20 injuries
- After (2010 – 2014) – no fatal crashes and six injury crashes with nine injuries

It is fair to speculate that the significant decrease in the number of broadside type crashes (19 total before to two after) is the result of signalizing the 23 Road intersection and the resulting shift in vehicles heading towards the southeast (downtown Grand Junction).

Table 1 – I-70B & G Road (MP 0.60) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
AADT (Major / Minor)	27,144 / 3,000 vpd	26,628 / 2,450 vpd
Filters:	All Crashes (intersection)	All Crashes (intersection)
Total Crashes	**17**	**8**
Fatal Crashes (Fatalities)	0 (0)	0
Injury Crashes (Injuries)	5 (7)	1 (3)
Property Damage Only	12	7
Crash Types: # (% of total crashes) [cumulative probability]		
Broadside	9 (52.9%) [99.91%]	1 (12.5%)
Rear End	3 (17.6%)	2 (25.0%)
Sideswipe Same	2 (11.8%)	2 (25.0%) [95.14%]
Approach Turn	0	2 (25.0%)

Table 2 – I-70B & 23 Road (MP 1.23) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
AADT (Major / Minor)	27,320 / 2,572 vpd	28.600 / 2,983 vpd (2,700 w/o signalization)
Filters:	All Crashes (intersection)	All Crashes (intersection)
Total Crashes	**15**	**9**
Fatal Crashes (Fatalities)	1 (1)	0
Injury Crashes (Injuries)	5 (13)	5 (6)
Property Damage Only	9	4
Crash Types: # (% of total crashes) [cumulative probability]		
Broadside	10 (66.7%) [100.0%]	1 (11.1%)
Fixed Object	2 (13.3%)	1 (11.1%)
Rear End	0	7 (77.8%) [98.36%]

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

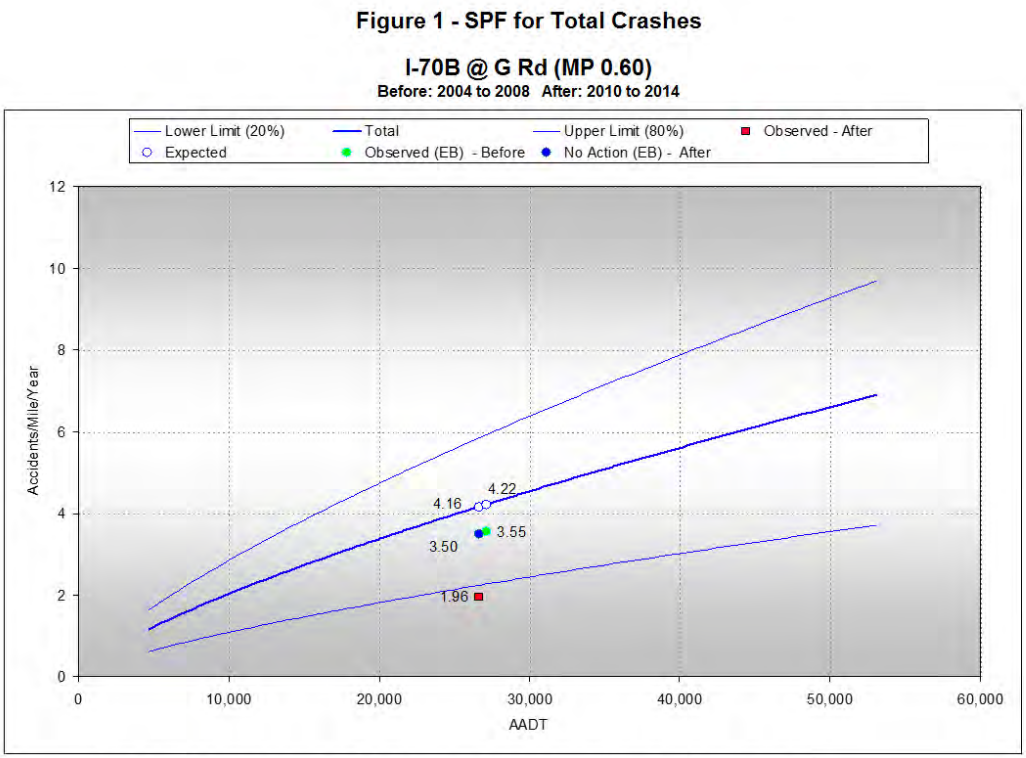
Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted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

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

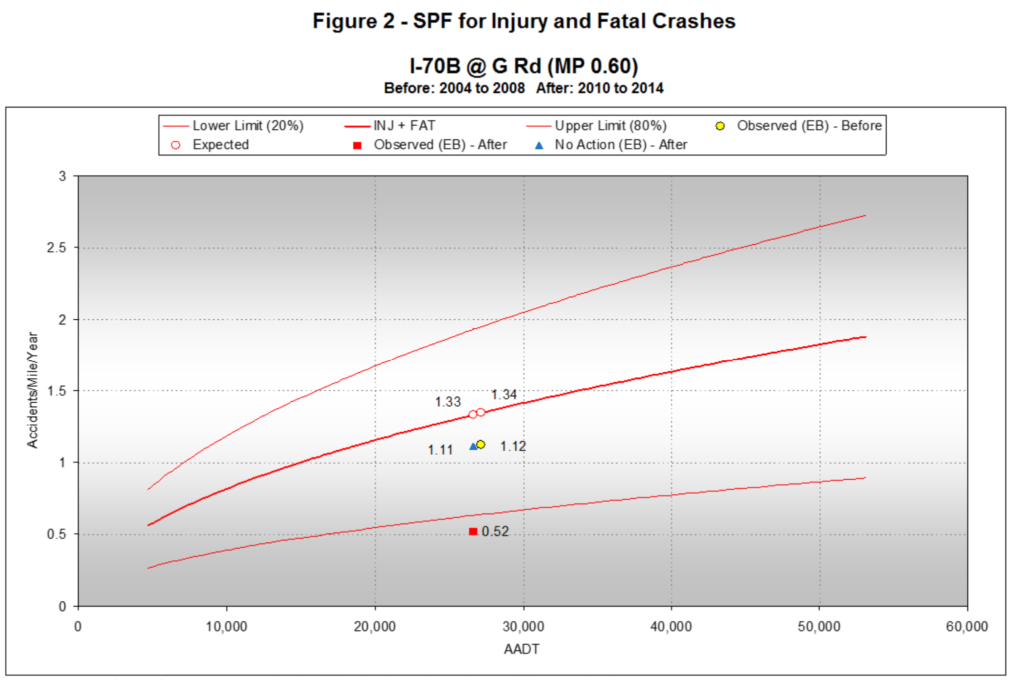
LOSS boundaries are calibrated by computing the 20^{th} and the 80^{th} percentiles using the Gamma Distribution Probability Density Function. Gradual change in the degree of deviation of the LOSS boundary line from the fitted model mean reflects the observed increase of variability in crashes as ADT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

<u>I-70B and G Road</u> - 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. LOSS improved from the LOSS II range for total crashes in the before period to LOSS I in the after period. Injury/Fatal crashes improved to LOSS I in the after period from the LOSS II range in the before period. **Figures 1** and **2** also show that the number and severity of crashes during the period after construction was much improved in comparison to what it could have been without the project. **Table 3** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

<u>I-70B and 23 Road</u> - SPF plots for both total crashes (see **Figures 3** and **5**) and for fatal and injury crashes (see **Figures 4** and **6**) reflect an improvement in the crash record. Since a traffic signal was installed, separate SPFs were necessary for the before condition (unsignalized) and the after condition (signalized). LOSS improved from the LOSS III range for total crashes in the before period (**Figure 3**) to LOSS I in the after period (**Figure 5**). Injury/Fatal crashes improved from LOSS IV in the before period (**Figure 4**) to the LOSS II range in the after period (**Figure 6**). **Figures 3** and **4** also show that the number and severity of crashes during the period after construction was much improved in comparison to what it could have been without the project. It should be noted in **Table 4** that the crashes per year (CPY) went down in the after period for both total and injury/fatal crashes while the mean CPY went up for the signalized condition.



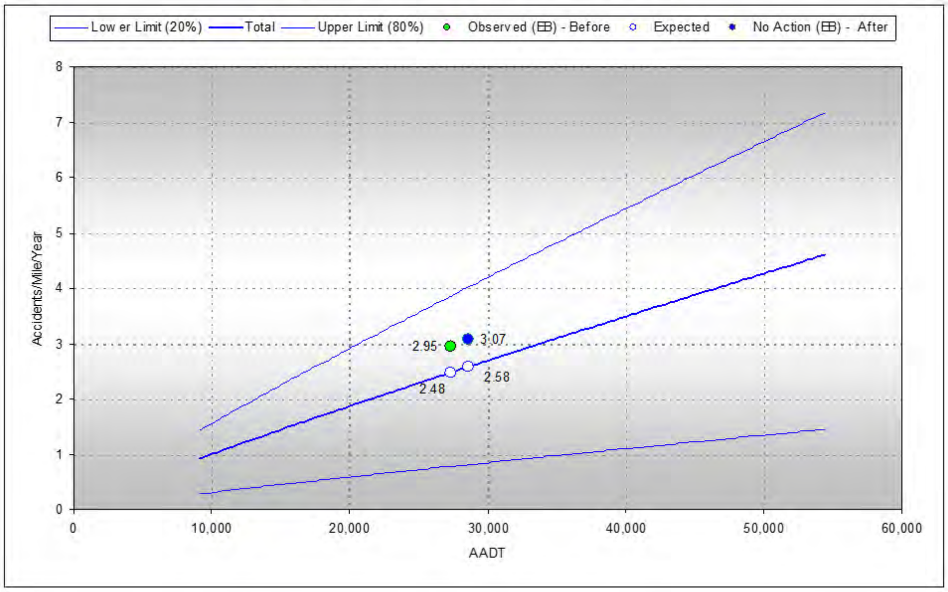
Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-lane Divided Unsignalized 4-Leg Intersection



Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-lane Divided Unsignalized 4-Leg Intersection

Figure 3 - SPF for Total Crashes

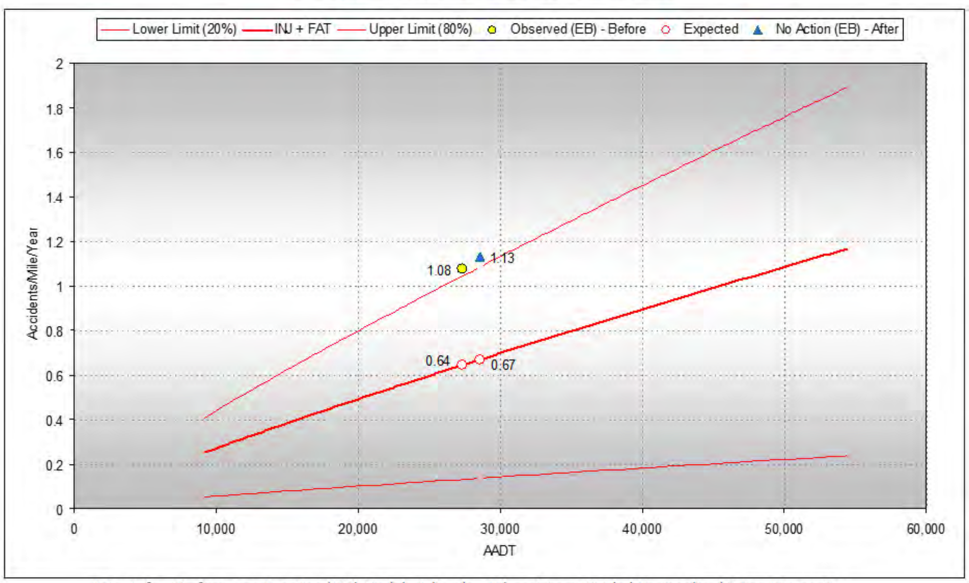
I-70B @ 23 Rd (MP 1.23) - Unsignalized
Before: 2004 to 2008 No Build After: 2010 to 2014



Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-lane Divided Unsignalized 3-Leg Intersection

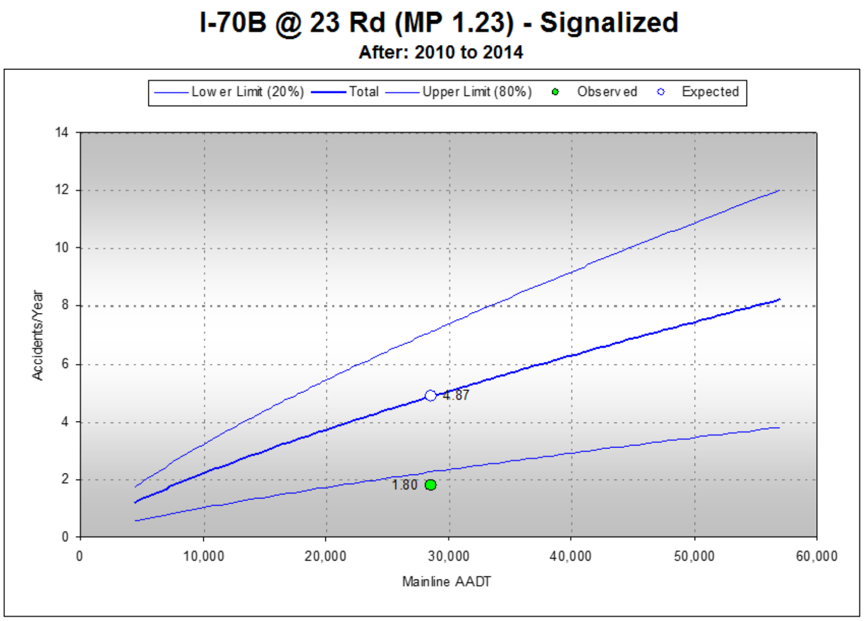
Figure 4 - SPF for Injury and Fatal Crashes

I-70B @ 23 Rd (MP 1.23) - Unsignalized
Before: 2004 to 2008 No Build After: 2010 to 2014



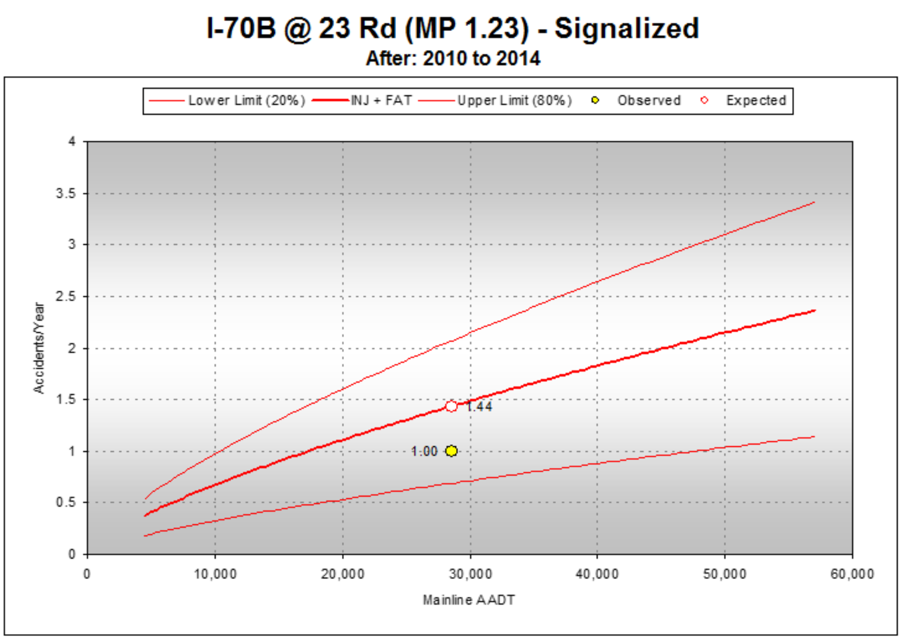
Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-Lane Divided Unsignalized 3-Leg Intersection

Figure 5 - SPF for Total Crashes



Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-lane Divided Signalized 3-Leg Intersection

Figure 6 - SPF for Injury and Fatal Crashes



Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-Lane Divided Signalized 3-Leg Intersection

Table 3 – I-70B & G Road (MP 0.60) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	Yes	Yes
SPF Graph	Urban, 4-lane Divided, Unsignalized, 4-Leg Intersection	Urban, 4-lane Divided, Unsignalized, 4-Leg Intersection	Urban, 4-lane Divided, Unsignalized, 4- Leg Intersection
Total Crashes:			
LOSS	LOSS II	LOSS I	LOSS II
CPY	3.55	1.96	3.50
Mean CPY	4.22	4.16	4.16
Proportion of Mean	0.841	0.471	0.841
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS I	LOSS II
CPY	1.12	0.52	1.11
Mean CPY	1.34	1.33	1.33
Proportion of Mean	0.836	0.391	0.836

Table 4 – I-70B & 23 Road (MP 1.23) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane Divided, Unsignalized, 3- Leg Intersection	Urban, 4-lane Divided, Signalized, 3-Leg Intersection	Urban, 4-lane Divided, Unsignalized, 3- Leg Intersection
Total Crashes:			
LOSS	LOSS III	LOSS I	LOSS III
CPY	2.95	1.80	3.07
Mean CPY	2.48	4.87	2.58
Proportion of Mean	1.190	0.370	1.190
Fatal & Injury Crashes:			
LOSS	LOSS IV	LOSS II	LOSS IV
CPY	1.08	1.00	1.13
Mean CPY	0.64	1.44	0.67
Proportion of Mean	1.688	0.694	1.688

A more detailed review of the before and after crash record reveals that a significant portion of the overall improvement in safety can be attributed to the installation of the signal and median. **Table 5** provides a comparison of the before and after crashes at each intersection. The No Build After crashes for the G Road intersection were estimated using the decrease in the mean of the SPF for total crashes found in **Table 4** (decrease is 0.986 = 3.50/3.55). After crashes for the 23 Road intersection were estimated using the increase in the ADT found in **Table 2** (increase is 1.047 = 28,600/27,320). **Table 5** shows a significant decrease in total crashes (from 32 in five years before to 17 in the five years after). The decrease in crashes by type ranges from 50 percent to 100 percent.

Table 5 – I-70B at G Road (MP 0.60) and 23 Road (MP 1.23) - Results of Crash Analyses

	Before	**After**	**No Build After**
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
I-70B at G Road			
Intersection – Total	**17**	**8**	**17**
Fatal (fatalities)	0 (0)	0 (0)	0 (0)
Injury (injuries)	5 (7)	1 (3)	5 (7)
PDO	12	7	12
I-70B at 23 Road			
Intersection - Total	**15**	**9**	**16**
Fatal (fatalities)	1 (1)	0 (0)	1 (1)
Injury (injuries)	5 (13)	5 (6)	5 (13)
PDO	9	4	10
Total	**32**	**17**	**33**
Fatal (fatalities)	1 (1)	0 (0)	1 (1)
Injury (injuries)	10 (20)	6 (9)	10 (20)
PDO	21	11	22
% Reduction in Total – (Fatal/Injuries/ PDO)		100% / 55% / 50%	

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 at the two intersections. **Figure 6** shows the result of the Benefit/Cost calculation is a B/C ratio of **5.63.** This result shows that the project was justified from an economic standpoint due to the significant decrease in the number and severity of crashes.

Figure 6 – I-70B at G Road (MP 0.60) and 23 Road (MP 1.23) – Benefit Cost Analysis

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

05/18/2016

Job #: 20160518132827

Location: 70B **Begin:** 0.40 **End:** 1.30 **From:** 01/01/2004 **To:** 12/31/2008

I-70B - Grand Junction - intersections at G Road and 23 Road

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	22		Weighted PDO:	5.10	50% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	10	20 :Injured	Weighted INJ:	4.64	55% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	1	1 :Killed	Weighted FAT:	0.23	100% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	53% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
	Cost:	$ 1,055,256				Service Life:	15
	From:	01/01/2004				Capital Recovery Factor:	0.096
	To:	12/31/2008	Days: 1827			Annual Maintenance/Delay Cost:	$ 1,000

Benefit Cost Ratio: 5.63 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Signalization at 23 Road also improved safety at G Road

Special Notes:

Exhibit 1 05/10/2016

Job #: 20160510090925

Location: 70B **Begin:** 0.58 **End:** 0.62 **From:** 01/01/2004 **To:** 12/31/2008

I-70B & G Rd - Grand Junction - Before - all Crashes

Severity

PDO:	12		
INJ:	5	7	:Injured
FAT:	0	0	:Killed
Total:	**17**		

Number of Vehicles

One Vehicle:	2
Two Vehicles:	14
Three or More:	1
Unknown:	0
Total:	**17**

Location

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

Lighting Conditions

Daylight:	14
Dawn or Dusk:	1
Dark - Lighted:	0
Dark - Unlighted:	1
Unknown:	1
Total:	**17**

Weather Conditions

None:	16
Rain:	0
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	1
Total:	**17**

Crash Rates

PDO:	8.34	*
INJ:	3.48	*
FAT:	0.00	**
Total:	**11.82**	*

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	17
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

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

Road Description

At Intersection:	14
At Driveway Access:	0
Intersection Related:	1
Non Intersection:	2
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**17**

Road Conditions

Dry:	16
Wet:	0
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	1
Total:	**17**

ADT: 27,144 **Length:** 0.02

Location: 70B **Begin:** 0.58 **End:** 0.62 **From:** 01/01/2004 **To:** 12/31/2008

I-70B & G Rd - Grand Junction - Before - all Crashes

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	9	7	0
Passenger Car/Van w/Trl:	1	0	0
Pickup Truck/Utility Van:	2	5	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	2	1	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	3	2	1
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**17**	**15**	**1**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	12	15	1
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	1	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	2	0	0
Total:	**17**	**15**	**1**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	17	15	1
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**17**	**15**	**1**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	10	4	0
Slowing:	1	3	0
Stopped in Traffic:	0	4	1
Making Right Turn:	3	2	0
Making Left Turn:	3	1	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	1	0
Unknown:	0	0	0
Total:	**17**	**15**	**1**

Direction	Veh 1	Veh 2	Veh 3
North:	6	0	0
Northeast:	1	0	0
East:	2	9	0
Southeast:	1	1	0
South:	6	3	0
Southwest:	0	0	0
West:	1	2	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**17**	**15**	**1**

ADT: 27,144 **Length:** 0.02

CDOT COLORADO Department of Transportation

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

Exhibit 2 05/10/2016

Job #: 20160510105712

Location: 70B **Begin:** 1.21 **End:** 1.25 **From:** 01/01/2004 **To:** 12/31/2008

I-70B & 23 Rd - Grand Junction - Before - all Crashes

Severity

PDO:	9		
INJ:	5	13	:Injured
FAT:	1	1	:Killed
Total:	**15**		

Number of Vehicles

One Vehicle:	3
Two Vehicles:	11
Three or More:	1
Unknown:	0
Total:	**15**

Location

On Road:	12
Off Road Left:	1
Off Road Right:	2
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**15**

Lighting Conditions

Daylight:	12
Dawn or Dusk:	0
Dark - Lighted:	2
Dark - Unlighted:	1
Unknown:	0
Total:	**15**

Weather Conditions

None:	13
Rain:	1
Snow/Sleet/Hail:	1
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**15**

Crash Rates

PDO:	4.75 *
INJ:	2.64 *
FAT:	52.72 **
Total:	**7.91** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	15
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**15**

Road Description

At Intersection:	14
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	1
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**15**

Road Conditions

Dry:	14
Wet:	0
Muddy:	0
Snowy:	0
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**15**

ADT: 27,320 **Length:** 0.03

Location: 70B	Begin: 1.21	End: 1.25	From: 01/01/2004	To: 12/31/2008

I-70B & 23 Rd - Grand Junction - Before - all Crashes

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	8	7	1
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	1	3	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	3	1	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	2	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**15**	**12**	**1**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	5	12	1
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	2	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	0	0	0
Driver Unfamilar with Area:	2	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	6	0	0
Total:	**15**	**12**	**1**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	14	12	1
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**15**	**12**	**1**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	3	11	1
Slowing:	0	1	0
Stopped in Traffic:	0	0	0
Making Right Turn:	2	0	0
Making Left Turn:	8	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**15**	**12**	**1**

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	0	2	1
Southeast:	0	0	0
South:	11	1	0
Southwest:	0	0	0
West:	3	9	0
Northwest:	1	0	0
Unknown:	0	0	0
Total:	**15**	**12**	**1**

ADT: 27,320 **Length:** 0.03

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

Exhibit 3 05/10/2016

Job #: 20160510094122

Location: 70B **Begin:** 0.58 **End:** 0.62 **From:** 01/01/2010 **To:** 12/31/2014

I-70B & G Rd - Grand Junction - After - all Crashes

Severity

PDO:	7	
INJ:	1	3 :Injured
FAT:	0	0 :Killed
Total:	**8**	

Number of Vehicles

One Vehicle:	1
Two Vehicles:	7
Three or More:	0
Unknown:	0
Total:	**8**

Location

On Road:	7
Off Road Left:	0
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**8**

Lighting Conditions

Daylight:	6
Dawn or Dusk:	0
Dark - Lighted:	0
Dark - Unlighted:	2
Unknown:	0
Total:	**8**

Weather Conditions

None:	8
Rain:	0
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**8**

Crash Rates

PDO:	4.96 *	* MVMT
INJ:	0.71 *	** 100 MVMT
FAT:	0.00 **	**Total: 5.67** *

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	8
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**8**

Road Description

At Intersection:	3
At Driveway Access:	1
Intersection Related:	1
Non Intersection:	3
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**8**

Road Conditions

Dry:	7
Wet:	1
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**8**

ADT: 26,628 **Length:** 0.02

Location: 70B **Begin:** 0.58 **End:** 0.62 **From:**01/01/2010 **To:**12/31/2014

I-70B & G Rd - Grand Junction - After - all Crashes

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

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	1	7	0
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	1	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	6	0	0
Total:	**8**	**7**	**0**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	7	7	0
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**8**	**7**	**0**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	4	6	0
Slowing:	0	0	0
Stopped in Traffic:	0	1	0
Making Right Turn:	1	0	0
Making Left Turn:	2	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**8**	**7**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	1	0	0
Northeast:	0	0	0
East:	1	1	0
Southeast:	0	0	0
South:	1	1	0
Southwest:	0	0	0
West:	5	5	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**8**	**7**	**0**

ADT: 26,628 **Length:** 0.02

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

Exhibit 4 05/10/2016

Job #: 20160510102935

Location: 70B **Begin:** 1.21 **End:** 1.25 **From:** 01/01/2010 **To:** 12/31/2014

I-70B & 23 Rd - Grand Junction - After - all Crashes

Severity

PDO:	4	
INJ:	5	6 :Injured
FAT:	0	0 :Killed
Total:	**9**	

Number of Vehicles

One Vehicle:	1
Two Vehicles:	7
Three or More:	1
Unknown:	0
Total:	**9**

Location

On Road:	8
Off Road Left:	0
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**9**

Lighting Conditions

Daylight:	6
Dawn or Dusk:	2
Dark - Lighted:	1
Dark - Unlighted:	0
Unknown:	0
Total:	**9**

Weather Conditions

None:	8
Rain:	0
Snow/Sleet/Hail:	0
Fog:	1
Dust:	0
Wind:	0
Unknown:	0
Total:	**9**

Crash Rates

PDO:	2.02 *	* MVMT
INJ:	2.52 *	** 100 MVMT
FAT:	0.00 **	**Total:** **4.54** *

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	9
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**9**

Road Description

At Intersection:	5
At Driveway Access:	0
Intersection Related:	3
Non Intersection:	1
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**9**

Road Conditions

Dry:	8
Wet:	0
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**9**

ADT: 28,600 **Length:** 0.03

Location: 70B **Begin:** 1.21 **End:** 1.25 **From:**01/01/2010 **To:**12/31/2014

I-70B & 23 Rd - Grand Junction - After - all Crashes

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	5	4	1
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	2	1	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	2	3	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**9**	**8**	**1**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	0	8	1
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	5	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	2	0	0
Total:	**9**	**8**	**1**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	8	8	1
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**9**	**8**	**1**

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

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	0	0	0
Southeast:	0	0	0
South:	0	1	0
Southwest:	0	0	0
West:	8	6	1
Northwest:	1	1	0
Unknown:	0	0	0
Total:	**9**	**8**	**1**

ADT: 28,600 **Length:** 0.03

Project Information

Project Name: I-70 Business Route at Peachtree Center, Access Improvements

Project Description: Hazard Elimination, Access Improvement and Signalization

CDOT Region: 3 Project Def: 16814 County: Mesa

Location: SH 70B Mile Points: 11.75-12.15 Length: 0.31 miles

Schedule: Work Start Date: 10/06/2008 Completion Date: 11/12/2008

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the crash history showed a higher than expected proportion of broadside crashes at the 2 unsignalized accesses of the Peachtree Shopping Center from I-70 Business Loop. There were 26 of these crashes during the five-year (1999 – 2003) period considered in the HSIP application. The eastern access was a full-movement 4-leg unsingalized access, while the western access was a full movement T.

Improvement Description: In fall 2008 a signal was installed at the eastern access, and the western access was modified to a ¾ movement.

The HSIP application anticipated that broadside, approach turn and rear end crashes would be impacted by this improvement. It was anticipated that there would be approximately a 35% crash reduction for these crashes. The expected benefit/cost ratio was estimated to be 1.88.

Summary and Findings

The analysis of safety before and after access improvements, including signalizing a full movement access and converting a full movement access to 3/4 movement found that safety performance was improved in the after period. For these accesses, there were 53 total crashes during the five-year period before the improvement (2003 – 2007). In the five years after construction (2009 – 2013), the number of crashes decreased to 26.

The new signal was apparently responsible for the elimination of broadside crashes at the intersection, but it also was apparently responsible for introducing 3 additional rear end crashes at the intersection in the after period, compared to 12 in the before period. The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 12.44 to one, showing that the improvement was justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 53 during the five-year period (2003 to 2007) before the new signal, with dilemma prevention and fully protected left turns for US 50, was installed (see **Table 1** and **Exhibit 1**) to 26 during the five-year after period (2009 to 2013) (see **Table 1** and **Exhibit 2**). The number of severe crashes also decreased in the five-year period after the improvements:

- Before (2003 – 2007) – 1 fatal crash with 1 fatality and 17 injury crashes with 29 injuries
- After (2009 – 2013) – no fatal crashes and 9 injury crashes with 16 injuries

Despite an increase in traffic volumes at the intersection, the crash rates at the intersection still decreased:

- Before (2003 – 2007): 1.10 crashes per million entering vehicles (cpmev)
- After (2009 – 2013): 0.49 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2003 to 12/31/2007 (5 yr.)	1/1/2009 to 12/31/2013(5 yr.)
AADT (SH 50/28 ½ Rd)	21,364 / 5,000 vpd	24,120 / 5,000 vpd
Filters:	At Intersection Intersection Related At Driveway Access	At Intersection Intersection Related At Driveway Access
Total Crashes	**53**	**26**
Fatal Crashes (Fatalities)	1 (1)	0
Injury Crashes (Injuries)	17 (29)	9 (16)
Property Damage Only	35	17
Crash Types: # (%) [significance]		
Broadside	32 (60.4%) [100.0]	5 (19.2%)
Approach Turn	4 (7.5%)	2 (7.7%)
Rear End	12 (22.6%)	15 (57.7%)

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

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level

of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

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

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

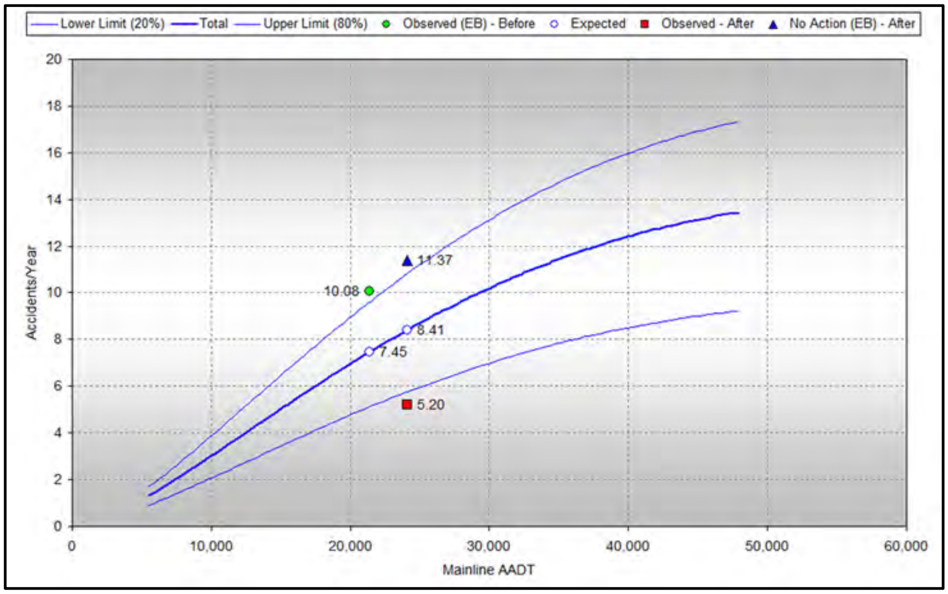
Unfortunately local law enforcement was very inconsistent about what mile-point corresponded to which driveway. There are no other intersections between MP 11.65 and MP 12.18, so all intersection and access crashes within the study limits are considered together – this results in total crashes for 2 locations being lumped together, which is not appropriate for analysis, but serves the purpose for comparison of before and after.

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. The frequency of crashes improved from LOSS IV category for the before period to LOSS I for the after period, while the severity of crashes improved from LOSS IV category for the before period to LOSS II for the after period (see **Table 2**).

Figure 1 - SPF for Total Crashes

SH 70B (MP 11.75-12.15) at Peachtree Center

Before: 2003 thru 2007 After: 2009 thru 2013

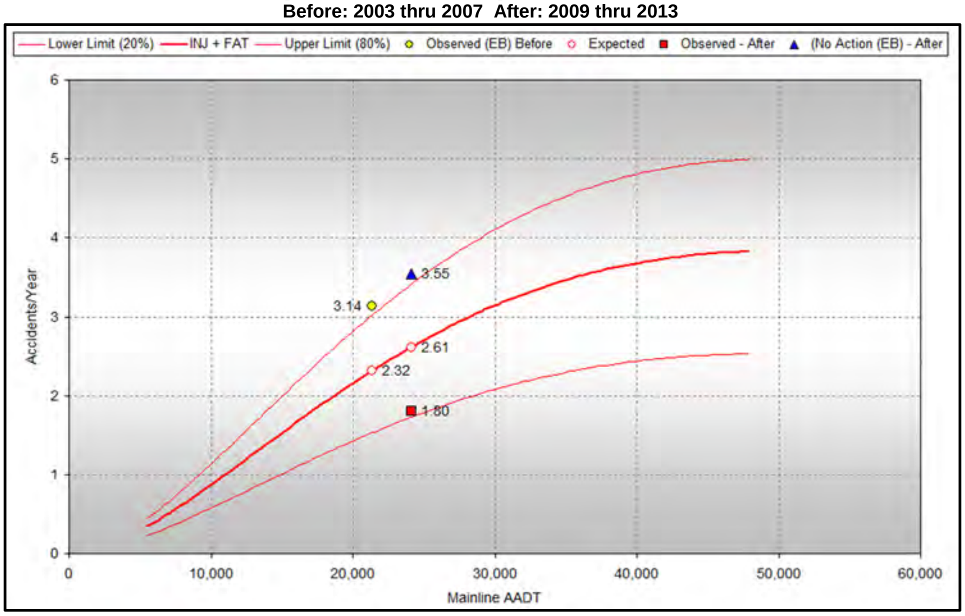


Note: Safety Performance Function (SPF) Model: Colorado – Urban 4-Lane Divided Signalized 4-Leg Intersection

Figure 2 – SPF Injury and Fatal Crashes

SH 70B (MP 11.75-12.15) at Peachtree Center

Before: 2003 thru 2007 After: 2009 thru 2013



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

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection*	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS IV*	LOSS I	LOSS IV*
CPY	10.08	5.20	11.37
Mean CPY	7.45	8.41	8.41
Proportion of Mean	1.35	0.62	1.35
Fatal & Injury Crashes:			
LOSS	LOSS IV*	LOSS II	LOSS IV*
CPY	3.14	1.80	3.55
Mean CPY	2.32	2.61	2.61
Proportion of Mean	1.35	0.69	1.35

**Intersection type changed by project to Signalized, so LOSS shown is not necessarily correct for the Before period, but is shown for comparison only. All Intersection and Access Crashes between MP 11.75 and MP 12.15 are included due to inconsistent identification of specific access location MPs by responding officers.*

A more detailed review of the before and after crash record reveals that improvement in safety can be attributed to the addition of a well-designed signal with fully protected left turns for the mainline. The signal accomplished the intended goals of reducing broadsides and approach turns, but it experienced additional mainline rear end crashes that might be expected when a signal is added. **Table 3** shows a comparison of primary types of crashes that are most directly affected by the improvement: broadside, approach turn and rear end, as well as the total intersection crashes. The No Build After crashes were estimated using the change in mean CPY found in **Table 2** (increase is 1.129 = 8.41/7.45).

Table 3 – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2003 to 12/31/2007 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)	1/1/2009 to 12/31/2013 (5 yr.)
Crash Types:			
Total Crashes	**53**	**26**	**60**
Fatal (fatalities)	1 (1)	0 (0)	1 (1)
Injury (injuries)	17 (29)	9 (16)	19 (33)
PDO	35	17	40
% Reduction in Total (Fatalities/Injuries/PDO)		100% / 52% / 58%	
Broadsides – Total	**32**	**5**	**36**
Fatal (fatalities)	1 (1)	0 (0)	1 (1)
Injury (injuries)	10 (17)	2 (3)	11 (19)
PDO	21	3	24
% Reduction in Total (Fatalities/Injuries/PDO)		100% / 84% / 88%	
Approach Turns - Total	**4**	**2**	**5**
Injury (injuries)	1 (2)	0 (0)	1 (2)
PDO	3	2	3
% Reduction in Total (Injuries/PDO)		100% / 33%	
Rear Ends – Total	**12**	**15**	**14**
Injury (injuries)	5 (8)	7 (13)	6 (9)
PDO	7	8	8
% Reduction in Total (Injuries/PDO)		-44% / 0%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crash types. As shown, the B/C ratio for the intersection, intersection related and driveway access crashes is 12.44, showing that the improvement was justified.

Figure 3 – Benefit Cost Analysis – Intersection and Intersection Related Crashes Only

COLORADO Department of Transportation

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

11/14/2016

Job #: 20161114145609

Location: 70B **Begin:** 11.75 **End:** 12.15 **From:** 01/01/2003 **To:** 12/31/2007

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	31		Weighted PDO:	6.80	88% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	16	27 :Injured	Weighted INJ:	5.93	84% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	1	1 :Killed	Weighted FAT:	0.22	100% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	86% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	10
						Capital Recovery Factor:	0.129
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 488,464
From: 01/01/2003
To: 12/31/2007 Days: 1826

Benefit Cost Ratio: 12.44 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: ACCESS IMPROVEMENTS (NEW SIGNAL + TURN RESTRICTIONS)
Special Notes:

Location: 70B **Begin:** 11.75 **End:** 12.15 **From:** 01/01/2003 **To:** 12/31/2007

Severity

PDO:	35	
INJ:	17	29 :Injured
FAT:	1	1 :Killed
Total:	**53**	

Number of Vehicles

One Vehicle:	2
Two Vehicles:	48
Three or More:	3
Unknown:	0
Total:	**53**

Location

On Road:	50
Off Road Left:	2
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**53**

Lighting Conditions

Daylight:	41
Dawn or Dusk:	2
Dark - Lighted:	8
Dark - Unlighted:	2
Unknown:	0
Total:	**53**

Weather Conditions

None:	53
Rain:	0
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**53**

Crash Rates

PDO:	2.78 *
INJ:	1.35 *
FAT:	7.94 **
Total:	**4.21** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	32	Embankment:	0
Head On:	0	Curb:	1
Rear End:	12	Delineator Post:	0
Sideswipe (Same):	1	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	4	Large Boulders or Rocks:	0
Overtaking Turn:	1	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	3
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	2	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**53**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	52
Crossroad (A):	0

Frontage/Ramp Intersections

M:	1	N:	0	O:	0	P:	0

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**53**

Road Description

At Intersection:	8
At Driveway Access:	35
Intersection Related:	10
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**53**

Road Conditions

Dry:	51
Wet:	2
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**53**

ADT: 21,364 **Length:** 0.32

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

Job #: 20161114165427

Location: 70B **Begin:** 11.75 **End:** 12.15 **From:** 01/01/2003 **To:** 12/31/2007

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	30	37	1
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	16	8	2
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	2	2	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	4	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	2	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	1	0
Total:	**53**	**51**	**3**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	14	49	3
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	6	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	25	1	0
Driver Unfamilar with Area:	5	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	1	0	0
Unknown:	0	1	0
Total:	**53**	**51**	**3**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	53	51	3
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**53**	**51**	**3**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	14	34	1
Slowing:	1	3	1
Stopped in Traffic:	0	8	1
Making Right Turn:	2	1	0
Making Left Turn:	34	3	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	2	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**53**	**51**	**3**

Direction	Veh 1	Veh 2	Veh 3
North:	21	9	0
Northeast:	0	1	0
East:	12	25	2
Southeast:	0	0	0
South:	2	5	0
Southwest:	0	0	0
West:	17	11	1
Northwest:	1	0	0
Unknown:	0	0	0
Total:	**53**	**51**	**3**

ADT: 21,364 **Length:** 0.32

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

Exhibit 2

11/14/2016

Job #: 20161114165543

Location: 70B **Begin:** 11.75 **End:** 12.15 **From:** 01/01/2009 **To:** 12/31/2013

Severity

PDO:	17	
INJ:	9	16 :Injured
FAT:	0	0 :Killed
Total:	**26**	

Number of Vehicles

One Vehicle:	0
Two Vehicles:	20
Three or More:	6
Unknown:	0
Total:	**26**

Location

On Road:	25
Off Road Left:	0
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**26**

Lighting Conditions

Daylight:	19
Dawn or Dusk:	2
Dark - Lighted:	5
Dark - Unlighted:	0
Unknown:	0
Total:	**26**

Weather Conditions

None:	26
Rain:	0
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**26**

Crash Rates

PDO:	1.22 *
INJ:	0.64 *
FAT:	0.00 **
Total:	**1.86** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	5	Embankment:	0
Head On:	0	Curb:	0
Rear End:	15	Delineator Post:	0
Sideswipe (Same):	2	Fence:	1
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	2	Large Boulders or Rocks:	0
Overtaking Turn:	1	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**26**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	24
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

B:	0	F:	0	J:	0
C:	0	G:	0	K:	0
D:	0	H:	0	L:	2
E:	0	I:	0		

Left Frontage Rd (L):	2
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**26**

Road Description

At Intersection:	8
At Driveway Access:	4
Intersection Related:	14
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**26**

Road Conditions

Dry:	25
Wet:	1
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**26**

ADT: 24,120 **Length:** 0.31

Location: 70B **Begin:** 11.75 **End:** 12.15 **From:** 01/01/2009 **To:** 12/31/2013

Vehicle Type

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	14	16	4
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	5	7	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	5	2	2
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	1	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**26**	**26**	**6**

Vehicle Movement

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	18	8	1
Slowing:	1	0	0
Stopped in Traffic:	0	13	4
Making Right Turn:	2	0	0
Making Left Turn:	3	4	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	1
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	1	1	0
Unknown:	0	0	0
Total:	**26**	**26**	**6**

Contributing Factor

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	8	26	6
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	3	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	4	0	0
Driver Unfamilar with Area:	2	0	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	7	0	0
Total:	**26**	**26**	**6**

Direction

Direction	Veh 1	Veh 2	Veh 3
North:	1	4	2
Northeast:	0	0	0
East:	13	10	1
Southeast:	0	0	0
South:	3	2	0
Southwest:	0	0	0
West:	9	10	3
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**26**	**26**	**6**

Condition of Driver

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	23	26	6
Alcohol Involved:	2	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**26**	**26**	**6**

ADT: 24,120 **Length:** 0.31

Project Information

Project Name:	I-225 Median Cable Barrier Installation	
Project Description:	Install Cable Barrier on I-225 and Concrete Barrier on SH 83	
CDOT Region: 6	Project Def: 16878	County: Arapahoe
Location: I-225 SH 83	Mile Points: 4.17 – 6.79 66.98 – 67.98	Length: 2.63 miles 1.00 miles
Schedule:	Work Start Date: 7/26/2009	Completion Date: 11/20/2009

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history (2000 – 2004) showed that there was a total of 23 crashes that were head-on, sideswipe opposite direction, or off road in the median. These 23 crashes included 12 PDO crashes, 10 injury crashes, and one fatal crash.

Improvement Description: Between July 26, 2009 and November 20, 2009, a cable rail was installed in the median on I-225 between MP 4.17 and MP 6.79. Additionally, a concrete barrier was installed in the median of SH 83 between MP 66.98 and MP 67.98. The cost of construction was $1,151,131.

The HSIP application anticipated that a 40% reduction in injury crashes and a 60% reduction in fatal crashes might be realized by the improvement. The initial benefit/cost ratio was estimated to be 2.11.

Summary and Findings

The analysis of safety before and after the cable rail on I-225 and concrete barrier on SH 83 showed a reduction in the crashes overturning in the median or crossing into oncoming traffic. However, there also was an increase in fixed object crashes due to the cable rail and concrete barrier.

Along the study segment of 4-lane divided highway on I-225, there were 112 total crashes during the two-year period before the cable rail was installed (7/1/07 to 6/30/09). In the two years after construction (12/1/09 to 11/30/11), the number of crashes increased to 152. While along the study segment of 4-lane divided highway on SH 83, there were 14 crashes during the before period and 26 crashes during the after period.

A comparison of overturning, head-on, and sideswipe opposite direction type crashes before and after the installation of the cable rail and concrete barrier showed that there was a decrease in injuries and fatalities. The ratio of benefits and cost for this project shows that benefits outweighed the cost as the B/C ratio was 20.55 to one. The result is the improvement was likely justified from an economic standpoint.

Results of Safety Analyses

For this analysis, only a two-year period before and after the improvements were used for crash data. Two years after the initial improvements, I-225 underwent major construction that involved adding lanes, constructing light rail, and changing the median from depressed with a cable rail to level with a concrete barrier. The construction period and changes made to the road made any further crash data irrelevant to this study. For consistency, the same two years of crash data were used for SH 83 as well.

Using Vision Zero Suite, the review of before and after crash records shows an increase in the number of crashes on both study corridors. On I-225 the total number of mainline crashes increased from 112 during the two-year period (7/1/07 to 6/30/09) before the cable rail was installed (see **Table 1** and **Exhibit 1**) to 152 during the two-year after period (12/1/09 to 11/30/11) (see **Table 1** and **Exhibit 2**). The number of injuries and fatalities also increased on I-225:

- Before (7/1/07 to 6/30/09) – 1 fatal crash with 1 fatality and 32 injury crashes with 50 injuries
- After (12/1/09 to 11/30/11) –2 fatal crashes with 2 fatalities and 41 injury crashes with 56 injuries

The cable rail crash type contributed to the increase in number of crashes with 11 crashes in the after period. There were no cable rail crashes in the before period. It is likely the cable rail prevented more severe crashes by keeping vehicles from traveling into oncoming traffic.

Table 1 – I-225 (MP 4.17 to MP 6.79) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	7/1/2007 to 6/30/09 (2 yr.)	12/1/09 to 11/30/11 (2 yr.)
AADT	108,085 vpd	105,850 vpd
Filters:	Mainline, Non-Intersection	Mainline, Non-Intersection
Total Crashes	**112**	**152**
Fatal Crashes (Fatalities)	1 (1)	2 (2)
Injury Crashes (Injuries)	32 (50)	41 (56)
Property Damage Only	79	109
Crash Types: # (% of total crashes) [cumulative probability]		
Rear-End	62 (55.4%)	96 (63.2%) [97.99%]
Sideswipe Same	22 (19.6%) [99.85%]	8 (5.3%)
Fixed Objects	10 (8.9%)	31 (20.4%) [97.82%]
Overturning	10 (8.9%) [99.80%]	11 (7.2%) [99.71%]
Head-On	3 (2.7%)	0
Fixed Object Crashes: # (% of FO) [cumulative probability]		
Fence	4 (40.0%)	0
Guardrail	3 (30%)	9 (29.0%) [98.98%]
Concrete Barrier	1 (10.0%)	4 (12.0%)
Cable Rail	0	11 (35.5%) [99.87%]

On SH 83, the total number of crashes also increased. There were 14 crashes during the two-year period before the concrete barrier was installed (see **Table 2** and **Exhibit 3**) and 26 crashes during the two-year period after the installation (see **Table 2** and **Exhibit 4**). The number of injuries increase while the number of fatalities decreased on SH 83:

- Before (7/1/07 to 6/30/09) – 1 fatal crash with 3 fatalities and 4 injury crashes with 4 injuries
- After (12/1/09 to 11/30/11) –0 fatal crashes and 10 injury crashes with 14 injuries

The concrete barrier crash type contributed to the increase in number of crashes with 5 crashes in the after period. There were no concrete barrier crashes in the before period. It is likely the concrete barrier prevented more severe crashes by keeping vehicles from traveling into oncoming traffic.

Table 2 – SH 83 (MP 66.98 to MP 67.98) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	7/1/2007 to 6/30/09 (2 yr.)	12/1/09 to 11/30/11 (2 yr.)
AADT	42,700 vpd	41,500 vpd
Filters:	Mainline	Mainline
Total Crashes	**14**	**26**
Fatal Crashes (Fatalities)	1 (3)	0
Injury Crashes (Injuries)	4 (4)	10 (14)
Property Damage Only	9	16
Crash Types: # (% of total crashes) [cumulative probability]		
Rear-End	5 (35.7%) [98.94%]	10 (38.5%) [99.94%]
Fixed Objects	3 (21.4%)	7 (26.9%)
Sideswipe Same	2 (14.3%)	3 (11.5%)
Head-On	2 (14.3%)	0
Sideswipe Opposite	1 (7.1%)	0
Overturning	1 (7.1%)	3 (11.5%)
Fixed Object Crashes: # (% of FO) [cumulative probability]		
Fence	1 (33.3%)	0
Guardrail	1 (33.3%)	0
Curb	1 (33.3%)	0
Concrete Barrier	0	5 (71.4%) [99.80%]

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

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

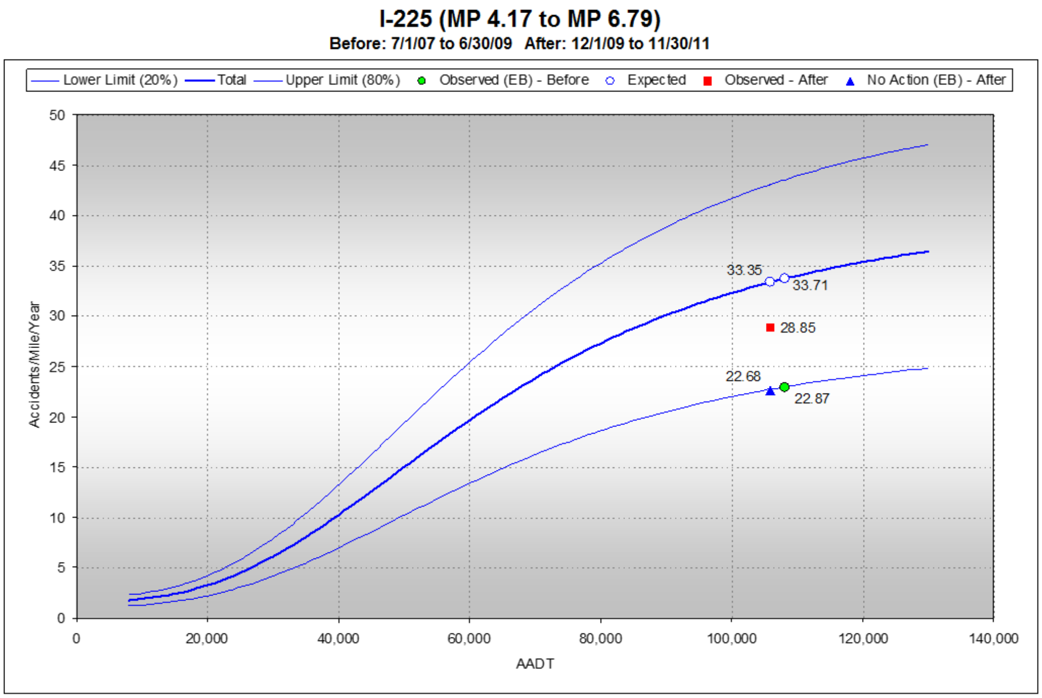
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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

I-225 SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) reflect the increase in crashes and severity of crashes. The frequency of crashes increased from the LOSS I/LOSS II boundary line to the LOSS II category. For the severity of crashes, LOSS remained in the LOSS II category for both the before and after periods. **Table 3** provides the results of the I-225 SPF analysis. It should be noted that the increase in crashes cannot be attributed to the construction of the cable rail. Other factors, possibly construction in the corridor are likely the cause as there were 8 crashes reported as construction related in the after period; while there were no construction related crashes in the before period.

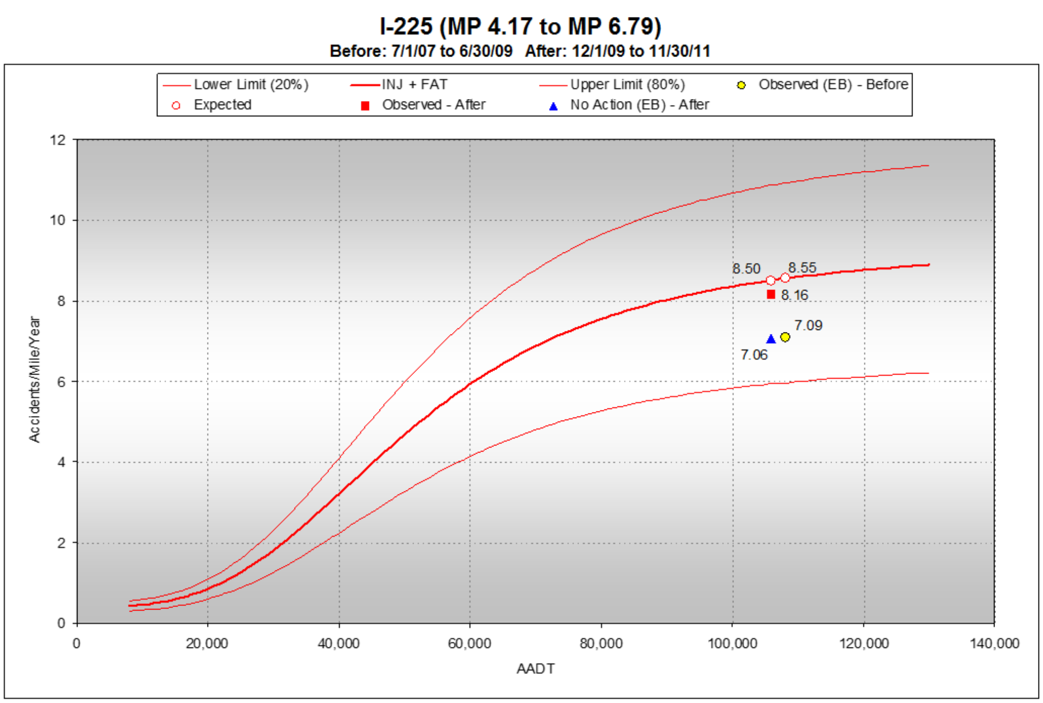
Total crash (see **Figure 3**) fatal and injury crash (see **Figure 4**) SPF plots were prepared for SH 83 as well. These also reflect the increase in frequency and severity of crashes. The frequency of crashes increased from the LOSS II category in the before period to the LOSS III category in the after period. The severity of crashes increased from the LOSS II category for the before period to the LOSS IV category for the after period. **Table 4** provides the results of the SPF analysis for SH 83.

Figure 1 - SPF for Total Crashes

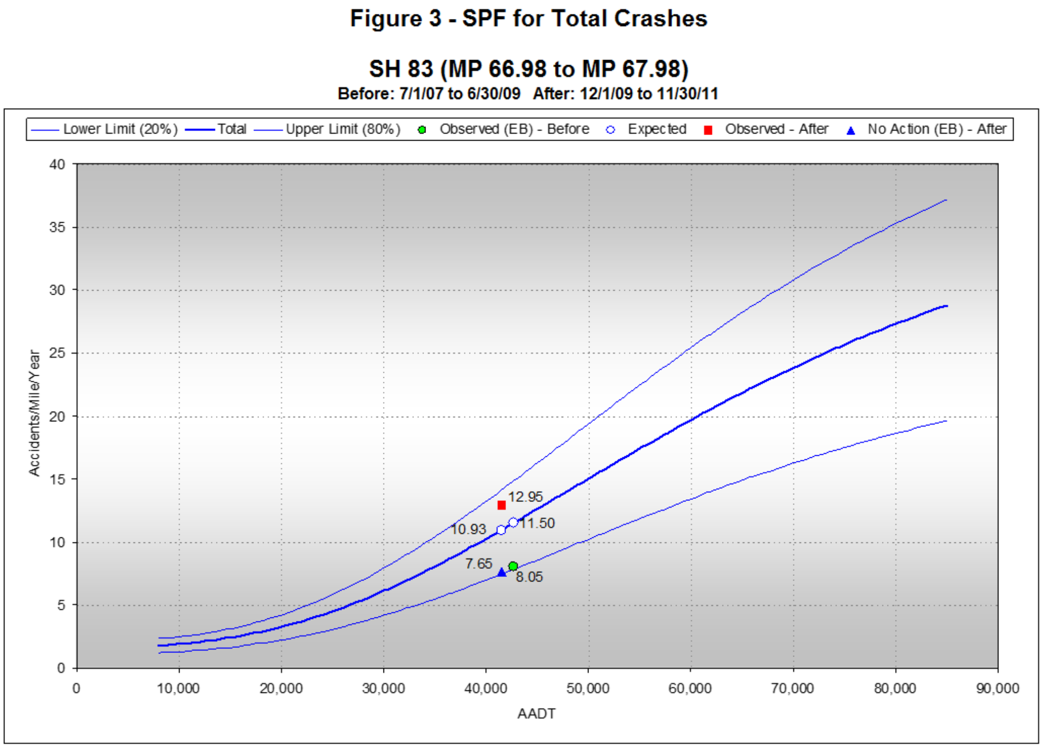


Note: Safety Performance Function (SPF) Model: Colorado - Urban Flat Rolling Mountainous 4-Lane Divided Freeway

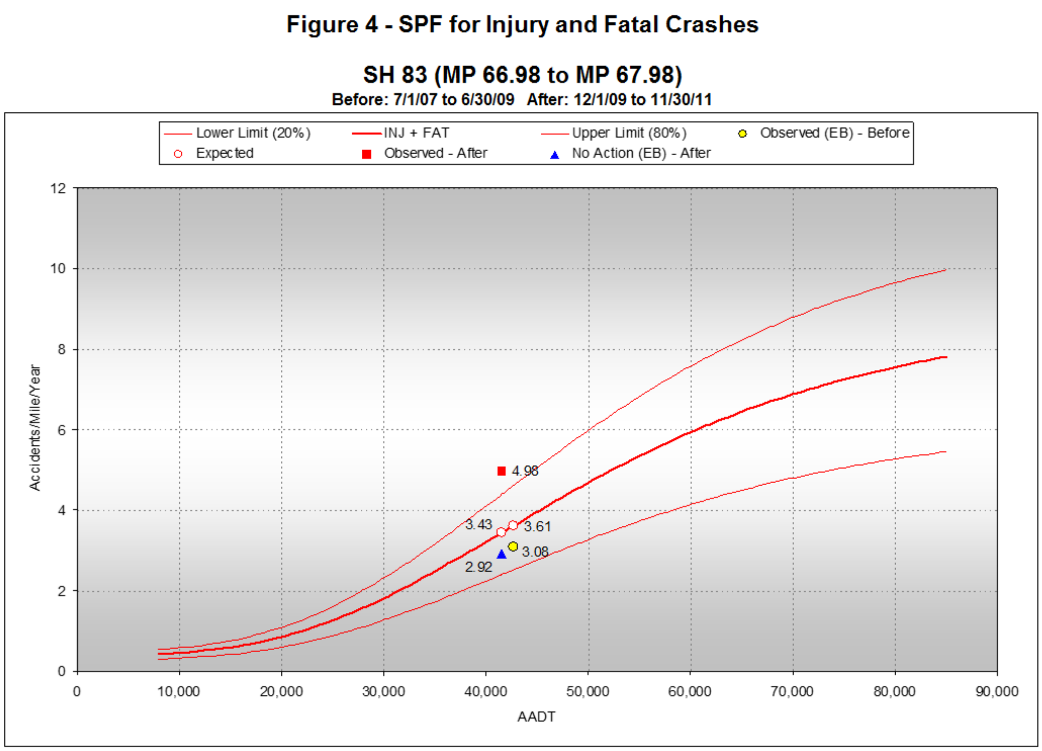
Figure 2 - SPF for Injury and Fatal Crashes



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



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



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

Table 3 – I-225 (MP 4.17 to MP 6.79) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, Flat Rolling Mountainous, 4-lane Divided Freeway	Urban, Flat Rolling Mountainous, 4-lane Divided Freeway	Urban, Flat Rolling Mountainous, 4-lane Divided Freeway
Total Crashes:			
LOSS	LOSS I/II	LOSS II	LOSS I/II
CPMPY	22.87	28.85	22.68
Mean CPMPY	33.71	33.35	33.35
Proportion of Mean	0.68	0.87	0.68
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS II	LOSS II
CPMPY	7.09	8.16	7.06
Mean CPMPY	8.55	8.50	8.50
Proportion of Mean	0.83	0.96	0.83

Table 4 – SH 83 (MP 66.98 to MP 67.98) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, Flat Rolling Mountainous, 4-lane Divided Freeway	Urban, Flat Rolling Mountainous, 4-lane Divided Freeway	Urban, Flat Rolling Mountainous, 4-lane Divided Freeway
Total Crashes:			
LOSS	LOSS II	LOSS III	LOSS II
CPMPY	8.05	12.95	7.65
Mean CPMPY	11.50	10.93	10.93
Proportion of Mean	0.70	1.18	0.70
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS IV	LOSS II
CPMPY	3.08	4.98	2.92
Mean CPMPY	3.61	3.43	3.43
Proportion of Mean	0.85	1.45	0.85

A more detailed review of the before and after crash record on I-225 reveals that the reduction in head-on and overturning crashes can be attributed to the installation of the cable rail. **Table 5** provides a comparison of the overturning and head-on crashes. There were no sideswipe opposite direction crashes in the before period, so those were not included in the analysis. The No Build After crashes were estimated using the increase in the mean of the SPF for total crashes found in **Table 3** (decrease is 0.99 = 33.35/33.71). **Table 5** shows a decrease in head-on and overturning crashes prevented by cable rail. However, there was a large number of cable rail crashes in the after period.

Table 5 – I-225 (MP 4.17 to MP 6.79) - Results of Cable Rail Crash Analyses

	Before	After	No Build After
Time Period:	7/1/2007 to 6/30/09 (2 yr.)	12/1/09 to 11/30/11 (2 yr.)	12/1/09 to 11/30/11 (2 yr.)
Crash Types:			
Head-On – Total	**3**	**0**	**3**
Fatal (fatalities)	1 (1)	0	1 (1)
Injury (injuries)	1 (2)	0	1 (2)
PDO	1	0	1
% Reduction in Total		100%	
Overturning – Total (off-left/off-median only)	**2**	**1**	**2**
Injury (injuries)	2 (7)	1 (1)	2 (7)
PDO	0	0	0
% Reduction in Total – (Injuries/ PDO)		85% / 100%	
Cable Rail – Total (off-left/off-median only)	**0**	**11**	**0**
Fatal (Fatalities)	0	0	0
Injury (injuries)	0	1 (1)	0
PDO	0	10	0

A review of the before and after crash record on SH 83 reveals that the reduction in head-on and sideswipe opposite direction crashes can be attributed to the installation of the concrete barrier. **Table 6** provides a comparison of the sideswipe opposite direction and head-on crashes. There were no overturning crashes in the median in the before period, so those were not included in the analysis. The No Build After crashes were estimated using the increase in the mean of the SPF for total crashes found in **Table 4** (decrease is 0.95 = 10.93/11.50). **Table 6** shows all head-on and sideswipe opposite direction crashes were prevented by the concrete barrier. However, there were concrete barrier crashes in the after period, although these likely prevented more severe crashes.

Table 6 – SH 83 (MP 66.98 to MP 67.98) - Results of Concrete Barrier Crash Analyses

	Before	**After**	**No Build After**
Time Period:	7/1/2007 to 6/30/09 (2 yr.)	12/1/09 to 11/30/11 (2 yr.)	12/1/09 to 11/30/11 (2 yr.)
Crash Types:			
Head-On – Total	**2**	**0**	**2**
Fatal (fatalities)	1 (3)	0	1 (3)
Injury (injuries)	0	0	0
PDO	1	0	1
% Reduction in Total		100%	
Sideswipe (Opp.)– Total	**1**	**0**	**1**
PDO	1	0	1
% Reduction in Total		100%	
Concrete Barrier – Total (off-left/off-median only)	**0**	**5**	**0**
Fatal (Fatalities)	0	0	0
Injury (injuries)	0	1 (1)	0
PDO	0	4	0

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for the cable rail improvement on I-225. Cable rail causes new crashes since it creates a barrier in the median. The increase in cable rail crashes was factored into the analysis by increasing the cost of construction for the cable rail. During the two-year after period, there were 1 injury and 10 property damage only cable rail crashes. Over the design life of 20 years for the cable rail system, the increased cost of crashes would be $1,737,000 (100 PDO = $930,000 and 10 injuries = $807,000). It seems that a cable rail was replaced with a concrete barrier only a few years following construction, however if it were to remain in place for 20 years the B/C would've been 5.71 (See **Figure 5**).

Figure 6 provides the B/C analysis for the concrete barrier improvement on SH 83. Like the cable rail, concrete barrier also causes new crashes because it creates a new barrier in the median. The increase in concrete barrier crashes was also factored in by increasing the cost of construction for the project. During the two-year after period, there were 1 injury and 4 property damage only concrete barrier crashes. Over the design life of 20 years for the barrier, the increased cost of crashes would be $1,179,000 (40 PDO = $372,000 and 10 injuries = $807,000). As shown in **Figure 6**, the B/C ratio for the concrete barrier is 14.84. When combined with the cable rail improvement, the resulting B/C ratio for the safety project is 20.55 (5.71 + 14.84), showing that the improvement was certainly justified.

Figure 5 – I-225 ((MP 4.17 to MP 6.79) - Benefit Cost Analysis – Overturning and Head-on Crash Types Only

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

08/19/2016

Job #: 20160819164034

Location: 225A **Begin:** 4.17 **End:** 6.79 **From:** 07/01/2007 **To:** 06/30/2009

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	1		Weighted PDO:	0.61	100% : CRF for PDO	Cost of PDO:	$ 9,300
INJ:	3	9 : Injured	Weighted INJ:	5.53	89% : CRF for INJ	Cost of INJ:	$ 80,700
FAT:	1	1 : Killed	Weighted FAT:	0.61	100% : CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	2.00	93% : Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 2,888,131
From: 07/01/2007
To: 06/30/2009 Days: 731

Benefit Cost Ratio: 5.71 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: CABLE RAIL - HEAD_ON AND OVERTURNING CRASHES
Special Notes: COST OF 10 INJ AND 100 PDO CABLE RAIL CRASHES ADDED TO CONSTRUCTION

Figure 6 – SH 83 (MP 66.98 to MP 67.98) - Benefit Cost Analysis – Sideswipe Opposite and Head-on Crash Types Only

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

08/19/2016

Job #: 20160819165755

Location: 83A **Begin:** 66.98 **End:** 67.98 **From:** 07/01/2007 **To:** 06/30/2009

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	2		Weighted PDO:	1.23	100% : CRF for PDO	Cost of PDO:	$ 9,300
INJ:	0	0 : Injured	Weighted INJ:	0.00	100% : CRF for INJ	Cost of INJ:	$ 80,700
FAT:	1	3 : Killed	Weighted FAT:	1.84	100% : CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	2.00	100% : Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 2,330,131
From: 07/01/2007
To: 06/30/2009 Days: 731

Benefit Cost Ratio: 14.84 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: CONCRETE BARRIER - HEAD-ON AND SIDESWIPE OPPOSITE CRASHES
Special Notes: COST OF 10 INJ AND 40 PDO CABLE RAIL CRASHES ADDED TO CONSTRUCTION

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

Exhibit 1

08/16/2016

Job #: 20160816155301

Location: 225A **Begin:** 4.17 **End:** 6.79 **From:** 07/01/2007 **To:** 06/30/2009

Severity

PDO:	79		
INJ:	32	50	:Injured
FAT:	1	1	:Killed
Total:	**112**		

Number of Vehicles

One Vehicle:	19
Two Vehicles:	69
Three or More:	24
Unknown:	0
Total:	**112**

Location

On Road:	92
Off Road Left:	6
Off Road Right:	10
Off Road at Tee:	0
Off in Median:	3
Unknown:	1
Total:	**112**

Lighting Conditions

Daylight:	78
Dawn or Dusk:	5
Dark - Lighted:	16
Dark - Unlighted:	10
Unknown:	3
Total:	**112**

Weather Conditions

None:	96
Rain:	4
Snow/Sleet/Hail:	12
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**112**

Crash Rates

PDO:	0.39 *
INJ:	0.16 *
FAT:	0.49 **
Total:	**0.55** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	10	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	1
Head On:	3	Curb:	0
Rear End:	62	Delineator Post:	0
Sideswipe (Same):	22	Fence:	4
Sideswipe (Opposite):	0	Tree:	1
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	10
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	3
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	1
Bridge Rail:	0	Total Other Objects:	4
Guard Rail:	3	Unknown:	0
Cable Rail:	0	**Total:**	**112**
Concrete Barrier:	1		

Mainline/Ramps/Frontage Roads

Mainline:	112
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**112**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	112
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**112**

Road Conditions

Dry:	86
Wet:	5
Muddy:	1
Snowy:	6
Icy:	9
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	1
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	2
Total:	**112**

ADT: 108,085 **Length:** 2.57

Location: 225A **Begin:** 4.17 **End:** 6.79 **From:** 07/01/2007 **To:** 06/30/2009

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	63	54	15
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	12	12	6
Pickup Truck/Utility Van w/Trl:	3	1	0
SUV:	23	25	2
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	6	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	2	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	1	0	0
Unknown:	0	0	1
Total:	**112**	**93**	**24**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	66	85	23
Asleep at the Wheel:	3	0	0
Illness:	2	0	0
Distracted by Passenger:	3	1	0
Driver Inexperience:	3	1	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	10	1	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	2	0	0
Unknown:	23	5	1
Total:	**112**	**93**	**24**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	106	93	24
Alcohol Involved:	5	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**112**	**93**	**24**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	59	39	5
Slowing:	16	32	7
Stopped in Traffic:	1	21	11
Making Right Turn:	1	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	3	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	17	1	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	4	0	0
Other:	9	0	0
Unknown:	2	0	1
Total:	**112**	**93**	**24**

Direction	Veh 1	Veh 2	Veh 3
North:	77	63	20
Northeast:	0	0	0
East:	0	0	0
Southeast:	0	0	0
South:	33	28	3
Southwest:	2	2	0
West:	0	0	0
Northwest:	0	0	0
Unknown:	0	0	1
Total:	**112**	**93**	**24**

ADT: 108,085 **Length:** 2.57

Location: 225A **Begin:** 4.17 **End:** 6.79 **From:**12/01/2009 **To:**11/30/2011

Severity

PDO:	109	
INJ:	41	56 :Injured
FAT:	2	2 :Killed
Total:	**152**	

Number of Vehicles

One Vehicle:	38
Two Vehicles:	79
Three or More:	35
Unknown:	0
Total:	**152**

Location

On Road:	112
Off Road Left:	20
Off Road Right:	19
Off Road at Tee:	0
Off in Median:	1
Unknown:	0
Total:	**152**

Lighting Conditions

Daylight:	108
Dawn or Dusk:	7
Dark - Lighted:	21
Dark - Unlighted:	16
Unknown:	0
Total:	**152**

Weather Conditions

None:	139
Rain:	8
Snow/Sleet/Hail:	5
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**152**

Crash Rates

PDO:	0.54 *
INJ:	0.20 *
FAT:	0.98 **
Total:	**0.75** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	11	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	1	Culvert/Headwall:	0
Broadside:	0	Embankment:	1
Head On:	0	Curb:	0
Rear End:	96	Delineator Post:	1
Sideswipe (Same):	8	Fence:	1
Sideswipe (Opposite):	1	Tree:	1
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	3	Wall/Building:	1
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	31
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	1
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	1
Guard Rail:	9	Unknown:	0
Cable Rail:	11	**Total:**	**152**
Concrete Barrier:	4		

Mainline/Ramps/Frontage Roads

Mainline:	152
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**152**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	152
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**152**

Road Conditions

Dry:	130
Wet:	11
Muddy:	0
Snowy:	3
Icy:	6
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**152**

ADT: 105,850 **Length:** 2.63

Location: 225A **Begin:** 4.17 **End:** 6.79 **From:** 12/01/2009 **To:** 11/30/2011

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	86	61	23
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	13	13	2
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	44	34	9
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	4	5	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	2	1	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	2	0	1
Other:	1	0	0
Unknown:	0	0	0
Total:	**152**	**114**	**35**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	105	21	7
Slowing:	12	49	4
Stopped in Traffic:	0	41	24
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	2	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	3	0
Changing Lanes:	13	0	0
Avoiding Object/Veh in Road:	1	0	0
Weaving:	3	0	0
Other:	15	0	0
Unknown:	1	0	0
Total:	**152**	**114**	**35**

Direction	Veh 1	Veh 2	Veh 3
North:	105	88	28
Northeast:	0	0	0
East:	0	0	0
Southeast:	0	0	0
South:	45	26	7
Southwest:	1	0	0
West:	1	0	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**152**	**114**	**35**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	47	113	33
Asleep at the Wheel:	5	0	0
Illness:	2	0	0
Distracted by Passenger:	11	0	0
Driver Inexperience:	3	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	20	0	2
Driver Unfamilar with Area:	21	1	0
Driver Emotionally Upset:	4	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	39	0	0
Total:	**152**	**114**	**35**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	141	113	34
Alcohol Involved:	7	0	1
RX, Medication, or Drugs Involved:	1	1	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	3	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**152**	**114**	**35**

ADT: 105,850 **Length:** 2.63

Location: 83A **Begin:** 66.98 **End:** 67.98 **From:** 07/01/2007 **To:** 06/30/2009

Severity

PDO:	9	
INJ:	4	4 :Injured
FAT:	1	3 :Killed
Total:	**14**	

Number of Vehicles

One Vehicle:	4
Two Vehicles:	6
Three or More:	4
Unknown:	0
Total:	**14**

Location

On Road:	10
Off Road Left:	2
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	1
Unknown:	0
Total:	**14**

Lighting Conditions

Daylight:	10
Dawn or Dusk:	0
Dark - Lighted:	1
Dark - Unlighted:	3
Unknown:	0
Total:	**14**

Weather Conditions

None:	7
Rain:	2
Snow/Sleet/Hail:	5
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**14**

Crash Rates

PDO:	0.29 *
INJ:	0.13 *
FAT:	3.19 **
Total:	**0.45** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	14
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**14**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	14
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**14**

Road Conditions

Dry:	8
Wet:	4
Muddy:	0
Snowy:	1
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**14**

ADT: 42,700 **Length:** 1.00

Location: 83A **Begin:** 66.98 **End:** 67.98 **From:** 07/01/2007 **To:** 06/30/2009

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	8	5	0
Passenger Car/Van w/Trl:	0	0	1
Pickup Truck/Utility Van:	2	1	2
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	4	4	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**14**	**10**	**4**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	9	10	4
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	2	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	2	0	0
Total:	**14**	**10**	**4**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	13	10	4
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**14**	**10**	**4**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	7	3	2
Slowing:	0	2	1
Stopped in Traffic:	0	1	0
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	1	2	1
Weaving:	0	0	0
Other:	5	2	0
Unknown:	1	0	0
Total:	**14**	**10**	**4**

Direction	Veh 1	Veh 2	Veh 3
North:	4	2	1
Northeast:	0	0	0
East:	0	0	0
Southeast:	5	3	1
South:	4	4	2
Southwest:	0	0	0
West:	0	0	0
Northwest:	1	1	0
Unknown:	0	0	0
Total:	**14**	**10**	**4**

ADT: 42,700 **Length:** 1.00

Location: 83A **Begin:** 66.98 **End:** 67.98 **From:** 12/01/2009 **To:** 11/30/2011

Severity

PDO:	16		
INJ:	10	14	:Injured
FAT:	0	0	:Killed
Total:	**26**		

Number of Vehicles

One Vehicle:	12
Two Vehicles:	13
Three or More:	1
Unknown:	0
Total:	**26**

Location

On Road:	16
Off Road Left:	4
Off Road Right:	5
Off Road at Tee:	0
Off in Median:	1
Unknown:	0
Total:	**26**

Lighting Conditions

Daylight:	19
Dawn or Dusk:	0
Dark - Lighted:	3
Dark - Unlighted:	4
Unknown:	0
Total:	**26**

Weather Conditions

None:	21
Rain:	2
Snow/Sleet/Hail:	2
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**26**

Crash Rates

PDO:	0.53	*
INJ:	0.33	*
FAT:	0.00	**
Total:	**0.85**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	3	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	0
Head On:	0	Curb:	0
Rear End:	10	Delineator Post:	0
Sideswipe (Same):	3	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	1	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	7
Wild Animal:	2	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**26**
Concrete Barrier:	5		

Mainline/Ramps/Frontage Roads

Mainline:	26
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**26**

Road Description

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

Road Conditions

Dry:	21
Wet:	3
Muddy:	0
Snowy:	2
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**26**

ADT: 41,500 **Length:** 1.00

Location: 83A **Begin:** 66.98 **End:** 67.98 **From:** 12/01/2009 **To:** 11/30/2011

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	18	9	1
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	3	1	0
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	2	4	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**26**	**14**	**1**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	8	13	1
Asleep at the Wheel:	0	0	0
Illness:	2	0	0
Distracted by Passenger:	3	0	0
Driver Inexperience:	2	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	6	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	5	1	0
Total:	**26**	**14**	**1**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	23	14	1
Alcohol Involved:	2	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**26**	**14**	**1**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	16	6	1
Slowing:	2	5	0
Stopped in Traffic:	0	2	0
Making Right Turn:	0	0	0
Making Left Turn:	1	0	0
Making U-Turn:	0	0	0
Passing:	1	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	0
Changing Lanes:	2	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	4	0	0
Unknown:	0	0	0
Total:	**26**	**14**	**1**

Direction	Veh 1	Veh 2	Veh 3
North:	10	4	0
Northeast:	0	0	0
East:	0	0	0
Southeast:	4	2	0
South:	10	7	1
Southwest:	0	0	0
West:	0	0	0
Northwest:	2	1	0
Unknown:	0	0	0
Total:	**26**	**14**	**1**

ADT: 41,500 **Length:** 1.00

Project Information

Project Name: SH 121 Conduit and Signal Improvement

Project Description: Traffic Signal Upgrade at Chatfield and F/O Conduit on SH 121

CDOT Region: 6 Project Def: 16941 County: Jefferson

Location: SH 121A Mile Points: 1.22 Length: N/A

Schedule: Work Start Date: 10/26/2009 Completion Date: 4/12/2010

Problem Description: The crash history showed a higher than expected number of broadsides at the intersection of SH 121 and Chatfield Avenue. During the 3 years of crash data (2001 – 2003), there were 27 property damage only and 19 injury crashes. Of these crashes, there were 12 broadsides, one pedestrian, and one bicycle crash.

Improvement Description: Between October 2009 and April 2010, the span wire was replaced with mast arms. In addition, traffic signal heads were replaced with LED signals with back-plates. A new detection system was installed with dilemma zone preemption and new pavement markings were placed for lanes, crosswalks, and stop bars. The cost of construction was $402,001.

It was anticipated that the primary crash types impacted by this improvement would be rear-end, approach turn, broadside, and pedestrian type crashes. It was anticipated that there would be a 15% crash reduction for these crash types. The initial benefit/cost ratio was estimated to be 1.24.

Summary and Findings

The analysis of safety before and after the signal improvements showed safety improved for broadsides and approach turns. The total crashes at the intersection decreased, as did the severity of crashes. For this intersection, there were 48 total crashes during the four-year period before the upgrades (2005 – 2008). In the four years after construction (2011 – 2014), the number of crashes decreased to 39. During that same time period, injuries decreased from 25 to 13. Traffic volumes also slightly decreased between the before and after periods.

The signal improvements were responsible for significant decreases in the number of broadside crashes and the severity of approach turn crashes. But, there was an increase in rear-end crashes. The B/C ratio of the safety improvement is 4.35, showing the improvement was likely justified from a safety standpoint.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 48 during the four-year period (2005 to 2008) before the signal was upgraded (see **Table 1** and **Exhibit 1**) to 39 during the four-year after period (2011 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes also decreased:

- Before (2005 – 2008) – no fatal crashes and 19 injury crashes with 25 injuries
- After (2011 – 2014) – no fatal crashes and 8 injury crashes with 13 injuries

The number of crashes decreased, additionally there was a slight decrease in traffic volumes at the intersection. This resulted in a decrease in the crash rates:

- Before (2005 – 2008): 0.89 crashes per million entering vehicles (cpmev)
- After (2011 – 2014): 0.73 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT (SH 121/Chatfield Ave)	24,500/12,600 vpd	23,750/12,600 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**48**	**39**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	19 (25)	8 (13)
Property Damage Only	29	31
Crash Types: # (%) [significance]		
Rear-End	21 (43.8%)	24 (61.5%) [98.6%]
Broadside	16 (33.3%) [99.9%]	2 (5.1%)
Approach Turn	6 (12.5%)	5 (12.8%)

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

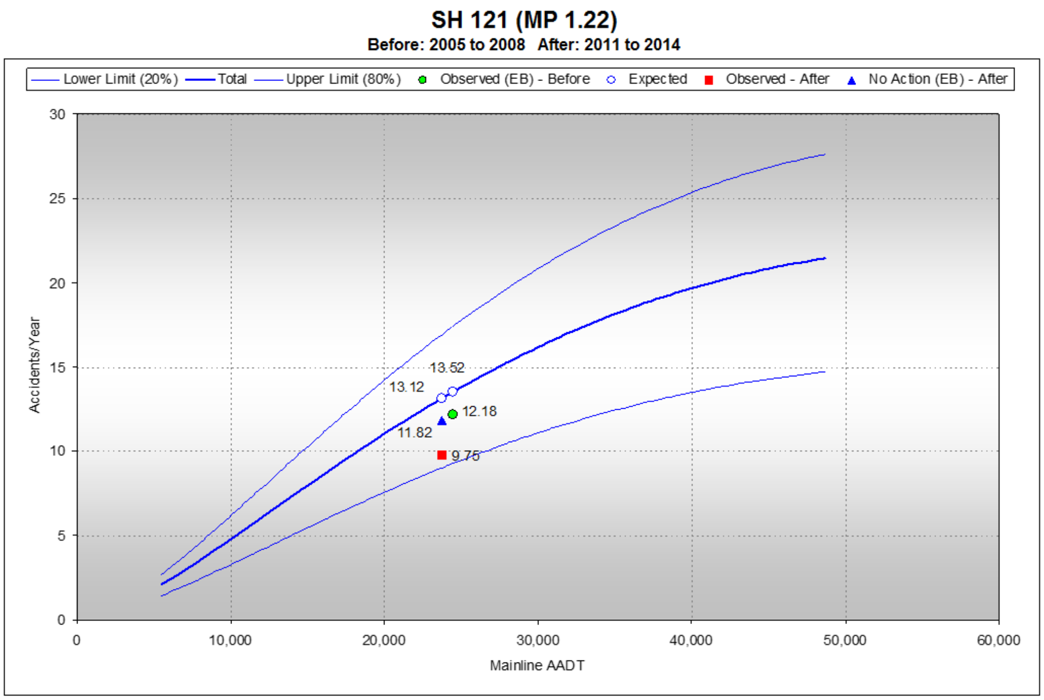
Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted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

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

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

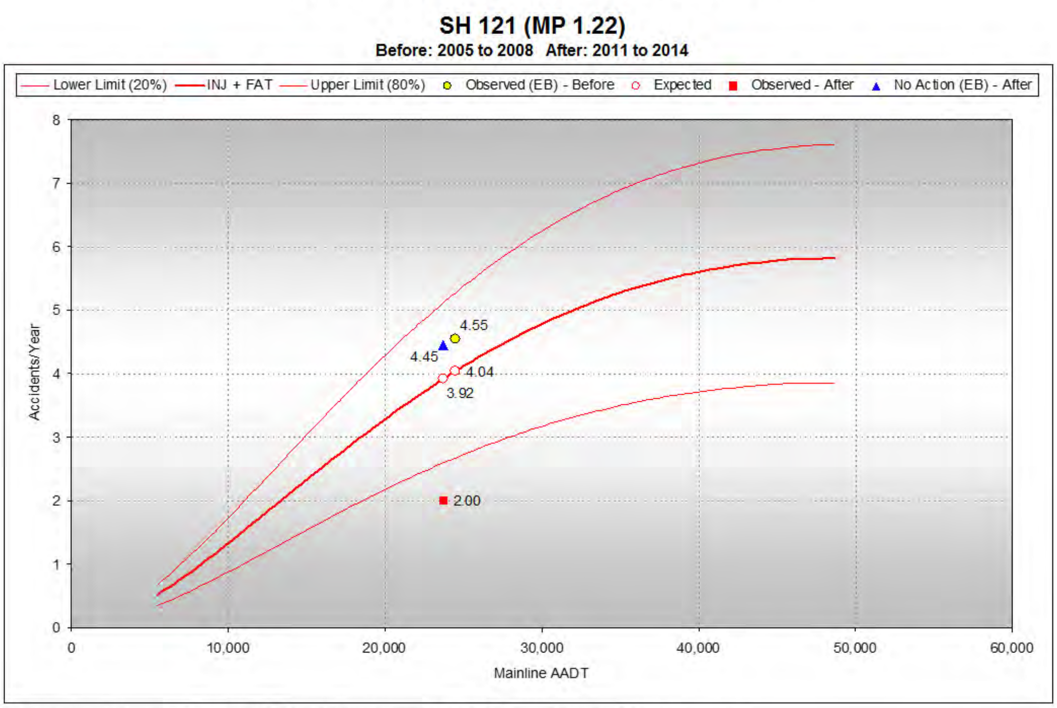
SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. The frequency of crashes was in the LOSS II category in the before period and after period. The severity of crashes decreased from the LOSS III category in the before period to the LOSS I category in the after period (see **Table 2**).

Figure 1 - SPF for Total Crashes



Note: Safety Performance Function (SPF) Model: Colorado - Urban 4-Lane Divided Signalized 4-LegIntersection

Figure 2 - SPF for Injury and Fatal Crashes



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

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS II	LOSS II	LOSS III
CPY	12.18	9.75	11.82
Mean CPY	13.52	13.12	13.12
Proportion of Mean	0.90	0.74	0.90
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS III	LOSS I
CPY	4.55	2.00	4.45
Mean CPY	4.04	3.92	3.92
Proportion of Mean	1.13	0.51	1.13

A more detailed review of the before and after crash record reveals a large reduction in broadside crashes due to the signal upgrade. In addition, the approach turn crashes experienced a significant decrease in severity. **Table 3** shows a comparison of total crashes in addition to crash types that are most directly affected by the improvement: approach turn, broadside, and rear-end. The safety improvement did not seem to have any impact on rear-end type crashes as the number of rear-end crashes increased. The No Build After crashes were estimated using the decrease in the mean of the SPF for total crashes found in **Table 2** (decrease is 0.97 = 13.12/13.52).

Table 3 – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:			
Total Crashes	**48**	**39**	**47**
Injury (injuries)	19 (25)	8 (13)	19 (25)
PDO	29	31	28
% Reduction in Total (Injuries/PDO)		48% / -11%	
Approach Turns – Total	**6**	**5**	**6**
Injury (injuries)	4 (7)	1 (1)	4 (7)
PDO	2	4	2
% Reduction in Total (Injuries/PDO)		100% / 63%	
Broadsides – Total	**16**	**2**	**16**
Injury (injuries)	6 (9)	0	6 (9)
PDO	10	2	10
% Reduction in Total (Injuries/PDO)		85% / -100%	
Rear-Ends – Total	**21**	**24**	**20**
Injury (injuries)	7 (7)	6 (11)	7 (7)
PDO	14	18	13
% Reduction in Total (Injuries/PDO)		-57% / -39%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of this B/C analysis are shown in **Figure 3** for the intersection crashes. While the injury crashes decreased, there was an increase in property damage only crashes. The increase in property damage only crashes was factored into the analysis by increasing the cost of construction for the signal. During the four-year after period, there were three additional property damage only crashes at the intersection. Over the design life of 10 years for the signal, the increased cost of crashes would be $69,750 (7.5 PDO = $69,750). As shown, the B/C ratio for signal improvements is 4.35, showing that the improvement was likely justified.

This project was very successful overall, however, it was noticed however that number of rear end crashes were not reduced despite deployment of the dilemma zone.

Figure 3 – Benefit Cost Analysis –Intersection and Intersection Related Crashes Only

COLORADO Department of Transportation

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

09/21/2016

Job #: 20160921122555

Location: 121A **Begin:** 1.20 **End:** 1.24 **From:** 01/01/2005 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	28		Weighted PDO:	7.68	0% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	19	25 :Injured	Weighted INJ:	6.86	48% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	15% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	19% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	10
						Capital Recovery Factor:	0.129
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 471,751
From: 01/01/2005
To: 12/31/2008 Days: 1461

Benefit Cost Ratio: 4.35 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: UPGRADE SIGNALS - INTERSECTION CRASHES ONLY
Special Notes:

Location: 121A **Begin:** 1.20 **End:** 1.24 **From:** 01/01/2005 **To:** 12/31/2008

Severity

PDO:	29		
INJ:	19	25	:Injured
FAT:	0	0	:Killed
Total:	**48**		

Number of Vehicles

One Vehicle:	1
Two Vehicles:	41
Three or More:	6
Unknown:	0
Total:	**48**

Location

On Road:	38
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	10
Total:	**48**

Lighting Conditions

Daylight:	47
Dawn or Dusk:	0
Dark - Lighted:	1
Dark - Unlighted:	0
Unknown:	0
Total:	**48**

Weather Conditions

None:	42
Rain:	4
Snow/Sleet/Hail:	2
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**48**

Crash Rates

PDO:	27.02 *
INJ:	17.70 *
FAT:	0.00 **
Total:	**44.73** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	16	Embankment:	0
Head On:	1	Curb:	0
Rear End:	21	Delineator Post:	0
Sideswipe (Same):	0	Fence:	0
Sideswipe (Opposite):	1	Tree:	0
Approach Turn:	6	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	1	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**48**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	48
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**48**

Road Description

At Intersection:	42
At Driveway Access:	0
Intersection Related:	6
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**48**

Road Conditions

Dry:	37
Wet:	7
Muddy:	0
Snowy:	2
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**48**

ADT: 24,485 **Length:** 0.03

Location: 121A **Begin:** 1.20 **End:** 1.24 **From:** 01/01/2005 **To:** 12/31/2008

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	29	31	6
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	10	6	0
Pickup Truck/Utility Van w/Trl:	2	0	0
SUV:	3	10	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	1	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**48**	**47**	**6**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	30	47	6
Asleep at the Wheel:	1	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	3	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	1	0	0
Physical Disability:	0	0	0
Unknown:	12	0	0
Total:	**48**	**47**	**6**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	47	47	6
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**48**	**47**	**6**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	36	17	0
Slowing:	6	2	0
Stopped in Traffic:	0	18	6
Making Right Turn:	0	0	0
Making Left Turn:	4	10	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	2	0	0
Unknown:	0	0	0
Total:	**48**	**47**	**6**

Direction	Veh 1	Veh 2	Veh 3
North:	26	18	2
Northeast:	0	0	0
East:	7	7	2
Southeast:	0	0	0
South:	14	7	2
Southwest:	0	0	0
West:	1	15	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**48**	**47**	**6**

ADT: 24,485 **Length:** 0.03

Location: 121A **Begin:** 1.20 **End:** 1.24 **From:** 01/01/2011 **To:** 12/31/2014

Severity

PDO:	31	
INJ:	8	13 :Injured
FAT:	0	0 :Killed
Total:	**39**	

Number of Vehicles

One Vehicle:	2
Two Vehicles:	35
Three or More:	2
Unknown:	0
Total:	**39**

Location

On Road:	37
Off Road Left:	1
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**39**

Lighting Conditions

Daylight:	29
Dawn or Dusk:	2
Dark - Lighted:	6
Dark - Unlighted:	2
Unknown:	0
Total:	**39**

Weather Conditions

None:	35
Rain:	1
Snow/Sleet/Hail:	3
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**39**

Crash Rates

PDO:	28.84 *
INJ:	7.44 *
FAT:	0.00 **
Total:	**36.28** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	2	Embankment:	0
Head On:	0	Curb:	1
Rear End:	24	Delineator Post:	0
Sideswipe (Same):	4	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	5	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	2
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	2
Traffic Signal Pole:	1	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	2
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**39**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	39
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**39**

Road Description

At Intersection:	21
At Driveway Access:	0
Intersection Related:	18
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**39**

Road Conditions

Dry:	34
Wet:	2
Muddy:	0
Snowy:	1
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	1
Total:	**39**

ADT: 23,733 **Length:** 0.03

Location: 121A **Begin:** 1.20 **End:** 1.24 **From:** 01/01/2011 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	17	16	0
Passenger Car/Van w/Trl:	0	0	1
Pickup Truck/Utility Van:	6	2	0
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	15	19	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**39**	**37**	**2**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	19	36	2
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	3	1	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	5	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	9	0	0
Total:	**39**	**37**	**2**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	37	37	2
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**39**	**37**	**2**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	20	6	1
Slowing:	3	1	0
Stopped in Traffic:	0	21	1
Making Right Turn:	5	2	0
Making Left Turn:	4	7	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	2	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	1	0	0
Other:	4	0	0
Unknown:	0	0	0
Total:	**39**	**37**	**2**

Direction	Veh 1	Veh 2	Veh 3
North:	8	7	1
Northeast:	0	0	0
East:	5	5	0
Southeast:	0	0	0
South:	15	13	1
Southwest:	0	0	0
West:	11	12	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**39**	**37**	**2**

ADT: 23,733 **Length:** 0.03

Project Information

Project Name: SH 285/Sherman Street Signal Upgrades

Project Description: Signal Upgrades

CDOT Region: 6 Project Def: 16957 County: Arapahoe

Location: SH 285 Mile Points: 260.30 Length: N/A

Schedule: Work Start Date: 5/19/09 Completion Date: 4/7/2010

Problem Description: The crash history showed a higher than expected number of approach turns for the permissive eastbound left-turn.

Improvement Description: In 2009/early 2010, the span wire was replaced with mast arms. In addition, the eastbound left-turn was changed from permissive to protected/permissive phasing. The cost of construction was $262,516.

It was anticipated that the primary crash types impacted by this improvement would be rear-end, approach turn, and broadside type crashes. It was anticipated that there would be a 40% crash reduction for these crash types. The initial benefit/cost ratio was estimated to be 1.42.

Summary and Findings

The analysis of safety before and after the addition of the protected/permissive phasing to the eastbound left turn and the signal upgrade to mast arms showed safety improved for approach turns. The total crashes at the intersection increased, but the severity of crashes decreased. For this intersection, there were 49 total crashes during the four-year period before the upgrades (2005 – 2008). In the four years after construction (2011 – 2014), the number of crashes increased to 53. During that same time period, injuries decreased from 20 to 13. Traffic volumes also decreased between the before and after periods.

The addition of the protected/permissive phasing was responsible for significant decreases in the number and severity of approach turn crashes. But, there was an increase in broadside and rear-end crashes. Despite the overall increase in crashes at the intersection, the B/C ratio of the safety improvement is 2.32, showing the improvement was likely justified from a safety standpoint.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows an increase in the number of crashes; the total number of crashes increased from 49 during the four-year period (2005 to 2008) before the signal was upgraded (see **Table 1** and **Exhibit 1**) to 53 during the four-year after period (2011 to 2014) (see **Table 1** and **Exhibit 2**). However, the number of severe crashes slightly decreased:

- Before (2005 – 2008) – no fatal crashes and 12 injury crashes with 20 injuries
- After (2011 – 2014) – no fatal crashes and 10 injury crashes with 13 injuries

The number of crashes increased slightly despite a decrease in traffic volumes at the intersection. This resulted in an increase in the crash rates:

- Before (2005 – 2008): 0.54 crashes per million entering vehicles (cpmev)
- After (2011 – 2014): 0.64 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT (SH 285/Sherman St)	59,150/Approx. 3,000 vpd	53,750/3,000 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**49**	**53**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	12 (20)	10 (13)
Property Damage Only	37	43
Crash Types: # (%) [significance]		
Rear-End	18 (36.7%)	28 (52.8%)
Approach Turn	12 (24.5%)	3 (5.7%)
Sideswipe Same Direction	7 (14.3%)	8 (15.1%)
Broadside	6 (12.2%)	12 (22.6%) [98.7%]

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

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

level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

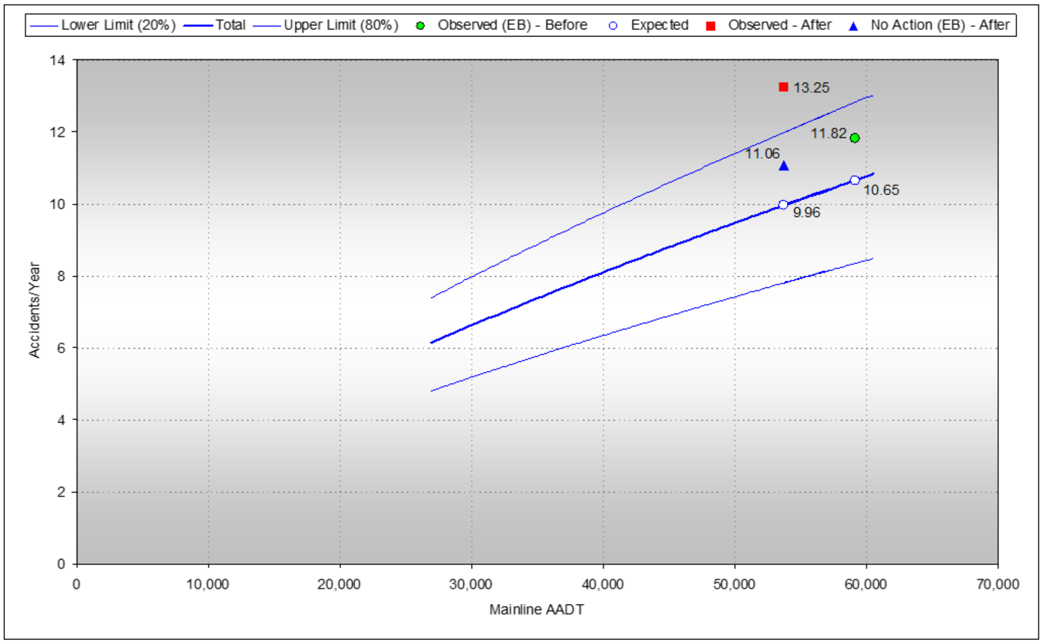
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. The frequency of crashes increased from the LOSS III category for the before period to LOSS IV in the after period. The severity of crashes remained in the LOSS II category for both the before and after periods, although there was improvement in the after period (see **Table 2**).

Figure 1 - SPF for Total Crashes

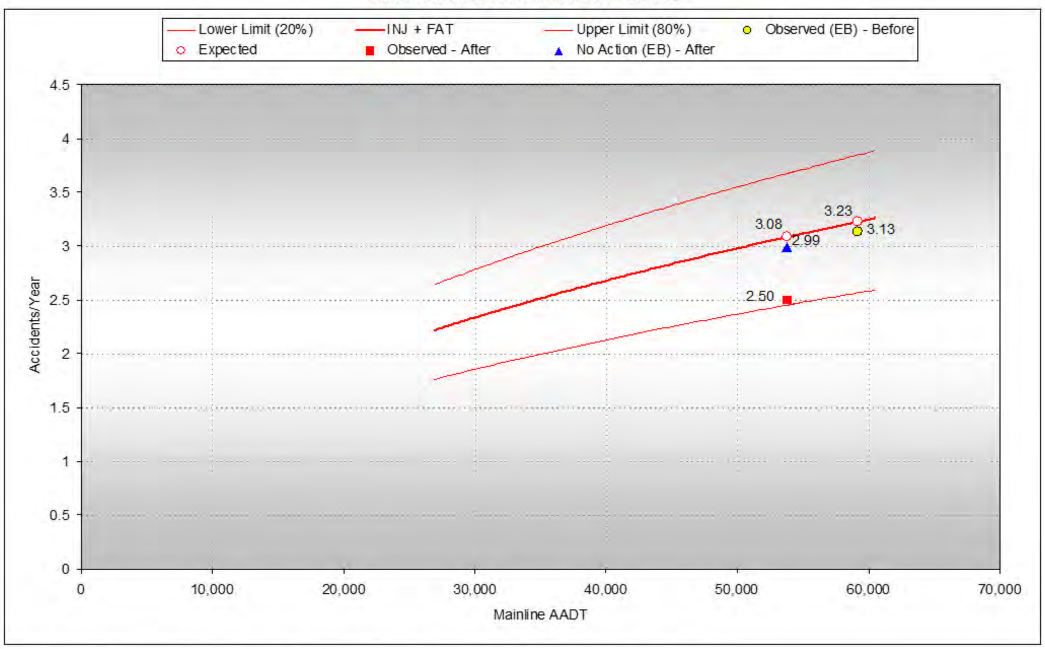
SH 285 (MP 260.30)
Before: 2005 to 2008 After: 2011 to 2014



Note: Safety Performance Function (SPF) Model: Colorado - Urban 6-Lane Divided Signalized 4-Leg Intersection

Figure 2 - SPF for Injury and Fatal Crashes

SH 285 (MP 260.30)
Before: 2005 to 2008 After: 2011 to 2014



Note: Safety Performance Function (SPF) Model: Colorado - Urban 6-Lane Divided Signalized 4-Leg Intersection

Table 2 – Safety Performance Function (SPF)

	Before	**After**	**No Build After**
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS III	LOSS IV	LOSS III
CPY	11.82	13.25	11.06
Mean CPY	10.65	9.96	9.96
Proportion of Mean	1.11	1.33	1.11
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS II	LOSS II
CPY	3.13	2.50	2.99
Mean CPY	3.23	3.08	3.08
Proportion of Mean	0.97	0.81	0.97

A more detailed review of the before and after crash record reveals a large reduction in approach turn crashes due to the addition of the eastbound left -turn protected/permissive phase. **Table 3** shows a comparison of total crashes in addition to crash types that are most directly affected by the improvement: approach turn, broadside, and rear-end. The safety improvement did not seem to have any impact on broadsides or rear-end as both these crash types experienced an increase in number of crashes. The No Build After crashes were estimated using the decrease in the mean of the SPF for total crashes found in **Table 2** (decrease is 0.94 = 9.96/10.65).

Table 3 – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:			
Total Crashes	**49**	**53**	**46**
Injury (injuries)	12 (20)	10 (13)	11 (19)
PDO	37	43	35
% Reduction in Total (Injuries/PDO)		32% / -23%	
Approach Turns – Total	**12**	**3**	**11**
Injury (injuries)	3 (7)	0	3 (7)
PDO	9	3	8
% Reduction in Total (Injuries/PDO)		100% / 63%	
Broadsides – Total	**6**	**12**	**6**
Injury (injuries)	3 (4)	3 (6)	3 (4)
PDO	3	9	3
% Reduction in Total (Injuries/PDO)		-50% / -00%	
Rear-Ends – Total	**18**	**28**	**17**
Injury (injuries)	5 (8)	7 (7)	5 (8)
PDO	13	21	12
% Reduction in Total (Injuries/PDO)		-13% / -75%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of this B/C analysis are shown in **Figure 3** for the intersection crashes. While the injury crashes decreased, there was an increase in property damage only crashes. The increase in property damage only crashes was factored into the analysis by increasing the cost of construction for the signal. During the four-year after period, there were eight additional property damage only crashes at the intersection. Over the design life of 10 years for the signal, the increased cost of crashes would be $186,000 (20 PDO = $186,000. As shown, the B/C ratio for signal improvements is 2.32, showing that the improvement was likely justified.

Figure 3 – Benefit Cost Analysis –Intersection and Intersection Related Crashes Only

COLORADO Department of Transportation

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

09/06/2016

Job #: 20160906093010

Location: 285D **Begin:** 260.28 **End:** 260.35 **From:** 01/01/2005 **To:** 12/31/2008

Benefit Cost Ratio Calculations

	Crashes		Projected Crashes and Reduction Factors			Other Information	
PDO:	35		Weighted PDO:	9.60	0% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	11	19 :Injured	Weighted INJ:	5.21	32% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	7% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	10
						Capital Recovery Factor:	0.129
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 448,516
From: 01/01/2005
To: 12/31/2008 Days: 1461

Benefit Cost Ratio: **2.32** (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: SIGNALS - ADD PROTECTED/PERMISSIVE PHASE
Special Notes:

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

Exhibit 1

08/26/2016

Job #: 20160826085829

Location: 285D **Begin:** 260.28 **End:** 260.35 **From:** 01/01/2005 **To:** 01/01/2008

Severity

PDO:	26		
INJ:	7	10	:Injured
FAT:	0	0	:Killed
Total:	**33**		

Number of Vehicles

One Vehicle:	0
Two Vehicles:	28
Three or More:	5
Unknown:	0
Total:	**33**

Location

On Road:	33
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**33**

Lighting Conditions

Daylight:	20
Dawn or Dusk:	3
Dark - Lighted:	10
Dark - Unlighted:	0
Unknown:	0
Total:	**33**

Weather Conditions

None:	30
Rain:	1
Snow/Sleet/Hail:	1
Fog:	0
Dust:	0
Wind:	0
Unknown:	1
Total:	**33**

Crash Rates

PDO:	6.91 *
INJ:	1.86 *
FAT:	0.00 **
Total:	**8.78** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	4	Embankment:	0
Head On:	0	Curb:	0
Rear End:	10	Delineator Post:	0
Sideswipe (Same):	5	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	10	Large Boulders or Rocks:	0
Overtaking Turn:	2	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**33**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	33
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**33**

Road Description

At Intersection:	24
At Driveway Access:	0
Intersection Related:	9
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**33**

Road Conditions

Dry:	30
Wet:	1
Muddy:	0
Snowy:	0
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	1
Total:	**33**

ADT: 59,150 **Length:** 0.05

User: Colleen.Guillotte on LAP14

Location: 285D **Begin:** 260.28 **End:** 260.35 **From:** 01/01/2005 **To:** 01/01/2008

Vehicle Type

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	18	24	3
Passenger Car/Van w/Trl:	0	1	0
Pickup Truck/Utility Van:	7	5	2
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	5	2	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	2	1	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**33**	**33**	**5**

Vehicle Movement

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	13	21	1
Slowing:	0	3	0
Stopped in Traffic:	0	6	4
Making Right Turn:	3	1	0
Making Left Turn:	11	1	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	5	1	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**33**	**33**	**5**

Direction

Direction	Veh 1	Veh 2	Veh 3
North:	2	2	0
Northeast:	0	0	0
East:	19	9	0
Southeast:	0	0	0
South:	0	2	1
Southwest:	0	0	0
West:	12	20	4
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**33**	**33**	**5**

Contributing Factor

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	25	29	5
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	1	1	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	5	3	0
Total:	**33**	**33**	**5**

Condition of Driver

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	29	33	5
Alcohol Involved:	3	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**33**	**33**	**5**

ADT: 59,150 **Length:** 0.05

Location: 285D **Begin:** 260.28 **End:** 260.35 **From:** 01/01/2011 **To:** 01/01/2014

Severity

PDO:	33		
INJ:	8	11	:Injured
FAT:	0	0	:Killed
Total:	**41**		

Number of Vehicles

One Vehicle:	0
Two Vehicles:	32
Three or More:	9
Unknown:	0
Total:	**41**

Location

On Road:	41
Off Road Left:	0
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**41**

Lighting Conditions

Daylight:	34
Dawn or Dusk:	3
Dark - Lighted:	4
Dark - Unlighted:	0
Unknown:	0
Total:	**41**

Weather Conditions

None:	38
Rain:	1
Snow/Sleet/Hail:	2
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**41**

Crash Rates

PDO:	9.03 *
INJ:	2.19 *
FAT:	0.00 **
Total:	**11.22** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	11	Embankment:	0
Head On:	0	Curb:	0
Rear End:	23	Delineator Post:	0
Sideswipe (Same):	6	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	1	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	0
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**41**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	41
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**41**

Road Description

At Intersection:	32
At Driveway Access:	0
Intersection Related:	9
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**41**

Road Conditions

Dry:	36
Wet:	4
Muddy:	0
Snowy:	1
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**41**

ADT: 53,750 **Length:** 0.06

Location: 285D **Begin:** 260.28 **End:** 260.35 **From:** 01/01/2011 **To:** 01/01/2014

Vehicle Type

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	29	20	6
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	3	8	1
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	8	12	2
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	1	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**41**	**41**	**9**

Vehicle Movement

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	22	15	1
Slowing:	5	6	0
Stopped in Traffic:	2	15	8
Making Right Turn:	3	0	0
Making Left Turn:	2	2	0
Making U-Turn:	0	1	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	5	1	0
Avoiding Object/Veh in Road:	1	0	0
Weaving:	0	0	0
Other:	1	1	0
Unknown:	0	0	0
Total:	**41**	**41**	**9**

Direction

Direction	Veh 1	Veh 2	Veh 3
North:	3	3	0
Northeast:	0	0	0
East:	14	14	3
Southeast:	0	0	0
South:	4	1	0
Southwest:	0	0	0
West:	20	23	6
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**41**	**41**	**9**

Contributing Factor

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	29	41	9
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	6	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	6	0	0
Total:	**41**	**41**	**9**

Condition of Driver

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	40	41	9
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**41**	**41**	**9**

ADT: 53,750 **Length:** 0.06

Project Information

Project Name: I-70 Variable Speed Limits Near EJMT-Phase I

Project Description: Adverse Weather Variable Speed Limit System

CDOT Region: 4 Project Def: 17014 Counties: Summit, Clear Creek

Location: I-70 Mile Points: 205-224 Length: 19 miles

Schedule: Work Start Date: 6/2/2009 Completion Date: 9/27/2010

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the crash history showed patterns of crashes in snowy, and icy condition on this high-mountain corridor. In a 5-year crash history from 9/1/2001-8/31/2006 there were 548 Property Damage Only (PDO), 161 Injury (INJ) and 1 Fatal (FAT) crashes during snowy, slushy or icy road conditions.

Improvement Description: From discussion of the project with CDOT Construction personnel, this project was intended to be phase 1 of 2 projects which together would provide the Variable Speed Limit system. Phase 1 was built from June 2009 thru September 2010, and included infrastructure improvements, primarily installation of a buried high voltage power line and installation of transformers along the project corridor, intended to support variable speed limit signs and associated ITS hardware. Phase 2, which was to include the actual variable speed limit signs, has not been built to date. The cost of construction was $ 1,037,528.

The HSIP application anticipated that crashes in adverse winter road conditions would be impacted by this improvement. It was anticipated that there would be approximately a 20% crash reduction for these crashes. The expected benefit/cost ratio was estimated to be 4.24.

Summary and Findings

Not surprisingly, since no improvements to the roadway were made, and VSL signing was not installed, the project has had no significant effect on safety. It is possible, however, that during the after period the combined efforts of CSP and CDOT to improve traffic operations and safety during adverse weather conditions have contributed to moderate crash reduction under icy and snowy conditions.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a very slight decrease in the number of crashes; the total number of crashes decreased from 1,368 during the four-year period (2005 to 2008) before the new underground infrastructure was installed (see **Table 1** and **Exhibit 1**) to 1,168 during the four-year after period (2011 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes also decreased very slightly in the four-year period after the project:

- Before (2005 – 2008) – 4 fatal crashes with 4 killed, and 279 injury crashes with 425 injuries.
- After (2011 – 2014) – 5 fatal crashes and 5 killed, and 258 injury crashes with 402 injuries.

While there was an increase in traffic volumes on the corridor, the crash rate decreased slightly. This may be due to efforts by the Colorado State Patrol, including pacing of traffic on high demand days during adverse winter weather on this winter resort travel route.

- Before (2008 – 2008): 1.71 crashes per million vehicle miles of travel (cpmvmt)
- After (2009 – 2013): 1.43 (cpmvmt)

Table 1 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014(4 yr.)
AADT	5,060 / 4,100 vpd	5,863 / 4,100 vpd
Filters:	Mainline	Mainline
Total Crashes	**1,368**	**1,168**
Fatal Crashes (Fatalities)	4 (4)	5 (5)
Injury Crashes (Injuries)	279 (425)	258 (402)
Property Damage Only	1,085	905
Crash Types: # (%) [significance]		
Broadside	13 (59.1%) [99.99%]	3 (27.3%)
Approach Turn	2(9.1%)	4 (36.4%)
Rear End	4(18.2%)	4 (36.4%)
Icy+Snowy+Slushy Crashes	**708**	**585**
Fatal Crashes (Fatalities)	3 (3)	1 (1)
Injury Crashes (Injuries)	138 (213)	131 (203)
Property Damage Only	567	453

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 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 uses qualitative measures that characterize safety of a roadway segment 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.

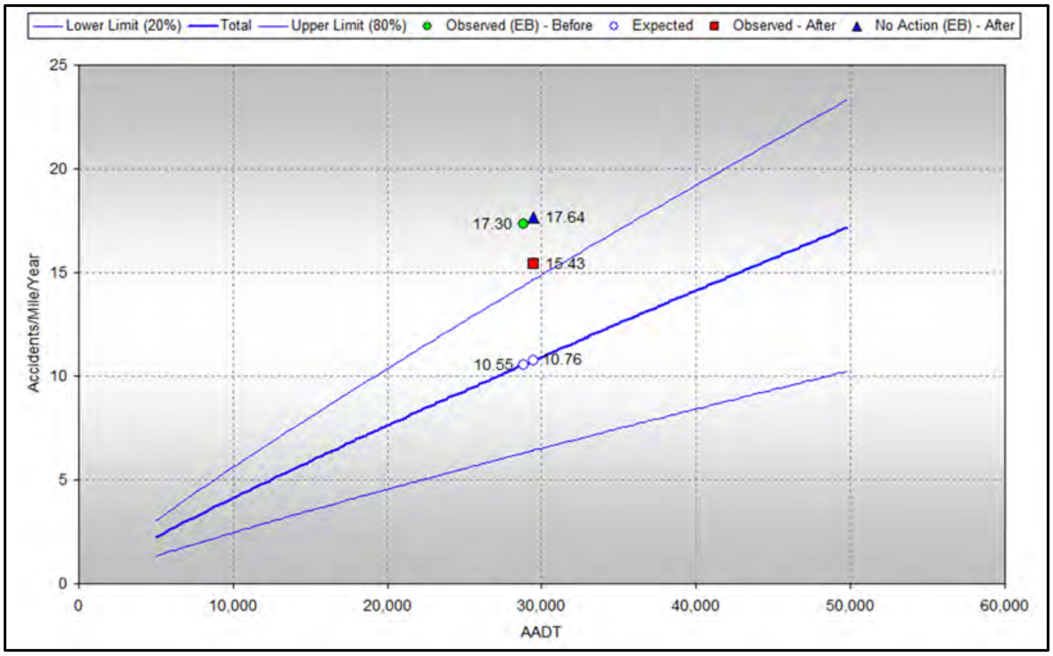
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. The frequency and severity of crashes remained in the LOSS IV category for both periods; however, while total crash frequency improved slightly compared with the EB corrected estimate, severe crashes were somewhat worse than predicted in the after period (see **Table 2**).

Figure 1 - SPF for Total Crashes

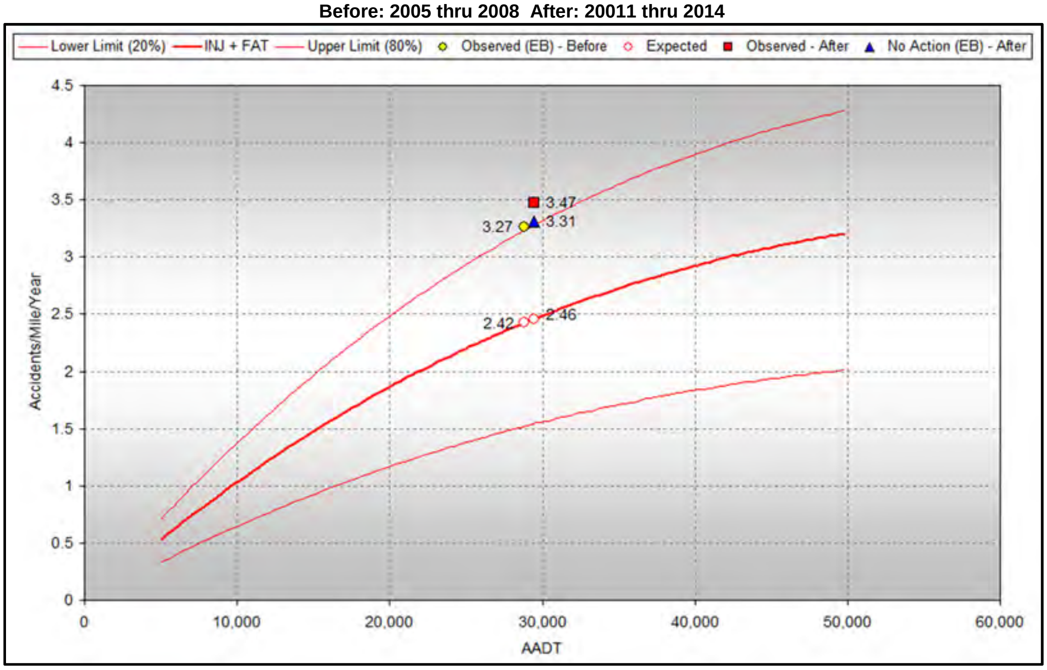
SH 070A MP 205.00 – 224.00
Before: 2005 thru 2008 After: 2011 thru 2014



Note: Safety Perfromance Function (SPF) Model: Colorado – Rural Mountainous 4-Lane Divided Freeway

Figure 2 – SPF Injury and Fatal Crashes

SH 070A MP 205.00 – 224.00
Before: 2005 thru 2008 After: 20011 thru 2014



Note: Safety Perfromance Function (SPF) Model: Colorado – Rural Mountainous 4-Lane Divided Freeway

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build 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	17.30	15.43	17.64
Mean CPMPY	10.55	10.76	10.76
Proportion of Mean	1.64	1.43	1.64
Fatal & Injury Crashes:			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPMPY	3.27	3.47	3.31
Mean CPMPY	2.42	2.46	2.46
Proportion of Mean	1.35	1.41	1.35

A more detailed review of the before and after crash record reveals more or less random changes in crash history after the infrastructure project. **Table 3** shows a comparison of the targeted Icy, Snowy and Slushy conditions crashes that are were intended to be affected by the improvement, as well as the total intersection crashes. The No Build After crashes were estimated using the change in mean CPMPY found in **Table 2** (increase is 1.017 = 2.46/2.42).

Table 3 – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:			
Total Crashes	**1,368**	**1,168**	**1391**
Fatal (Fatalities)	4 (4)	5 (5)	4 (4)
Injury (injuries)	279 (425)	258 (402)	284 (432)
PDO	1,085	905	1,103
% Reduction in Total (Fatalities/Injuries/PDO)		-25% / 7% / 18%	
Icy+Snowy+Slushy	**708**	**585**	**720**
Fatal (Fatalities)	3 (3)	1 (1)	3 (3)
Injury (injuries)	138 (213)	131 (203)	140 (217)
PDO	567	453	576
% Reduction in Total (Fatalities/Injuries/PDO)		67% / 6% / 21%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the impacted crash types. As shown, the B/C ratio for the Adverse Conditions Variable Speed Limit System, Phase I, reducing crashes in adverse conditions is 10.52. This primarily reflect the decrease in fatal crashes during icy, slushy and snow conditions, which cannot reasonably be attributed to the improvements constructed by the project, and may or may not be related to CSP efforts (pacing traffic during icy and snowy conditions at peak travel times) in the after period.

Figure 3 – Benefit Cost Analysis – Intersection and Intersection Related Crashes Only

CDOT
COLORADO Department of Transportation

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

11/14/2016
Job #: 20161114095634

Location: 70A **Begin:** 205.00 **End:** 224.00 **From:** 01/01/2005 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	567		Weighted PDO:	155.58	21% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	138	213 :Injured	Weighted INJ:	58.44	6% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	3	3 :Killed	Weighted FAT:	0.82	67% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	18% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	10
						Capital Recovery Factor:	0.129
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 1,037,528
From: 01/01/2005
To: 12/31/2008 Days: 1461

Benefit Cost Ratio: 10.52 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: ADVERSE WEATHER VARIABLE SPEED LIMIT SYSTEM - PHASE I
Special Notes: IOCY, SNOWY AND SLUSHY ROAD CONDITIONS CRASHES

Location: 70A **Begin:** 205.00 **End:** 224.00 **From:** 01/01/2005 **To:** 12/31/2008

Severity

PDO:	1085		
INJ:	279	425	:Injured
FAT:	4	4	:Killed
Total:	**1368**		

Number of Vehicles

One Vehicle:	805
Two Vehicles:	485
Three or More:	78
Unknown:	0
Total:	**1368**

Location

On Road:	557
Off Road Left:	408
Off Road Right:	397
Off Road at Tee:	0
Off in Median:	6
Unknown:	0
Total:	**1368**

Lighting Conditions

Daylight:	899
Dawn or Dusk:	91
Dark - Lighted:	94
Dark - Unlighted:	283
Unknown:	1
Total:	**1368**

Weather Conditions

None:	636
Rain:	50
Snow/Sleet/Hail:	639
Fog:	1
Dust:	0
Wind:	38
Unknown:	4
Total:	**1368**

Crash Rates

PDO:	1.36 *
INJ:	0.35 *
FAT:	0.50 **
Total:	**1.71** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	190	Bridge Abutment:	0
Other Non Collision:	17	Column/Pier:	0
Pedestrians:	2	Culvert/Headwall:	4
Broadside:	0	Embankment:	121
Head On:	3	Curb:	0
Rear End:	265	Delineator Post:	18
Sideswipe (Same):	203	Fence:	1
Sideswipe (Opposite):	3	Tree:	19
Approach Turn:	0	Large Boulders or Rocks:	27
Overtaking Turn:	3	Barricade:	0
Parked Motor Vehicle:	33	Wall/Building:	29
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	3
Domestic Animal:	0	Total Fixed Objects:	559
Wild Animal:	34	Rocks in Roadway:	0
Light/Utility Pole:	4	Vehicle Cargo/Debris:	3
Traffic Signal Pole:	0	Road Maintenance Equipment:	4
Sign:	29	Involving Other Object:	49
Bridge Rail:	3	Total Other Objects:	56
Guard Rail:	124	Unknown:	0
Cable Rail:	35	**Total:**	**1368**
Concrete Barrier:	142		

Mainline/Ramps/Frontage Roads

Mainline:	1368
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**1368**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	1368
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**1368**

Road Conditions

Dry:	388
Wet:	133
Muddy:	0
Snowy:	245
Icy:	361
Slushy:	102
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	7
Wet w/Icy Road Treatment:	10
Snowy w/Icy Road Treatment:	56
Icy w/Icy Road Treatment:	42
Slushy w/Icy Road Treatment:	21
Unknown:	3
Total:	**1368**

ADT: 28,825 **Length:** 18.97

Location: 70A **Begin:** 205.00 **End:** 224.00 **From:** 01/01/2005 **To:** 12/31/2008

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	671	253	48
Passenger Car/Van w/Trl:	4	1	0
Pickup Truck/Utility Van:	318	109	10
Pickup Truck/Utility Van w/Trl:	22	13	1
SUV:	222	76	12
SUV w/Trl:	8	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	97	92	2
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	2	0	0
Motorhome:	4	5	0
Motorcycle:	7	3	2
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	6	4	2
Other:	6	3	0
Unknown:	1	4	1
Total:	**1368**	**563**	**78**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	830	282	30
Slowing:	71	121	13
Stopped in Traffic:	6	89	27
Making Right Turn:	2	0	0
Making Left Turn:	2	0	0
Making U-Turn:	3	0	0
Passing:	35	18	0
Backing:	13	0	0
Enter/Leave Parked Position:	3	1	0
Starting in Traffic:	0	0	0
Parked:	2	30	3
Changing Lanes:	80	7	0
Avoiding Object/Veh in Road:	12	9	3
Weaving:	7	0	0
Other:	301	5	1
Unknown:	1	1	1
Total:	**1368**	**563**	**78**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	1048	552	75
Asleep at the Wheel:	22	0	0
Illness:	5	0	0
Distracted by Passenger:	7	0	0
Driver Inexperience:	165	2	1
Driver Fatigue:	7	0	0
Driver Preoccupied:	25	1	0
Driver Unfamilar with Area:	52	1	1
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	1	0	0
Unknown:	36	7	1
Total:	**1368**	**563**	**78**

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	587	301	49
Southeast:	0	0	0
South:	0	0	0
Southwest:	0	0	0
West:	781	261	29
Northwest:	0	0	0
Unknown:	0	1	0
Total:	**1368**	**563**	**78**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	1337	563	78
Alcohol Involved:	24	0	0
RX, Medication, or Drugs Involved:	4	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	3	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**1368**	**563**	**78**

ADT: 28,825 **Length:** 18.97

Location: 70A **Begin:** 205.00 **End:** 224.00 **From:** 01/01/2011 **To:** 12/31/2014

Severity

PDO:	905	
INJ:	258	402 :Injured
FAT:	5	5 :Killed
Total:	**1168**	

Number of Vehicles

One Vehicle:	627
Two Vehicles:	435
Three or More:	106
Unknown:	0
Total:	**1168**

Location

On Road:	548
Off Road Left:	313
Off Road Right:	306
Off Road at Tee:	1
Off in Median:	0
Unknown:	0
Total:	**1168**

Lighting Conditions

Daylight:	744
Dawn or Dusk:	90
Dark - Lighted:	47
Dark - Unlighted:	287
Unknown:	0
Total:	**1168**

Weather Conditions

None:	516
Rain:	39
Snow/Sleet/Hail:	601
Fog:	1
Dust:	0
Wind:	11
Unknown:	0
Total:	**1168**

Crash Rates

PDO:	1.11 *	* MVMT
INJ:	0.32 *	** 100 MVMT
FAT:	0.61 **	**Total: 1.43** *

Crash Type

Overturning:	69	Bridge Abutment:	0
Other Non Collision:	19	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	3
Broadside:	0	Embankment:	84
Head On:	2	Curb:	0
Rear End:	280	Delineator Post:	21
Sideswipe (Same):	175	Fence:	0
Sideswipe (Opposite):	2	Tree:	15
Approach Turn:	0	Large Boulders or Rocks:	12
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	15	Wall/Building:	7
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	2
Domestic Animal:	0	Total Fixed Objects:	544
Wild Animal:	42	Rocks in Roadway:	0
Light/Utility Pole:	12	Vehicle Cargo/Debris:	3
Traffic Signal Pole:	0	Road Maintenance Equipment:	6
Sign:	14	Involving Other Object:	11
Bridge Rail:	0	Total Other Objects:	20
Guard Rail:	144	Unknown:	0
Cable Rail:	66	**Total:**	**1168**
Concrete Barrier:	164		

Mainline/Ramps/Frontage Roads

Mainline:	1168
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**1168**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	1168
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**1168**

Road Conditions

Dry:	321
Wet:	102
Muddy:	1
Snowy:	260
Icy:	265
Slushy:	60
Foreign Material:	1
With Road Treatment:	0
Dry w/Icy Road Treatment:	3
Wet w/Icy Road Treatment:	8
Snowy w/Icy Road Treatment:	76
Icy w/Icy Road Treatment:	31
Slushy w/Icy Road Treatment:	40
Unknown:	0
Total:	**1168**

ADT: 29,472 **Length:** 18.92

Location: 70A **Begin:** 205.00 **End:** 224.00 **From:** 01/01/2011 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	412	151	24
Passenger Car/Van w/Trl:	4	2	0
Pickup Truck/Utility Van:	216	76	19
Pickup Truck/Utility Van w/Trl:	32	7	3
SUV:	360	189	44
SUV w/Trl:	7	2	1
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	101	94	8
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	3	0
Motorhome:	3	1	1
Motorcycle:	6	2	1
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	22	6	1
Other:	5	5	2
Unknown:	0	3	2
Total:	**1168**	**541**	**106**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	552	507	98
Asleep at the Wheel:	18	0	0
Illness:	6	0	0
Distracted by Passenger:	5	0	0
Driver Inexperience:	184	7	0
Driver Fatigue:	11	0	0
Driver Preoccupied:	81	8	4
Driver Unfamilar with Area:	137	6	1
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	1	0	0
Physical Disability:	1	0	0
Unknown:	171	13	3
Total:	**1168**	**541**	**106**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	1132	536	106
Alcohol Involved:	23	5	0
RX, Medication, or Drugs Involved:	7	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	6	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**1168**	**541**	**106**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	385	243	36
Slowing:	71	119	20
Stopped in Traffic:	6	98	29
Making Right Turn:	1	0	0
Making Left Turn:	0	0	0
Making U-Turn:	1	0	0
Passing:	21	7	1
Backing:	5	1	0
Enter/Leave Parked Position:	1	1	0
Starting in Traffic:	0	0	0
Parked:	1	15	3
Changing Lanes:	86	4	0
Avoiding Object/Veh in Road:	21	23	8
Weaving:	16	0	0
Other:	553	30	9
Unknown:	0	0	0
Total:	**1168**	**541**	**106**

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	1
Northeast:	1	0	0
East:	516	265	51
Southeast:	1	0	0
South:	1	0	0
Southwest:	0	0	0
West:	647	274	53
Northwest:	1	0	0
Unknown:	1	2	1
Total:	**1168**	**541**	**106**

ADT: 29,472 **Length:** 18.92

Project Information

Project Name: US 287 / LCR 21C Intersection

Project Description: Intersection Improvements at US 287 and LCR 21C

CDOT Region: 4 Project Def: 17015 County: Larimer

Location: US 287C Mile Points: 352.35 Length: N/A

Schedule: Work Start Date: 6/21/2010 Completion Date: 11/18/2010

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the crash history showed a higher than expected number of fatal broadside crashes. This was due to the large skew at the unsignalized intersection.

Improvement Description: In 2010, the intersection north/south approaches were realigned to decrease the skew of the intersection. The cost of construction was $497,816.

The HSIP application anticipated that broadside type crashes would be impacted by this improvement and it was anticipated that there would be a 35% crash reduction for these crash types. The initial benefit/cost ratio was estimated to be 1.86.

Summary and Findings

The analysis of safety before and after intersection improvements completed at US 287 and LCR 21C showed safety improved for the affected crash types. For this intersection, there were five total crashes during the four-year period before the upgrades (2006 – 2009) and only two crashes in the four years after construction (2011 – 2014).

The intersection improvements decreased the amount of skew present at the intersection and were responsible for decreases in the number and severity of broadside and approach turn crashes. The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 2.75 to one, showing that the improvement was likely justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from five during the four-year period (2006 to 2009) before the intersection improvements (see **Table 1** and **Exhibit 1**) to two during the four-year after period (2011 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes slightly decreased while the number of injuries increased:

- Before (2006 – 2009) – one fatal crash with one fatality and two injury crashes with three injuries
- After (2011 – 2014) – no fatal crashes and two injury crashes with seven injuries

The decrease in the number of crashes at the study intersection resulted in a decrease in the crash rates:

- Before (2006 – 2009): 0.35 crashes per million entering vehicles (cpmev)
- After (2011 – 2014): 0.14 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2006 to 12/31/2009 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT (US 287/LCR 21C)	7,700/2,200 vpd	7,750/2,200 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**5**	**2**
Fatal Crashes (Fatalities)	1 (1)	0
Injury Crashes (Injuries)	2 (3)	2 (7)
Property Damage Only	2	0
Crash Types: # (%)		
Broadside	3 (60.0%)	1 (50.0%)
Approach Turn	1 (20.0%)	0
Overturning	1 (20.0%)	0
Bicycle	0	1 (50.0%)

Normally, the magnitude of safety problems on highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. However, in the case of this 3-lane, rural intersection, no SPFs have been developed to use for analysis. Additionally, no crash pattern norms for diagnostic analyses are available for analysis.

A more detailed review of the before and after crash record reveals that improvements in safety can be attributed to the intersection improvements. The number of severe crashes decreased, although the number of injuries increased. **Table 3** shows a comparison of two types of crashes that are most directly affected by the improvement: approach turn and broadside. The No Build After crashes were estimated using the increase in the daily volumes found in **Table 2** (increase is 1.01 = 7,750/7,700).

Table 2 – Results of Crash Analyses

	Before	**After**	**No Build After**
Time Period:	1/1/2006 to 12/31/2009 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:			
Broadsides – Total	**3**	**1**	**3**
Fatal (Fatalities)	1 (1)	0	1 (1)
Injury (injuries)	1 (2)	1 (6)	1 (1)
PDO	1	0	1
% Reduction in Total (Fatalities/Injuries/PDO)		100%/-200%/100%	
Approach Turn – Total	**1**	**0**	**1**
PDO	1	0	1
% Reduction in Total		100%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 1** for the impacted crash types. The increase in injuries crashes was factored into the analysis by increasing the cost of construction for the project. During the five-year after period, there were four additional injuries. Over the design life of 20 years for the intersection improvements, the increased cost of crashes would be $1,614,000. As shown, the B/C ratio for approach turn and broadside crashes is 2.75, showing that the improvement was likely justified.

This outcome, however favorable, may have been influenced by the number of individuals injured in the after period. The number of injured is subject to chance and may’ve biased our conclusion therefore the B/C provided in our analysis should be viewed as conservative.

Figure 1 – Benefit Cost Analysis –Approach Turn and Broadside Crashes Only

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

08/22/2016

Job #: 20160822142454

Location: 287C **Begin:** 352.16 **End:** 352.54 **From:** 01/01/2006 **To:** 12/31/2009

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors				Other Information	
PDO:	2		Weighted PDO:	0.61	100%	:CRF for PDO	Cost of PDO:	$ 9,300
INJ:	1	2 :Injured	Weighted INJ:	0.61	0%	:CRF for INJ	Cost of INJ:	$ 80,700
FAT:	1	1 :Killed	Weighted FAT:	0.31	100%	:CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	75%	:Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
							Service Life:	20
							Capital Recovery Factor:	0.080
							Annual Maintenance/Delay Cost:	$ 0

Cost: $ 2,111,816
From: 01/01/2006
To: 12/31/2009 Days: 1461

Benefit Cost Ratio: 2.75 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: INTERSECTION - RELOCATION/REALIGNMENT - BROADSIDE AND APPROACH TURN CRASHES
Special Notes: COST OF 20 INJURIES ADDED TO CONSTRUCTION

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

Exhibit 1

08/22/2016

Job #: 20160822132927

Location: 287C **Begin:** 352.16 **End:** 352.54 **From:** 01/01/2006 **To:** 12/31/2009

Severity

PDO:	2	
INJ:	2	3 :Injured
FAT:	1	1 :Killed
Total:	**5**	

Number of Vehicles

One Vehicle:	0
Two Vehicles:	4
Three or More:	1
Unknown:	0
Total:	**5**

Location

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

Lighting Conditions

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

Weather Conditions

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

Crash Rates

PDO:	0.46 *
INJ:	0.46 *
FAT:	22.87 **
Total:	**1.14** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	5
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

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

Road Description

At Intersection:	3
At Driveway Access:	0
Intersection Related:	2
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**5**

Road Conditions

Dry:	4
Wet:	1
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**5**

ADT: 7,712 **Length:** 0.38

User: Colleen.Guillotte on LAP14

Location: 287C **Begin:** 352.16 **End:** 352.54 **From:** 01/01/2006 **To:** 12/31/2009

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

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

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

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

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

ADT: 7,712 **Length:** 0.38

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

Exhibit 2

08/22/2016

Job #: 20160822133722

Location: 287C **Begin:** 352.16 **End:** 352.54 **From:** 01/01/2011 **To:** 12/31/2011

Severity

PDO:	0		
INJ:	2	7	:Injured
FAT:	0	0	:Killed
Total:	**2**		

Number of Vehicles

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

Location

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

Lighting Conditions

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

Weather Conditions

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

Crash Rates

PDO:	0.00	*
INJ:	1.83	*
FAT:	0.00	**
Total:	**1.83**	*

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	2
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**2**

Road Description

At Intersection:	2
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**2**

Road Conditions

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

ADT: 7,731 **Length:** 0.38

User: Colleen.Guillotte on LAP14

Location: 287C **Begin:** 352.16 **End:** 352.54 **From:** 01/01/2011 **To:** 12/31/2011

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

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

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

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

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

ADT: 7,731 **Length:** 0.38

Project Information

Project Name: SH 392 / LCR 9 Intersection

Project Description: Intersection Improvements at SH 392 and LCR 9

CDOT Region: 4 Project Def: 17016 County: Larimer

Location: SH 392 Mile Points: 98.50 Length: N/A

Schedule: Work Start Date: 9/14/2009 Completion Date: 11/20/2009

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the crash history showed a higher than expected number of westbound rear-end crashes. There were 12 rear-end crashes during the five-year (2002 – 2006) time period. During that time period, there was no westbound left-turn lane at the intersection. As a result, vehicles slowing to make a westbound left-turn were getting struck by westbound through vehicles.

Improvement Description: In 2009, a westbound left-turn lane was constructed. The cost of construction was $316,627.

The HSIP application anticipated that westbound rear-end crashes would be impacted by this improvement. It was anticipated that there would be approximately a 50% crash reduction for these crashes. The initial benefit/cost ratio was estimated to be 1.42.

Summary and Findings

The analysis of safety before and after a westbound left-turn lane was constructed at the intersection of SH 392 and LCR 9 showed safety improved for the affected crash types. For this intersection, there were eight total crashes during the five-year period before the improvement (2004 – 2008). In the five years after construction (2010 – 2014), the number of crashes decreased to five and all westbound rear-end crashes were eliminated.

The westbound left-turn lane was responsible for decreases in the number of rear-end and approach turn crashes, while there was an increase in broadside crashes. The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 0.42 to one, showing that the improvement was likely not justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from eight during the five-year period (2004 to 2008) before the left-turn lane was installed (see **Table 1** and **Exhibit 1**) to five during the five-year after period (2010 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes remained the same while the number of injuries increase:

- Before (2004 – 2008) – no fatal crashes and 2 injury crashes with 2 injuries
- After (2010 – 2014) – no fatal crashes and 2 injury crashes with 3 injuries

The number of crashes decreased slightly along with a decrease in traffic volumes at the intersection. This resulted in a small increase in the crash rates:

- Before (2004 – 2008): 0.31 crashes per million entering vehicles (cpmev)
- After (2010 – 2014): 0.23 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
AADT (SH 392/LCR 9)	13,550/500 vpd	11,550/500 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**8**	**5**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	2 (2)	2 (3)
Property Damage Only	6	3
Crash Types: # (%) [significance]		
Rear-End	6 (75.0%) [99.99%]	0
Approach Turn	1 (12.5%)	0
Overturning	1 (12.5%)	0
Broadside	0	3 (60.0%)

Normally, the magnitude of safety problems on highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. However, in the case of this 3-lane, rural intersection, no SPFs have been developed to use for analysis.

A more detailed review of the before and after crash record reveals that improvement in safety can be attributed to the addition of the westbound left-turn lane. **Table 2** shows a comparison of total intersection crashes as well as the primary types of crashes that are most directly affected by the improvement: rear-end and approach turn. As shown, there were no rear-end or approach turn crashes in the after period. There was an after period crash that involved a vehicle hitting a hydraulic jack that was left in the roadway. Because this crash was not related to the improvements, it was removed from the analysis. The No Build After crashes were estimated using the change in daily volumes on the mainline found in **Table 1** (increase is 0.85 = 11,550/13,550).

Table 2 – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
Crash Types:			
Total Crashes	**8**	**4**	**7**
Injury (injuries)	2 (2)	2 (3)	2 (2)
PDO	6	2	5
% Reduction in Total (Injuries/PDO)		-50% / 60%	
Rear-Ends – Total (Westbound Only)	**6**	**0**	**5**
Injury (injuries)	1 (1)	0	1 (1)
PDO	5	0	4
% Reduction in Total		100%	
Approach Turns – Total	**1**	**0**	**1**
Injury (injuries)	1 (1)	0	1 (1)
PDO	0	0	0
% Reduction in Total		100%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 1** for the impacted crash types. The increase in injury crashes in the after period was factored into the analysis by increasing the cost of construction for the safety improvement. During the five-year after period, there were one additional injury. Over the design life of 20 years for the project, the increased cost of injuries would be $322,800 (4 injuries = $322,800). As shown, the B/C ratio for the study intersection is 0.42, showing that the improvement was somewhat less cost-effective than expected. This outcome, however. may have been influenced by the number of individuals injured in the after period. The number of injured is subject to chance and may have biased the conclusion.

Figure 1 – Benefit Cost Analysis – Rear-End and Approach Turn Crashes Only

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

09/06/2016

Job #: 20160906082812

Location: 392A **Begin:** 98.33 **End:** 98.73 **From:** 01/01/2004 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	6		Weighted PDO:	1.47	40% : CRF for PDO	Cost of PDO:	$ 9,300
INJ:	2	2 : Injured	Weighted INJ:	0.49	40% : CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 : Killed	Weighted FAT:	0.00	40% : CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	40% : Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 639,427
From: 01/01/2004
To: 12/31/2008 Days: 1827

Benefit Cost Ratio: 0.42 (B/C Based on Crash Numbers : PDO/INJ/FAT)

Type of Improvement: ADD LEFT TURN
Special Notes:

Location: 392A **Begin:** 98.33 **End:** 98.73 **From:** 01/01/2004 **To:** 12/31/2008

Severity

PDO:	6	
INJ:	2	2 :Injured
FAT:	0	0 :Killed
Total:	**8**	

Number of Vehicles

One Vehicle:	1
Two Vehicles:	7
Three or More:	0
Unknown:	0
Total:	**8**

Location

On Road:	7
Off Road Left:	1
Off Road Right:	0
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**8**

Lighting Conditions

Daylight:	8
Dawn or Dusk:	0
Dark - Lighted:	0
Dark - Unlighted:	0
Unknown:	0
Total:	**8**

Weather Conditions

None:	5
Rain:	3
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**8**

Crash Rates

PDO:	0.61 *	* MVMT
INJ:	0.20 *	** 100 MVMT
FAT:	0.00 **	**Total:** **0.81** *

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	8
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**8**

Road Description

At Intersection:	3
At Driveway Access:	0
Intersection Related:	5
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**8**

Road Conditions

Dry:	4
Wet:	3
Muddy:	0
Snowy:	0
Icy:	1
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**8**

ADT: 13,554 **Length:** 0.40

Location: 392A **Begin:** 98.33 **End:** 98.73 **From:** 01/01/2004 **To:** 12/31/2008

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	5	6	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	1	0	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	2	1	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**8**	**7**	**0**

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

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	0	1	0
Southeast:	0	0	0
South:	0	0	0
Southwest:	0	0	0
West:	8	6	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**8**	**7**	**0**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	5	7	0
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	1	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	0	0	0
Total:	**8**	**7**	**0**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	7	7	0
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**8**	**7**	**0**

ADT: 13,554 **Length:** 0.40

Location: 392A **Begin:** 98.33 **End:** 98.73 **From:** 01/01/2010 **To:** 12/31/2014

Severity

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

Number of Vehicles

One Vehicle:	2
Two Vehicles:	3
Three or More:	0
Unknown:	0
Total:	**5**

Location

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

Lighting Conditions

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

Weather Conditions

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

Crash Rates

PDO:	0.36 *	
INJ:	0.24 *	
FAT:	0.00 **	**Total: 0.59** *

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	5
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

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

Road Description

At Intersection:	4
At Driveway Access:	0
Intersection Related:	1
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**5**

Road Conditions

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

ADT: 11,565 **Length:** 0.40

Location: 392A **Begin:** 98.33 **End:** 98.73 **From:** 01/01/2010 **To:** 12/31/2014

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

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

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

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

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	4	3	0
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**5**	**3**	**0**

ADT: 11,565 **Length:** 0.40

Project Information

Project Name: Install Guardrail on US 50A West

Project Description: Install guardrail on the westbound shoulder

CDOT Region: 2 Project Def: 17025 County: Fremont

Location: US 50 Mile Points: 271.00 – 275.00 Length: 3.82 miles

Schedule: Work Start Date: 5/18/2009 Completion Date: 6/19/2009

Problem Description: The four-year crash history (2003 – 2006) showed that there was a total of 29 crashes. These 29 crashes included 22 PDO crashes and 7 injury crashes.

Improvement Description: Between May 18, 2009 and June 19, 2009, guardrail was installed along the westbound shoulder of US 50 between MP 271.00 and MP 275.00. The cost of construction was $245,724.

The project was anticipated to have no reduction in property damage only crashes, a 40% reduction in injury crashes, and a 60% reduction in fatal crashes as a result of the improvement. The initial benefit/cost ratio was estimated to be 1.26.

Summary and Findings

The analysis of safety before and after the guardrail that was installed along the south side of US 50 showed a reduction in the frequency and severity of overturning crashes. Along this segment of 3-lane undivided highway, there were 62 total crashes during the five-year period before the guardrail was installed (2004 – 2008). In the five years after construction (2010 – 2014), the number of crashes decreased to 60. This decrease in crashes occurred despite a slight increase in AADT on the roadway.

A comparison of overturning and fixed object type crashes before and after the installation of the guardrail showed that there was a decrease in total crashes and injuries. There was one additional fatality that occurred after the guardrail was installed. However, this was discounted from the analysis as it did not seem to be related to the new guardrail. The ratio of benefits and cost for this project shows that benefits outweighed costs as the B/C ratio was 2.12 to one. The result is an improvement was likely justified from an economic standpoint.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records shows slight decrease in the number of crashes; the total number of non-intersection crashes decreased from 62 during the five-year period (2004 to 2008) before the guardrail was installed (see **Table 1** and **Exhibit 1**) to 60 during the five-year after period (2010 to 2014) (see **Table 1** and **Exhibit 2**). Along with the total number of crashes decreasing, the number of injuries decreased although the number of fatalities increased:

- Before (2004 – 2008) – 1 fatal crash with 1 fatality and 22 injury crashes with 30 injuries
- After (2010 – 2014) – 3 fatal crashes with 4 fatalities and 17 injury crashes with 26 injuries

The overturning and embankment crashes saw the largest decrease in the after period. It is likely the guardrail prevented more severe off-road crashes.

Table 1 – US 50A (MP 271.00 to MP 275.00) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
AADT	7,608 vpd	7,899 vpd
Filters:	Non-Intersection	Non-Intersection
Total Crashes	**62**	**60**
Fatal Crashes (Fatalities)	1 (1)	3 (4)
Injury Crashes (Injuries)	22 (30)	17 (26)
Property Damage Only	39	40
Crash Types: # (% of total crashes) [cumulative probability]		
Fixed Objects	18 (29.0%)	25 (41.7%)
Wild Animals	18 (29.0%)	19 (31.7%) [98.21%]
Overturning	15 (24.2%) [99.99%]	9 (15.0%) [98.60%]
Fixed Object Crashes: # (% of FO) [cumulative probability]		
Embankment	9 (50.0%) [98.60%]	6 (24.0%)
Guardrail	3 (16.7%)	3 (12.0%)
Large Boulder	2 (11.1%)	5 (24.0%) [99.93%]
Tree	0	3 (12.0%)

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

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level

of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

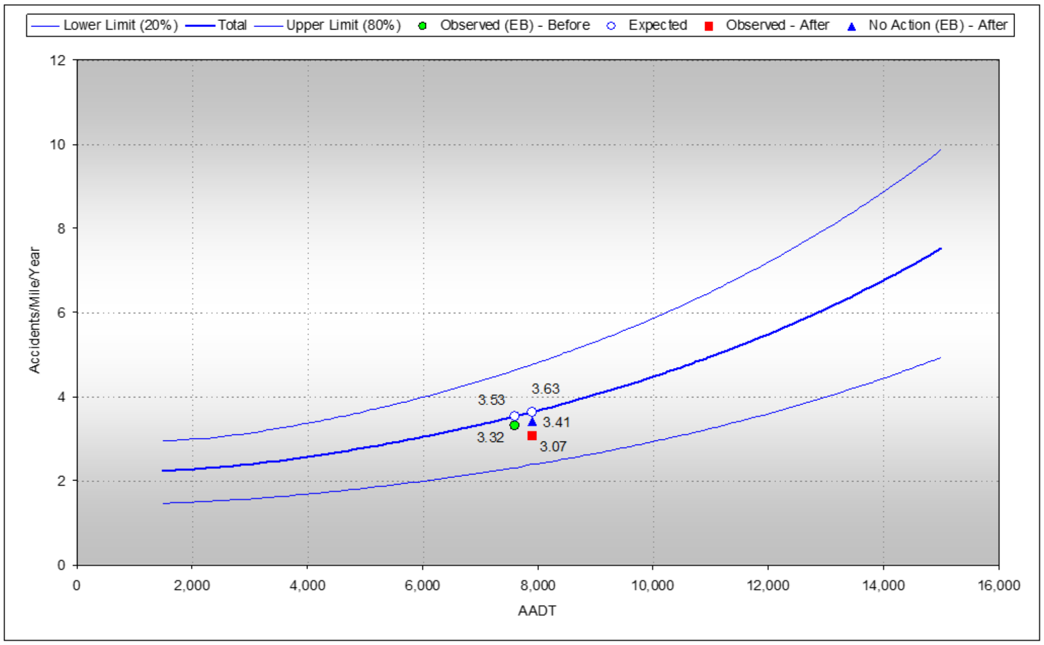
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect this change in the crash record. The crash rate decreased in the after period in both frequency and severity. However, the frequency of crashes remained in the LOSS II category in the after period and the severity of crashes remained in the LOSS III category. **Table 2** provides the results of the SPF analysis.

Figure 1 - SPF for Total Crashes

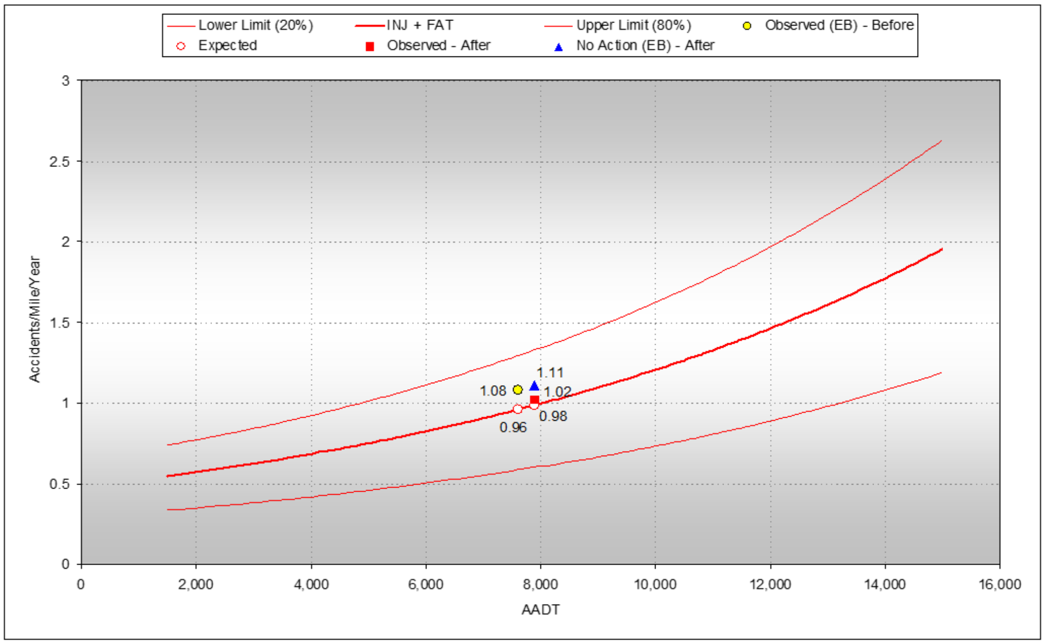
US 50A (MP 271.00 to MP 275.00)
Before: 2004 to 2008 After: 2010 to 2014



Note: Safety Performance Function (SPF) Model: Colorado - Rural Mountainous 3-Lane Undivided Highway

Figure 2 - SPF for Injury and Fatal Crashes

US 50A (MP 271.00 to MP 275.00)
Before: 2004 to 2008 After: 2010 to 2014



Note: Safety Performance Function (SPF) Model: Colorado - Rural Mountainous 3-Lane Undivided Highway

Table 2 – US 50A (MP 271.00 to MP 275.0) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Rural, Mountainous, 3-lane Undivided Highway	Rural, Mountainous, 3-lane Undivided Highway	Rural, Mountainous, 3-lane Undivided Highway
Total Crashes:			
LOSS	LOSS II	LOSS II	LOSS II
CPMPY	3.32	3.07	3.41
Mean CPMPY	3.53	3.63	3.63
Proportion of Mean	0.94	0.85	0.94
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS III	LOSS III
CPMPY	1.08	1.02	1.11
Mean CPMPY	0.96	0.98	0.98
Proportion of Mean	1.13	1.04	1.13

A more detailed review of the before and after crash record reveals that there was a reduction in frequency and severity of overturning crashes that occurred off the south side of the roadway. The number of fixed object crashes increased in the after period with a fatality when no fatality was recorded in the before period. Typically, there is an increase in guardrail crashes with the installation of guardrail, however there were no guardrail crashes in the before or after period. **Table 3** provides a comparison of the overturning and fixed object crashes. The No Build After crashes were estimated using the increase in the mean of the SPF for total crashes found in **Table 2** (increase is 1.03 = 3.63/3.53). **Table 3** shows a decrease in frequency and severity of overturning crash types prevented by guardrail. However, the number and severity of fixed object crashes increased in the after period.

Table 3 – US 50A (MP 271.00 to MP 275.0) - Results of Guardrail Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
Crash Types:			
Overturning – Total (Off-Road South Only)	**9**	**3**	**9**
Injury (injuries)	4 (5)	1 (1)	4 (5)
PDO	5	2	5
% Reduction in Total – (Injuries/ PDO)		80% / 60%	
Fixed Objects – Total (Off-Road South Only, excluding Guardrail)	**10**	**14**	**10**
Fatal (fatalities	0	1 (1)	0
Injury (injuries)	3 (3)	4 (5)	3 (3)
PDO	7	9	7
% Reduction in Total – (Fatalities/Injuries/ PDO)		NA / -66% / -28%	
Guardrail – Total (South Onlyl)	**0**	**0**	**0**

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the guardrail improvement. The analysis only includes off-road crashes occurring off the south side of the roadway where the new guardrail was constructed. The B/C ratio for the improvement is 2.12 showing that the improvement was likely justified. Based on the review of the after period crash history this location will benefit from more guardrail and center line rumble strips.

Figure 3 – US 50A (MP 271.00 to MP 275.00) - Benefit Cost Analysis – Overturning and Fixed Object Off-Road South Crashes Only

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

08/16/2016

Job #: 20160816140508

Location: 50A **Begin:** 271.00 **End:** 275.00 **From:** 01/01/2010 **To:** 12/31/2014

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors				Other Information	
PDO:	12		Weighted PDO:	2.95	8%	CRF for PDO	Cost of PDO:	$ 9,300
INJ:	7	8 :Injured	Weighted INJ:	1.97	25%	CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0%	CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	14%	Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
							Service Life:	20
							Capital Recovery Factor:	0.080
							Annual Maintenance/Delay Cost:	$ 0

Cost: $ 245,724
From: 01/01/2010
To: 12/31/2014

Days: 1826

Benefit Cost Ratio: 2.12 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: GUARDRAIL - INSTALLATION (OFF-ROAD CRASHES ONLY)
Special Notes:

Location: 50A **Begin:** 271.00 **End:** 275.00 **From:** 01/01/2004 **To:** 12/31/2008

Severity

PDO:	39		
INJ:	22	30	:Injured
FAT:	1	1	:Killed
Total:	**62**		

Number of Vehicles

One Vehicle:	52
Two Vehicles:	8
Three or More:	2
Unknown:	0
Total:	**62**

Location

On Road:	27
Off Road Left:	9
Off Road Right:	26
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**62**

Lighting Conditions

Daylight:	34
Dawn or Dusk:	4
Dark - Lighted:	1
Dark - Unlighted:	23
Unknown:	0
Total:	**62**

Weather Conditions

None:	45
Rain:	3
Snow/Sleet/Hail:	13
Fog:	0
Dust:	0
Wind:	0
Unknown:	1
Total:	**62**

Crash Rates

PDO:	0.73	*
INJ:	0.41	*
FAT:	1.88	**
Total:	**1.17**	*

* MVMT
** 100 MVMT

Crash Type

Overturning:	15	Bridge Abutment:	0
Other Non Collision:	2	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	2
Broadside:	0	Embankment:	9
Head On:	0	Curb:	0
Rear End:	3	Delineator Post:	1
Sideswipe (Same):	1	Fence:	0
Sideswipe (Opposite):	2	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	2
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	1	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	1	Total Fixed Objects:	18
Wild Animal:	18	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	1
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	1
Guard Rail:	3	Unknown:	0
Cable Rail:	0	**Total:**	**62**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	62
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**62**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	62
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**62**

Road Conditions

Dry:	43
Wet:	4
Muddy:	0
Snowy:	2
Icy:	10
Slushy:	2
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	1
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**62**

ADT: 7,608 **Length:** 3.82

Location: 50A **Begin:** 271.00 **End:** 275.00 **From:** 01/01/2004 **To:** 12/31/2008

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	39	8	1
Passenger Car/Van w/Trl:	1	0	0
Pickup Truck/Utility Van:	15	1	0
Pickup Truck/Utility Van w/Trl:	2	0	0
SUV:	4	0	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**62**	**10**	**2**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	49	7	1
Slowing:	2	1	0
Stopped in Traffic:	0	1	1
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	2	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	8	0	0
Unknown:	1	0	0
Total:	**62**	**10**	**2**

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	38	4	2
Southeast:	0	0	0
South:	0	0	0
Southwest:	0	0	0
West:	24	6	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**62**	**10**	**2**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	42	10	2
Asleep at the Wheel:	4	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	5	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	5	0	0
Driver Unfamilar with Area:	2	0	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	2	0	0
Total:	**62**	**10**	**2**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	60	10	2
Alcohol Involved:	2	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**62**	**10**	**2**

ADT: 7,608 **Length:** 3.82

Detailed Summary of Crashes Report

Exhibit 2

08/15/2016

Job #: 20160815161301

Location: 50A **Begin:** 271.00 **End:** 275.00 **From:** 01/01/2010 **To:** 12/31/2014

Severity

PDO:	40		
INJ:	17	26	:Injured
FAT:	3	4	:Killed
Total:	**60**		

Number of Vehicles

One Vehicle:	52
Two Vehicles:	8
Three or More:	0
Unknown:	0
Total:	**60**

Location

On Road:	27
Off Road Left:	11
Off Road Right:	22
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**60**

Lighting Conditions

Daylight:	33
Dawn or Dusk:	2
Dark - Lighted:	1
Dark - Unlighted:	24
Unknown:	0
Total:	**60**

Weather Conditions

None:	45
Rain:	0
Snow/Sleet/Hail:	12
Fog:	1
Dust:	0
Wind:	2
Unknown:	0
Total:	**60**

Crash Rates

PDO:	0.71 *
INJ:	0.30 *
FAT:	5.32 **
Total:	**1.06** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	9	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	6
Head On:	1	Curb:	1
Rear End:	2	Delineator Post:	1
Sideswipe (Same):	1	Fence:	1
Sideswipe (Opposite):	1	Tree:	3
Approach Turn:	0	Large Boulders or Rocks:	6
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	1	Wall/Building:	2
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	25
Wild Animal:	19	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	2	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	3	Unknown:	0
Cable Rail:	0	**Total:**	**60**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	60
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**60**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	60
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**60**

Road Conditions

Dry:	43
Wet:	1
Muddy:	0
Snowy:	2
Icy:	11
Slushy:	3
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**60**

ADT: 7,899 **Length:** 3.90

Location: 50A **Begin:** 271.00 **End:** 275.00 **From:** 01/01/2010 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	20	3	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	15	1	0
Pickup Truck/Utility Van w/Trl:	4	0	0
SUV:	17	2	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	1	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	3	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	1	0
Unknown:	0	0	0
Total:	**60**	**8**	**0**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	34	4	0
Slowing:	3	1	0
Stopped in Traffic:	0	0	0
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	2	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	1	1	0
Weaving:	2	0	0
Other:	18	1	0
Unknown:	0	0	0
Total:	**60**	**8**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	1	0	0
Northeast:	0	0	0
East:	31	3	0
Southeast:	0	0	0
South:	1	0	0
Southwest:	0	0	0
West:	27	5	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**60**	**8**	**0**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	46	8	0
Asleep at the Wheel:	2	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	4	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	6	0	0
Total:	**60**	**8**	**0**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	54	8	0
Alcohol Involved:	4	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	2	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**60**	**8**	**0**

ADT: 7,899 **Length:** 3.90

Project Information

Project Name: US-550 at Niagara in Montrose, Intersection Improvements

Project Description: Hazard Elimination, Access Improvement and Signalization

CDOT Region: 3 Project Def: 17034 County: Mesa

Location: SH 550 Mile Point: 12.24 Length: NA

Schedule: Work Start Date: est 10/2009 Completion Date: 10/27/2010

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the crash history showed a higher than expected frequency of crashes at the signalized T-intersection of Niagara and US 550 (and adjacent driveway accesses) in Montrose. There were 64 of these crashes during the five-year (1999 – 2003) period considered in the application.
.
Improvement Description: In fall 2010 The intersection was modified by widening Niagara (the minor street) to add an additional left turn lane – allowing an existing lane to become a dedicated right turn lane. The median of US-550 was also modified, a direct access from the intersection became a right-in from southbound US-550 and a full movement access south of the intersection from US-550 became right-in, right-out from northbound US-550. Construction cost $423, 714.

The HSIP application anticipated that broadside, approach turn and rear end crashes would be impacted by this improvement. It was anticipated that there would be approximately a 15% crash reduction for these crashes. The expected benefit/cost ratio was estimated to be 1.55.

Summary and Findings

The analysis of safety before and after intersection improvements, an added lane on the minor approach, median modification and access restrictions on the major road, showed that safety was improved. For the intersection and adjacent access there were 35 total crashes during the four-year period before the improvements were constructed (2006-2009) In the four years after construction the number of crashes decreased to 27.

The additional left turn lane, median improvements and access restrictions were apparently responsible for the reduction of broadside and rear end crashes at the intersection. Approach turn crashes were not effectively reduced, and occurred with the same frequency in both periods. The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 1.30 to one, showing that the improvement was justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 53 during the five-year period (2003 to 2007) before the new signal was installed and the other driveway access modified. (see **Table 1** and **Exhibit 1**) to 26 during the five-year after period (2009 to 2013) (see **Table 1** and **Exhibit 2**). The number of severe crashes also decreased in the five-year period after the improvements:

- Before (2006 – 2009) – no fatal crashes and 11injury crashes with 12 injuries
- After (20011 – 2014) – no fatal crashes and 5 injury crashes with 9 injuries

Despite an increase in traffic volumes at the intersection, the crash rates at the intersection still decreased:

- Before (2006 – 2009): 0.68 crashes per million entering vehicles (cpmev)
- After (2009 – 2013): 0.51 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2006 to 12/31/2009 (4 yr.)	1/1/2011 to 12/31/2013(4 yr.)
AADT (SH 550/Niagara)	25,812 / 9,600 vpd	26,356 / 9,600 vpd
Filters:	At Intersection Intersection Related At Driveway Access	At Intersection Intersection Related At Driveway Access
Total Crashes	**35**	**27**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	11 (12)	5 (9)
Property Damage Only	24	22
Crash Types: # (%) [significance]		
Broadside	6 (17.1%)	3 (11.1%)
Approach Turn	7 (20.0%)	7 (25.9%)
Rear End	14 (40.0%)	11 (40.7%)

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

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level

of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

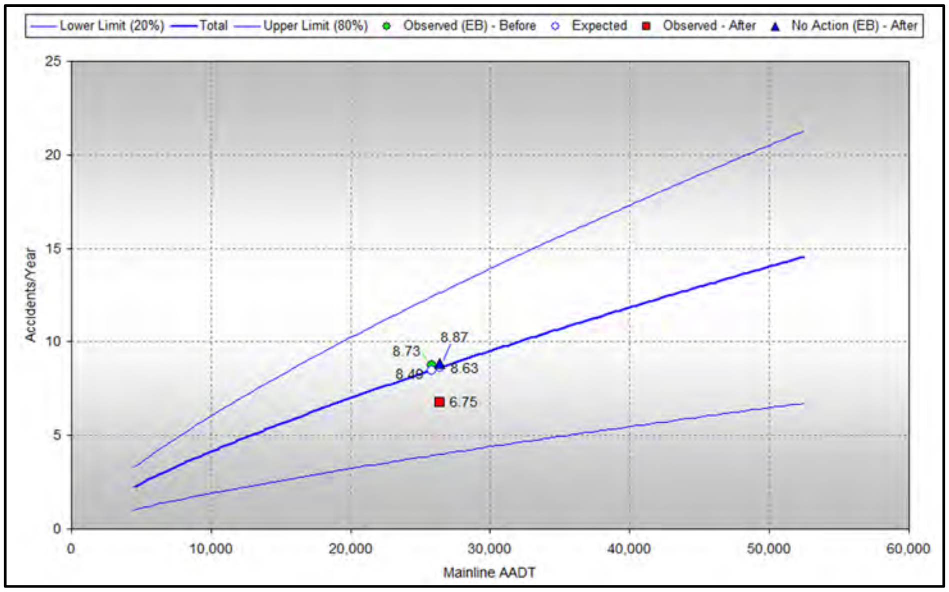
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. The frequency and severity of crashes improved from LOSS III category for the before period to LOSS II for the after period. (see **Table 2**).

Figure 1 - SPF for Total Crashes

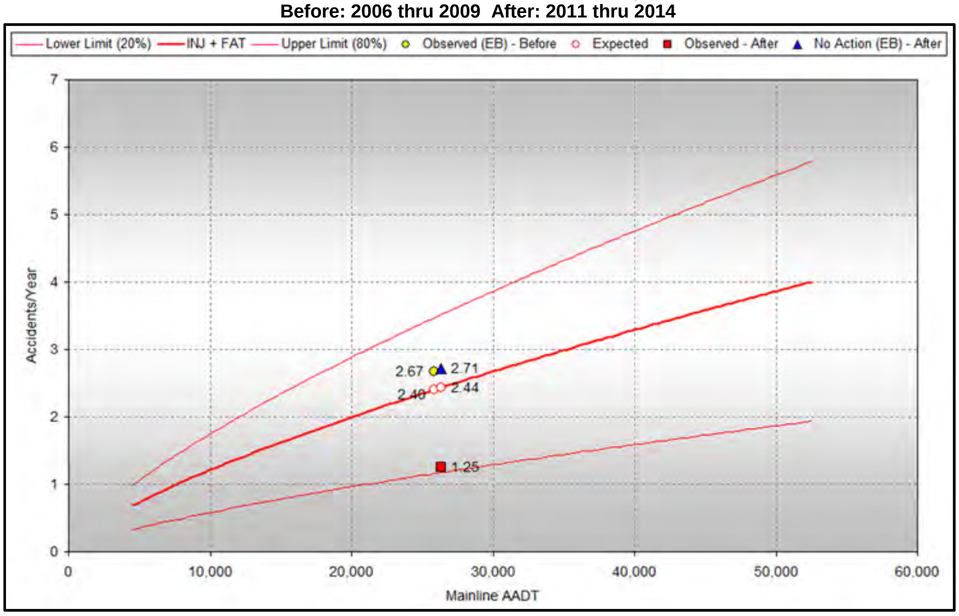
SH 550B (MP 12.24) at Niagara
Before: 2006 thru 2009 After: 2011 thru 2014



Note: Safety Performance Function (SPF) Model: Colorado – Urban 4-Lane Divided Signalized 3-Leg Intersection

Figure 2 – SPF Injury and Fatal Crashes

SH 550B (MP 12.24) at Niagara
Before: 2006 thru 2009 After: 2011 thru 2014



Note: Safety Perfromance Function (SPF) Model: Colorado – Urban 4-Lane Divided Signalized 3-Leg Intersection

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection*	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS III	LOSS II	LOSS III
CPY	8.73	6.75	8.87
Mean CPY	8.49	8.63	8.63
Proportion of Mean	1.03	0.78	1.03
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS II	LOSS III
CPY	2.67	1.25	2.71
Mean CPY	2.40	2.44	2.44
Proportion of Mean	1.11	0.51	1.11

A more detailed review of the before and after crash record reveals that improvement in safety can be attributed to the added lane on Niagara and the access restrictions on US-550. **Table 3** shows a comparison of primary types of crashes that were expected to be most directly affected by the improvement: broadside, approach turn and rear end, as well as the total intersection crashes. The No Build After crashes were estimated using the change in mean CPY found in **Table 2** (increase is 1.016 = 8.63/8.49).

Table 3 – Results of Crash Analyses

	Before	**After**	**No Build After**
Time Period:	1/1/2006 to 12/31/20011 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:			
Total Crashes	**35**	**27**	**36**
Fatal (fatalities)	0	0	0
Injury (injuries)	11 (12)	5 (9)	11 (12)
PDO	24	22	24
% Reduction in Total (Injuries/PDO)		25% / 8%	
Broadsides – Total	**6**	**3**	**6**
Fatal (fatalities)	0	0	0
Injury (injuries)	2 (2)	0	2 (2)
PDO	4	3	4
% Reduction in Total (Injuries/PDO)		100% / 25%	
Approach Turns - Total	**7**	**7**	**7**
Injury (injuries)	1 (1)	2 (4)	1 (1)
PDO	6	5	6
% Reduction in Total (Injuries/PDO)		-400% / 16%	
Rear Ends – Total	**14**	**11**	**14**
Injury (injuries)	5 (6)	1 (3)	5 (6)
PDO	9	10	9
% Reduction in Total (Injuries/PDO)		50% / -11%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crash types. As shown, the B/C ratio for the intersection, intersection related and driveway access crashes is 1.30, showing that the improvement was justified.

Figure 3 – Benefit Cost Analysis – Intersection and Intersection Related Crashes Only

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

11/14/2016
Job #: 20161114193353

Location: 550B **Begin:** 128.19 **End:** 128.29 **From:** 01/01/2006 **To:** 12/31/2009

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors				Other Information	
PDO:	24		Weighted PDO:	6.59	8%	:CRF for PDO	Cost of PDO:	$ 9,300
INJ:	11	12 :Injured	Weighted INJ:	3.29	25%	:CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0%	:CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	13%	:Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
		Cost: $ 423,714					Service Life:	10
		From: 01/01/2006					Capital Recovery Factor:	0.129
		To: 12/31/2009	Days: 1461				Annual Maintenance/Delay Cost:	$ 0

Benefit Cost Ratio: 1.30 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: INTERSECTION IMPROVEMENTS - ADDED LANE ON NIAGARA AND ACCESS RESTRICTIONS
Special Notes: INTERSECTION AND ACCESS CRASHES

Location: 550B **Begin:** 128.19 **End:** 128.29 **From:** 01/01/2006 **To:** 12/31/2009

Severity

PDO:	24	
INJ:	11	12 :Injured
FAT:	0	0 :Killed
Total:	**35**	

Number of Vehicles

One Vehicle:	1
Two Vehicles:	30
Three or More:	4
Unknown:	0
Total:	**35**

Location

On Road:	34
Off Road Left:	0
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**35**

Lighting Conditions

Daylight:	30
Dawn or Dusk:	0
Dark - Lighted:	5
Dark - Unlighted:	0
Unknown:	0
Total:	**35**

Weather Conditions

None:	34
Rain:	0
Snow/Sleet/Hail:	1
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**35**

Crash Rates

PDO:	6.30 *
INJ:	2.89 *
FAT:	0.00 **
Total:	**9.19** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	2	Culvert/Headwall:	0
Broadside:	6	Embankment:	0
Head On:	0	Curb:	0
Rear End:	14	Delineator Post:	0
Sideswipe (Same):	3	Fence:	1
Sideswipe (Opposite):	1	Tree:	0
Approach Turn:	7	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	1	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	1
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**35**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	35
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**35**

Road Description

At Intersection:	17
At Driveway Access:	9
Intersection Related:	9
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**35**

Road Conditions

Dry:	34
Wet:	0
Muddy:	0
Snowy:	1
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**35**

ADT: 25,812 **Length:** 0.10

Location: 550B **Begin:** 128.19 **End:** 128.29 **From:** 01/01/2006 **To:** 12/31/2009

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	20	17	3
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	12	6	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	3	8	1
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	1	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	2	0
Unknown:	0	0	0
Total:	**35**	**34**	**4**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	19	34	4
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	5	0	0
Driver Unfamilar with Area:	3	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	6	0	0
Total:	**35**	**34**	**4**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	34	34	4
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**35**	**34**	**4**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	12	16	0
Slowing:	4	1	0
Stopped in Traffic:	0	14	4
Making Right Turn:	4	2	0
Making Left Turn:	13	1	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**35**	**34**	**4**

Direction	Veh 1	Veh 2	Veh 3
North:	14	22	3
Northeast:	0	0	0
East:	2	3	0
Southeast:	0	0	0
South:	9	4	0
Southwest:	1	0	0
West:	9	5	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**35**	**34**	**4**

ADT: 25,812 **Length:** 0.10

Location: 550B **Begin:** 128.19 **End:** 128.29 **From:** 01/01/2011 **To:** 12/31/2014

Severity

PDO:	22		
INJ:	5	9	:Injured
FAT:	0	0	:Killed
Total:	**27**		

Number of Vehicles

One Vehicle:	0
Two Vehicles:	23
Three or More:	4
Unknown:	0
Total:	**27**

Location

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

Lighting Conditions

Daylight:	23
Dawn or Dusk:	2
Dark - Lighted:	2
Dark - Unlighted:	0
Unknown:	0
Total:	**27**

Weather Conditions

None:	24
Rain:	1
Snow/Sleet/Hail:	2
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**27**

Crash Rates

PDO:	5.66 *
INJ:	1.29 *
FAT:	0.00 **
Total:	**6.94** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	3	Embankment:	0
Head On:	0	Curb:	0
Rear End:	11	Delineator Post:	0
Sideswipe (Same):	4	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	7	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	1	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	0
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**27**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	27
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

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

Road Description

At Intersection:	17
At Driveway Access:	0
Intersection Related:	10
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**27**

Road Conditions

Dry:	22
Wet:	3
Muddy:	0
Snowy:	2
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**27**

ADT: 26,356 **Length:** 0.10

Location: 550B **Begin:** 128.19 **End:** 128.29 **From:** 01/01/2011 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	8	13	2
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	11	3	1
Pickup Truck/Utility Van w/Trl:	0	2	0
SUV:	5	6	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	1	0
School Bus < 15 People:	0	0	1
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	1	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	3	1	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**27**	**27**	**4**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	9	14	1
Slowing:	3	3	0
Stopped in Traffic:	1	6	3
Making Right Turn:	2	1	0
Making Left Turn:	9	2	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	1	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**27**	**27**	**4**

Direction	Veh 1	Veh 2	Veh 3
North:	12	17	1
Northeast:	0	0	0
East:	0	0	0
Southeast:	0	0	0
South:	10	5	2
Southwest:	0	0	0
West:	5	5	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**27**	**27**	**4**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	17	27	4
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	3	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	4	0	0
Total:	**27**	**27**	**4**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	26	27	4
Alcohol Involved:	0	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**27**	**27**	**4**

ADT: 26,356 **Length:** 0.10

Project Information

Project Name: SH 402 / CR 11 Construction and ROW

Project Description: Intersection Improvements

CDOT Region: 4 Project Def: 17115 County: Larimer

Location: SH 402 Mile Points: 1.00 Length: N/A

Schedule: Work Start Date: 6/20/2009 Completion Date: 1/14/2010

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the crash history showed a large number of rear-end crashes due to the lack of turn lanes on SH 402.

Improvement Description: From June 2009 to January 2010, an eastbound left-turn lane was constructed. In addition, the southbound leg went from a single left/right lane to having a left-turn and right-turn lane. Lastly, the intersection was also signalized. The cost of construction was $1,035,567.

The HSIP application anticipated that rear-end, broadside, and approach turn crashes would be impacted by this improvement. It was anticipated that there would be a 35% crash reduction for these crash types. The initial benefit/cost ratio was estimated to be 1.19.

Summary and Findings

Safety improvements at the intersection of SH 402 and CR 11 included constructing turn lanes and signalizing the intersection The analysis of safety before and after the improvements showed safety improved for the affected crash types, including rear-end and broadside. For this intersection, there were 33 total crashes during the four-year period before the improvement (2005 – 2008). In the five years after construction (2011 – 2014), the number of crashes decreased to 10.

The eastbound left-turn lane was responsible for decreases in the number of rear-end crashes and signalizing the intersection likely reduced the number of broadsides. However, the ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 0.81 to one. This shows that the improvements may not have been justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 33 during the four-year period (2005 to 2008) before the project (see **Table 1** and **Exhibit 1**) to 10 during the four-year after period (2011 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes also decreased in the four-year period after the improvements:

- Before (2005 – 2008) – no fatal crashes and 10 injury crashes with 12 injuries
- After (2011 – 2014) – no fatal crashes and 6 injury crashes with 11 injuries

Despite a decrease in traffic volumes at the intersection, the crash rates at the intersection still decreased:

- Before (2005 – 2008): 1.09 crashes per million entering vehicles (cpmev)
- After (2011 – 2014): 0.35 cpmev

Table 1 - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT (SH 402/CR 11)	15,775/4,950 vpd	14,500/4,950 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**33**	**10**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	10 (12)	6 (11)
Property Damage Only	23	4
Crash Types: # (%) [significance]		
Rear-End	21 (63.6%) [99.99%]	4 (40.0%)
Fixed Object	5 (15.2%)	0
Broadside	5 (15.2%)	2 (20.0%)

Normally, the magnitude of safety problems on highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. However, in the case of this 2-lane, divided, signalized, 3-leg intersection that was the result of the improvements, no SPFs were available to use for the analysis.

A more detailed review of the before and after crash record reveals that improvement in safety can be attributed to the safety improvement project. **Table 2** shows a comparison of the crash types most directly affected by the improvement: rear-end and broadside. As shown, the number of rear-end decreased significantly in the after period. The No Build After crashes were estimated using the change in daily volumes found in **Table 1** (decrease is 0.92 = 14,500/15,775).

Table 2 – Results of Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:			
Total Crashes	**33**	**10**	**30**
Injury (injuries)	10 (12)	6 (11)	9 (11)
PDO	23	4	21
% Reduction in Total (Injuries/PDO)		0% / 81%	
Rear Ends – Total (Eastbound Only)	**19**	**3**	**17**
Injury (injuries)	7 (9)	3 (5)	6 (8)
PDO	12	0	11
% Reduction in Total (Injuries/PDO)		38% / 100%	
Broadside – Total	**5**	**2**	**5**
Injury (injuries)	1 (1)	1 (3)	1 (1)
PDO	4	1	4
% Reduction in Total (Injuries/PDO)		-200% / 75%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 1** for the impacted crash types. As shown, the B/C ratio for intersection crashes is 0.32, reflecting that cost-effectiveness of the improvement was somewhat less than expected. This outcome, however, may've been influenced by the number of individuals injured in the after period. The number of injured is subject to chance and may've biased the conclusion. If the reduction in the number of injury accidents is considered instead, the B/C outcome is approximately 0.81:1 (See **Figure 2**). It is important to acknowledge that approximately 40% reduction in the number of injury crashes was observed and 82% reduction in PDOs.

Figure 1 – Benefit Cost Analysis – Intersection and Intersection Related Crashes Only, Calculated Based on Number of Injuries

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

09/05/2016

Job #: 20160905225238

Location: 402A **Begin:** 0.90 **End:** 1.10 **From:** 01/01/2005 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors				Other Information	
PDO:	21		Weighted PDO:	5.76	81% :	CRF for PDO	Cost of PDO:	$ 9,300
INJ:	9	11 :Injured	Weighted INJ:	3.02	0% :	CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :	CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	56% :	Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
							Service Life:	10
							Capital Recovery Factor:	0.129
							Annual Maintenance/Delay Cost:	$ 0

Cost: $ 1,035,567
From: 01/01/2005
To: 12/31/2008 Days: 1461

Benefit Cost Ratio: 0.32 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: ADDING TURDN LANES, SIGNALIZE
Special Notes:

Figure 1 – Benefit Cost Analysis – Intersection and Intersection Related Crashes Only, Calculated Based on Number of Injury Crashes

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

09/26/2016

Job #: 20160926143739

Location: 402A **Begin:** 0.90 **End:** 1.10 **From:** 01/01/2005 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors				Other Information	
PDO:	21		Weighted PDO:	5.76	81% :	CRF for PDO	Cost of PDO:	$ 9,300
INJ:	9	11 :Injured	Weighted INJ:	2.47	33% :	CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :	CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	66% :	Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
							Service Life:	10
							Capital Recovery Factor:	0.129
							Annual Maintenance/Delay Cost:	$ 0

Cost: $ 1,035,567
From: 01/01/2005
To: 12/31/2008 Days: 1461

Benefit Cost Ratio: 0.81 (B/C Based on Crash Numbers : PDO/INJ/FAT)

Type of Improvement: ADD TURN LANES, SIGNALIZE
Special Notes:

Location: 402A **Begin:** 0.90 **End:** 1.10 **From:** 01/01/2005 **To:** 12/31/2008

Severity

PDO:	23	
INJ:	10	12 :Injured
FAT:	0	0 :Killed
Total:	**33**	

Number of Vehicles

One Vehicle:	5
Two Vehicles:	26
Three or More:	2
Unknown:	0
Total:	**33**

Location

On Road:	28
Off Road Left:	0
Off Road Right:	2
Off Road at Tee:	3
Off in Median:	0
Unknown:	0
Total:	**33**

Lighting Conditions

Daylight:	23
Dawn or Dusk:	1
Dark - Lighted:	0
Dark - Unlighted:	9
Unknown:	0
Total:	**33**

Weather Conditions

None:	28
Rain:	3
Snow/Sleet/Hail:	1
Fog:	1
Dust:	0
Wind:	0
Unknown:	0
Total:	**33**

Crash Rates

PDO:	4.96 *
INJ:	2.16 *
FAT:	0.00 **
Total:	**7.12** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	0	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	5	Embankment:	0
Head On:	1	Curb:	0
Rear End:	21	Delineator Post:	0
Sideswipe (Same):	0	Fence:	2
Sideswipe (Opposite):	1	Tree:	2
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	5
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**33**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	33
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**33**

Road Description

At Intersection:	18
At Driveway Access:	0
Intersection Related:	15
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**33**

Road Conditions

Dry:	26
Wet:	5
Muddy:	0
Snowy:	0
Icy:	2
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**33**

ADT: 15,775 **Length:** 0.20

Location: 402A **Begin:** 0.90 **End:** 1.10 **From:** 01/01/2005 **To:** 12/31/2008

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	24	16	0
Passenger Car/Van w/Trl:	0	1	0
Pickup Truck/Utility Van:	7	7	2
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	2	4	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	0	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**33**	**28**	**2**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	21	28	2
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	4	0	0
Driver Unfamilar with Area:	2	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	1	0	0
Total:	**33**	**28**	**2**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	32	28	2
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**33**	**28**	**2**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	22	5	0
Slowing:	2	1	0
Stopped in Traffic:	0	20	2
Making Right Turn:	1	1	0
Making Left Turn:	5	1	0
Making U-Turn:	0	0	0
Passing:	1	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	1	0	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**33**	**28**	**2**

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	0	0	0
East:	22	19	2
Southeast:	0	0	0
South:	9	4	0
Southwest:	0	0	0
West:	2	5	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**33**	**28**	**2**

ADT: 15,775 **Length:** 0.20

COLORADO Department of Transportation

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

Exhibit 2

09/05/2016

Job #: 20160905212229

Location: 402A **Begin:** 0.90 **End:** 1.10 **From:** 01/01/2011 **To:** 12/31/2014

Severity

PDO:	4		
INJ:	6	11	:Injured
FAT:	0	0	:Killed
Total:	**10**		

Number of Vehicles

One Vehicle:	1
Two Vehicles:	9
Three or More:	0
Unknown:	0
Total:	**10**

Location

On Road:	9
Off Road Left:	0
Off Road Right:	1
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**10**

Lighting Conditions

Daylight:	8
Dawn or Dusk:	0
Dark - Lighted:	1
Dark - Unlighted:	1
Unknown:	0
Total:	**10**

Weather Conditions

None:	10
Rain:	0
Snow/Sleet/Hail:	0
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**10**

Crash Rates

PDO:	0.94	*
INJ:	1.42	*
FAT:	0.00	**
Total:	**2.36**	*

* MVMT
** 100 MVMT

Crash Type

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

Mainline/Ramps/Frontage Roads

Mainline:	10
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**10**

Road Description

At Intersection:	6
At Driveway Access:	0
Intersection Related:	4
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**10**

Road Conditions

Dry:	10
Wet:	0
Muddy:	0
Snowy:	0
Icy:	0
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**10**

ADT: 14,500 **Length:** 0.20

Location: 402A **Begin:** 0.90 **End:** 1.10 **From:** 01/01/2011 **To:** 12/31/2014

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

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	4	4	0
Slowing:	1	0	0
Stopped in Traffic:	0	3	0
Making Right Turn:	2	1	0
Making Left Turn:	1	0	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**10**	**9**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	1	0	0
Northeast:	0	0	0
East:	4	3	0
Southeast:	0	0	0
South:	2	1	0
Southwest:	0	0	0
West:	3	5	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**10**	**9**	**0**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	6	9	0
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	0	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	2	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	2	0	0
Total:	**10**	**9**	**0**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	9	9	0
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**10**	**9**	**0**

ADT: 14,500 **Length:** 0.20

Project Information

Project Name: SH 119 / Hover St Intersection Improvements

Project Description: Hazard Elimination, Left-Turn Lane Extension and Acceleration Lane

CDOT Region: 4 Project Def: 17116 County: Boulder

Location: SH 119 Mile Points: 54.41 Length: N/A

Schedule: Work Start Date: 6/9/2009 Completion Date: 7/16/2009

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the crash history showed a higher than expected number of SH 119 eastbound rear-end and sideswipe same direction crashes. There were 17 of these crashes during the five-year (2001 – 2005) time period. The eastbound left-turn lane was not sufficient at this intersection causing the rear-end and sideswipe same direction crashes.

Improvement Description: In 2009, the eastbound left-turn lane was extended, as was the southbound to westbound acceleration lane. The cost of construction was $88,350.

The HSIP application anticipated that westbound rear-end crashes would be impacted by this improvement. It was anticipated that there would be approximately a 10% crash reduction for these crashes. The initial benefit/cost ratio was estimated to be 0.76.

Summary and Findings

The analysis of safety before and after a westbound left-turn lane and the westbound to southbound acceleration lane were extended at the intersection of SH 119 and Hover Street showed safety improved for the affected crash types. For this intersection, there were 175 total crashes during the five-year period before the improvement (2004 – 2008). In the five years after construction (2010 – 2014), the number of crashes decreased to 159.

The westbound left-turn lane extension was responsible for decreases in the number of sideswipe same direction crashes. In addition, there was a decrease in westbound sideswipe same direction crashes due to the extension of the southbound to westbound acceleration lane. The ratio of benefits and cost for this project shows that benefits outweigh costs by a ratio of 15.77 to one, showing that the improvement was justified.

Results of Safety Analyses

Using VZS, the review of before and after crash records shows a decrease in the number of crashes; the total number of crashes decreased from 175 during the five-year period (2004 to 2008) before the eastbound left-turn lane and southbound to westbound acceleration lanes were extended (see **Table 1** and **Exhibit 1**) to 145 during the five-year after period (2010 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes also decreased in the five-year period after the improvements:

- Before (2004 – 2008) – no fatal crashes and 44 injury crashes with 65 injuries
- After (2010 – 2014) – no fatal crashes and 39 injury crashes with 55 injuries

Despite a decrease in traffic volumes at the intersection, the crash rates at the intersection still decreased:

- Before (2004 – 2008): 1.59 crashes per million entering vehicles (cpmev)
- After (2010 – 2014): 1.38 cpmev

Although approach turns do not rise to the pattern threshold, it should be noted there are more than five per year in the after period. Most of these approach turn crashes occurred on Hover Street. Of the 27 approach turn crashes, 12 resulted in injury with 19 injuries. It is recommended that the left turns on Hover Street be changed to protected phasing to reduce the approach turn crashes.

Table 1 - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
AADT (SH 119/Hover St)	29,000/31,250 vpd	26,250/31,250 vpd
Filters:	At Intersection Intersection Related	At Intersection Intersection Related
Total Crashes	**175**	**145**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	44 (65)	39 (55)
Property Damage Only	131	106
Crash Types: # (%) [significance]		
Rear-End	104 (59.4%) [100.0%]	87 (60.0%) [99.9%]
Approach Turn	35 (20.0%)	27 (18.6%)
Sideswipe Same Direction	19 (10.9%)	10 (6.9%)
Broadside	8 (4.6%)	10 (6.9%)

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

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

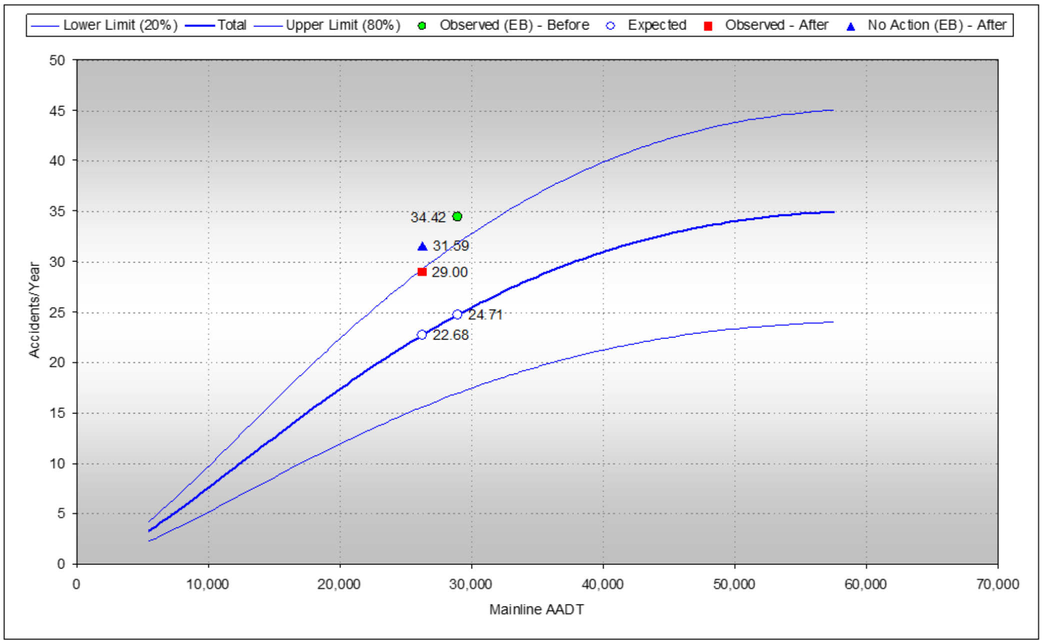
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. The frequency of crashes decreased from the LOSS IV category in the before period to the LOSS III / LOSS IV boundary and after period. The severity of crashes remained in the LOSS III category (see **Table 2**).

Figure 1 - SPF for Total Crashes

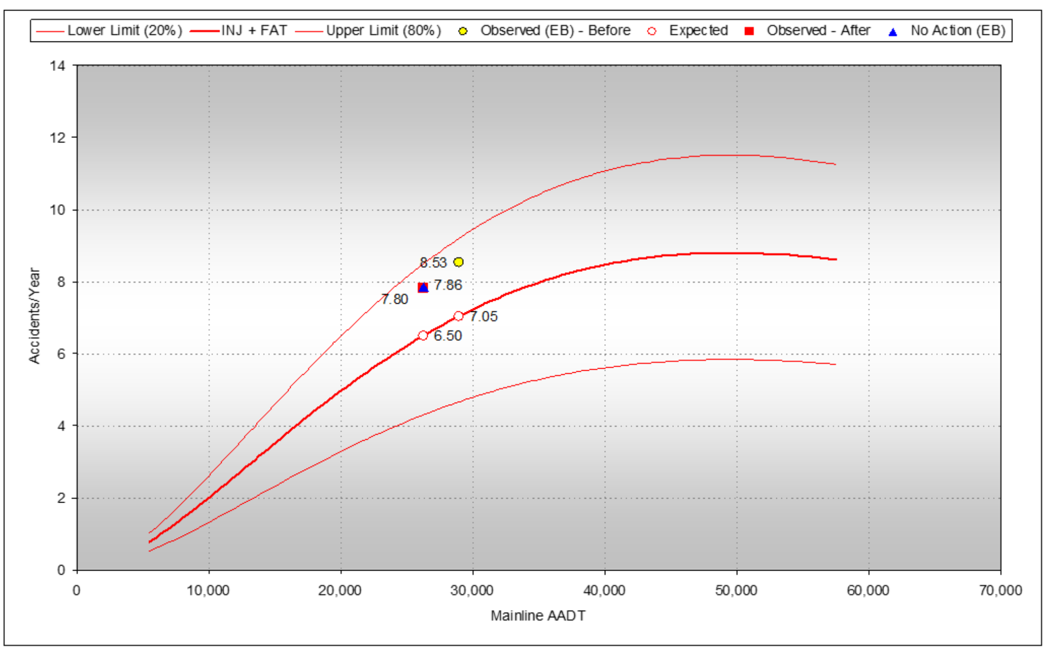
SH 119 (MP 54.41)
Before: 2004 to 2008 After: 2010 to 2014



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

Figure 2 - SPF for Injury and Fatal Crashes

SH 119 (MP 54.41)
Before: 2004 to 2008 After: 2010 to 2014



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

Table 2 – Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection	Urban, 4-lane, Divided, Signalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS IV	LOSS III/IV	LOSS IV
CPY	34.42	29.00	31.59
Mean CPY	24.71	22.68	22.68
Proportion of Mean	1.39	1.28	1.39
Fatal & Injury Crashes:			
LOSS	LOSS III	LOSS III	LOSS III
CPY	8.53	7.80	7.86
Mean CPY	7.05	6.50	6.50
Proportion of Mean	1.21	1.20	1.21

A more detailed review of the before and after crash record reveals that some improvement in safety can be attributed to the extension of the westbound left-turn lane and southbound to westbound acceleration lane. **Table 3** shows a comparison of primary types of crashes that are most directly affected by the improvement: rear-end and sideswipe same direction, as well as the total intersection crashes. The No Build After crashes were estimated using the change in mean CPY found in **Table 1** (decrease is 0.91 = 24.71/22.68).

Table 3 – Results of Crash Analyses

	Before	**After**	**No Build After**
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
Crash Types:			
Total Crashes	**175**	**145**	**159**
Injury (injuries)	44 (65)	39 (55)	40 (59)
PDO	131	106	119
% Reduction in Total (Injuries/PDO)		7% / 11%	
Rear-Ends – Total (Eastbound Only)	**26**	**25**	**24**
Injury (injuries)	7 (8)	9 (12)	7 (8)
PDO	19	16	17
% Reduction in Total (Injuries/PDO)		-50% / 6%	
Sideswipe Same Direction – Total (West Leg Only)	**8**	**3**	**7**
Injury (injuries)	1 (3)	0	1 (3)
PDO	7	3	6
% Reduction in Total (Injuries/PDO)		100% / 50%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the impacted crash types. As shown, the B/C ratio for the intersection and intersection related crashes is 15.77, showing that the improvement was justified.

Figure 3 – Benefit Cost Analysis – Intersection and Intersection Related Crashes Only

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

10/11/2016

Job #: 20161011230151

Location: 119B **Begin:** 54.31 **End:** 54.51 **From:** 01/01/2004 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes			Projected Crashes and Reduction Factors			Other Information	
PDO:	119		Weighted PDO:	29.24	11% :CRF for PDO	Cost of PDO:	$ 9,300
INJ:	40	59 :Injured	Weighted INJ:	14.50	7% :CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	9% :Weighted CRF	Interest Rate:	5%
						AADT Growth Factor:	2.0%
						Service Life:	20
						Capital Recovery Factor:	0.080
						Annual Maintenance/Delay Cost:	$ 0

Cost: $ 88,350
From: 01/01/2004
To: 12/31/2008 Days: 1827

Benefit Cost Ratio: 15.77 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: EXTEND ACCEL/DECEL LANES ON WEST LEG
Special Notes:

Location: 119B **Begin:** 54.31 **End:** 54.51 **From:** 01/01/2004 **To:** 12/31/2008

Severity

PDO:	131		
INJ:	44	65	:Injured
FAT:	0	0	:Killed
Total:	**175**		

Number of Vehicles

One Vehicle:	7
Two Vehicles:	165
Three or More:	3
Unknown:	0
Total:	**175**

Location

On Road:	168
Off Road Left:	2
Off Road Right:	4
Off Road at Tee:	0
Off in Median:	1
Unknown:	0
Total:	**175**

Lighting Conditions

Daylight:	126
Dawn or Dusk:	6
Dark - Lighted:	36
Dark - Unlighted:	2
Unknown:	5
Total:	**175**

Weather Conditions

None:	160
Rain:	5
Snow/Sleet/Hail:	5
Fog:	1
Dust:	0
Wind:	1
Unknown:	3
Total:	**175**

Crash Rates

PDO:	12.31 *
INJ:	4.13 *
FAT:	0.00 **
Total:	**16.44** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	2	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	8	Embankment:	0
Head On:	0	Curb:	2
Rear End:	104	Delineator Post:	0
Sideswipe (Same):	19	Fence:	0
Sideswipe (Opposite):	0	Tree:	1
Approach Turn:	35	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	1	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	6
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	2	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**175**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	175
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**175**

Road Description

At Intersection:	120
At Driveway Access:	0
Intersection Related:	55
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**175**

Road Conditions

Dry:	153
Wet:	9
Muddy:	0
Snowy:	1
Icy:	9
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	3
Total:	**175**

ADT: 28,981 **Length:** 0.20

Location: 119B **Begin:** 54.31 **End:** 54.51 **From:** 01/01/2004 **To:** 12/31/2008

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	120	129	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	28	24	3
Pickup Truck/Utility Van w/Trl:	1	1	0
SUV:	17	9	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	3	2	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	1	0	0
Motorhome:	0	0	0
Motorcycle:	2	3	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	3	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**175**	**168**	**3**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	114	160	2
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	7	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	24	1	0
Driver Unfamilar with Area:	6	0	0
Driver Emotionally Upset:	0	1	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	20	6	1
Total:	**175**	**168**	**3**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	172	168	3
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	2	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**175**	**168**	**3**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	91	51	0
Slowing:	13	10	0
Stopped in Traffic:	4	87	3
Making Right Turn:	7	4	0
Making Left Turn:	40	10	0
Making U-Turn:	0	1	0
Passing:	0	0	0
Backing:	3	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	0
Changing Lanes:	12	3	0
Avoiding Object/Veh in Road:	1	1	0
Weaving:	1	0	0
Other:	3	0	0
Unknown:	0	0	0
Total:	**175**	**168**	**3**

Direction	Veh 1	Veh 2	Veh 3
North:	45	45	0
Northeast:	1	1	0
East:	36	38	1
Southeast:	0	1	0
South:	55	49	1
Southwest:	5	3	0
West:	33	31	1
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**175**	**168**	**3**

ADT: 28,981 **Length:** 0.20

Location: 119B **Begin:** 54.31 **End:** 54.51 **From:** 01/01/2010 **To:** 12/31/2014

Severity

PDO:	106	
INJ:	39	55 :Injured
FAT:	0	0 :Killed
Total:	**145**	

Number of Vehicles

One Vehicle:	9
Two Vehicles:	123
Three or More:	13
Unknown:	0
Total:	**145**

Location

On Road:	137
Off Road Left:	6
Off Road Right:	2
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**145**

Lighting Conditions

Daylight:	112
Dawn or Dusk:	7
Dark - Lighted:	22
Dark - Unlighted:	4
Unknown:	0
Total:	**145**

Weather Conditions

None:	129
Rain:	5
Snow/Sleet/Hail:	8
Fog:	1
Dust:	1
Wind:	1
Unknown:	0
Total:	**145**

Crash Rates

PDO:	11.76 *
INJ:	4.33 *
FAT:	0.00 **
Total:	**16.08** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	10	Embankment:	0
Head On:	1	Curb:	5
Rear End:	87	Delineator Post:	1
Sideswipe (Same):	10	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	27	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	8
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**145**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	145
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**145**

Road Description

At Intersection:	81
At Driveway Access:	0
Intersection Related:	64
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**145**

Road Conditions

Dry:	129
Wet:	6
Muddy:	0
Snowy:	6
Icy:	3
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**145**

ADT: 26,260 **Length:** 0.18

Location: 119B **Begin:** 54.31 **End:** 54.51 **From:** 01/01/2010 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	90	80	9
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	23	15	1
Pickup Truck/Utility Van w/Trl:	1	2	0
SUV:	24	37	2
SUV w/Trl:	0	1	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	3	1	1
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	3	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**145**	**136**	**13**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	59	132	12
Asleep at the Wheel:	1	0	0
Illness:	1	0	0
Distracted by Passenger:	3	0	1
Driver Inexperience:	4	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	27	1	0
Driver Unfamilar with Area:	6	1	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	44	2	0
Total:	**145**	**136**	**13**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	138	136	13
Alcohol Involved:	5	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	2	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**145**	**136**	**13**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	78	37	2
Slowing:	10	7	0
Stopped in Traffic:	3	76	11
Making Right Turn:	18	6	0
Making Left Turn:	29	8	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	3	1	0
Avoiding Object/Veh in Road:	2	0	0
Weaving:	0	0	0
Other:	1	1	0
Unknown:	0	0	0
Total:	**145**	**136**	**13**

Direction	Veh 1	Veh 2	Veh 3
North:	24	29	2
Northeast:	12	10	1
East:	24	23	5
Southeast:	0	0	0
South:	32	27	1
Southwest:	10	10	1
West:	41	35	3
Northwest:	2	2	0
Unknown:	0	0	0
Total:	**145**	**136**	**13**

ADT: 26,260 **Length:** 0.18

Project Information

Project Name: Guardrail Installation on SH 115

Project Description: Install guardrail at select locations and shoulder widening

CDOT Region: 2 Project Def: 17143 County: Fremont

Location: SH 115 Mile Points: 3.80 - 6.80 Length: 3.02 miles

Schedule: Work Start Date: 7/6/2009 Completion Date: 10/6/2009

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history (1999 – 2003) showed that there was a total of 76 crashes. These 76 crashes included 44 PDO crashes, 31 injury crashes, and one fatal crashes.

Improvement Description: Between July 6, 2009 and October 6, 2010, guardrail was installed along portions of SH 115 between MP 3.80 and 6.80. The cost of construction was $569,129.

The HSIP application anticipated no reduction in property damage only crashes, a 40% reduction in injury crashes, and a 60% reduction in fatal crashes might be realized by the improvement. The initial benefit/cost ratio was estimated to be 3.28.

Summary and Findings

The analysis of safety before and after the guardrail that was installed along SH 115 showed a reduction in the severity of overturning and fixed object crashes. However, there also was an increase in fixed object crashes due to the guardrail type crashes. Along this segment of 2-lane undivided highway, there were 49 total crashes during the five-year period before the guardrail was installed (2004 – 2008). In the five years after construction (2010 – 2014), the number of crashes increased to 78. This increase in crashes was accompanied by a slight decrease in AADT.

A comparison of overturning and fixed object type crashes before and after the installation of the guardrail showed that there was a decrease in injuries and fatalities. However, this decrease was offset by a large increase in guardrail crashes in the after period. The ratio of benefits and cost for this project shows that cost outweighed benefits as the B/C ratio was 0.71 to one, which is less than the desired B/C ratio of 1:1 or better. The result is an improvement that may not have been justified from an economic standpoint.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records shows an increase in the number of crashes; the total number of non-intersection crashes increased from 49 during the five-year period (2004 to 2008) before the guardrail was installed (see **Table 1** and **Exhibit 1**) to 78 during the five-year after period (2010 to 2014) (see **Table 1** and **Exhibit 2**). Along with the total number of crashes increasing, the number of injuries and fatalities also increased:

- Before (2004 – 2008) – no fatal crashes and 17 injury crashes with 23 injuries
- After (2010 – 2014) –1 fatal crashes with 1 fatality and 22 injury crashes with 44 injuries

The guardrail crash type was the primary contributor to the increase in number of crashes with 21 crashes in the after period. There were only 2 guardrail crashes in the before period. It is likely the guardrail prevented more severe crashes.

Table 1 – SH 115A (MP 3.80 to MP 6.80) - Results of Overall Crash Analyses

	Before	After
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
AADT	5,834 vpd	5,633 vpd
Filters:	Non-Intersection	Non-Intersection
Total Crashes	**49**	**78**
Fatal Crashes (Fatalities)	0	1 (1)
Injury Crashes (Injuries)	17 (23)	22 (24)
Property Damage Only	32	55
Crash Types: # (% of total crashes) [cumulative probability]		
Fixed Objects	20 (40.8%) [99.8%]	35 (44.9%) [100.0%]
Wild Animals	17 (34.7%)	19 (24.4%)
Rear-end	5 (10.2%)	5 (6.4%)
Overturning	3 (6.1%)	6 (7.7%)
Fixed Object Crashes: # (% of FO) [cumulative probability]		
Light Pole/Utility Pole	6 (30.0%)	1 (2.9%)
Fence	4 (20.0%)	0
Embankment	4 (20.0%)	8 (22.9%) [99.6%]
Guardrail	2 (10.0%)	21 (60.0%) [100.0%]

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

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level

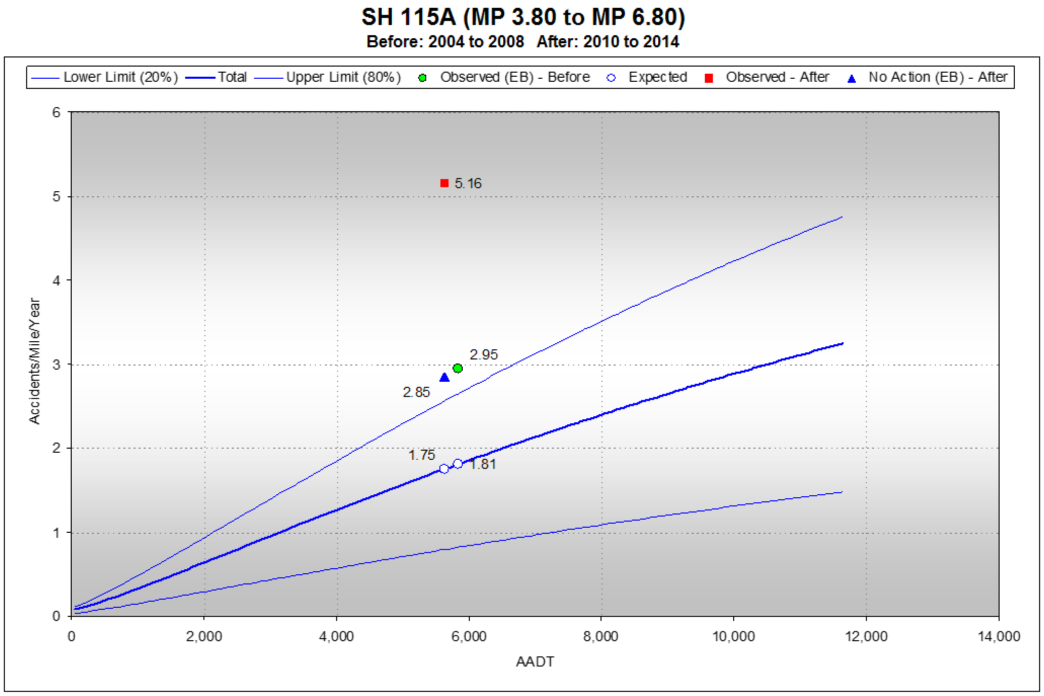
of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

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

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

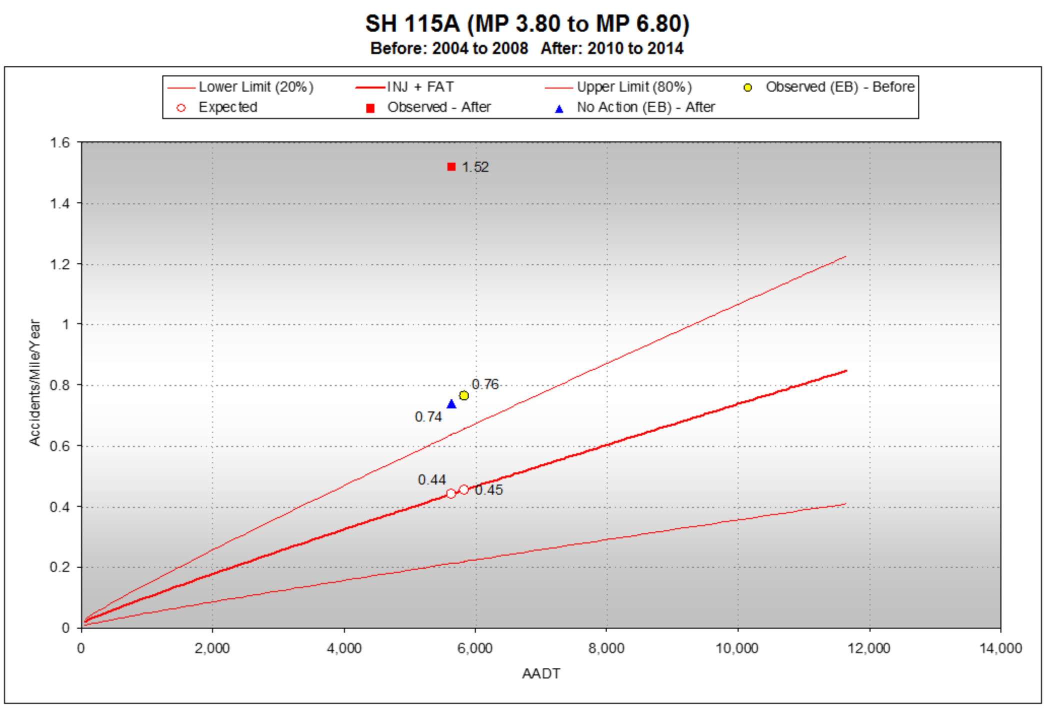
SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect this change in the crash record. Although the crash rate increased in the after period, the roadway was in the LOSS IV category for both the before and after period in both frequency and severity of crashes. **Table 2** provides the results of the SPF analysis.

Figure 1 - SPF for Total Crashes



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

Figure 2 - SPF for Injury and Fatal Crashes



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

Table 2 – SH 115A (MP 3.80 to MP 6.80) - Safety Performance Function (SPF)

	Before	**After**	**No Build After**
EB Correction:	Yes	No	Yes
SPF Graph	Rural, Flat and Rolling, 2-lane Undivided Highway	Rural, Flat and Rolling, 2-lane Undivided Highway	Rural, Flat and Rolling, 2-lane Undivided Highway
Total Crashes:			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPMPY	2.95	5.16	2.85
Mean CPMPY	1.81	1.75	1.75
Proportion of Mean	1.63	2.95	1.63
Fatal & Injury Crashes:			
LOSS	LOSS IV	LOSS IV	LOSS IV
CPMPY	0.76	1.52	0.74
Mean CPMPY	0.45	0.44	0.44
Proportion of Mean	1.69	3.45	1.69

A more detailed review of the before and after crash record reveals that the reduction in severity of off-road overturning and fixed object crashes is offset by the increased frequency and severity of guardrail type crashes. **Table 3** provides a comparison of the overturning and fixed object crashes. The No Build After crashes were estimated using the increase in the mean of the SPF for total crashes found in **Table 2** (decrease is 0.97 = 1.75/1.81). **Table 3** shows a decrease in severity of crash types prevented by guardrail. However, there was a large number of guardrail crashes in the after period.

Table 3 – SH 115A (MP 3.80 to MP 6.80) - Results of Cable Rail Crash Analyses

	Before	**After**	**No Build After**
Time Period:	1/1/2004 to 12/31/2008 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)	1/1/2010 to 12/31/2014 (5 yr.)
Crash Types:			
Overturning – Total (Off-Road Only)	**3**	**5**	**3**
Injury (injuries)	2 (4)	3 (3)	2 (4)
PDO	1	2	1
% Reduction in Total – (Injuries/ PDO)		25% / 100%	
Fixed Objects – Total (Off-Road Only, excluding Guardrail)	**18**	**14**	**18**
Injury (injuries)	9 (10)	3 (3)	9 (10)
PDO	9	11	9
% Reduction in Total – (Injuries/ PDO)		70% / -22%	
Guardrail – Total	**2**	**21**	**2**
Injury (injuries)	1 (1)	6 (6)	1 (1)
PDO	1	15	1
% Reduction in Total – (Injuries/ PDO)		-500% / -1400%	

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the guardrail improvement. The increase in guardrail crashes was factored into the analysis by increasing the cost of construction for the guardrail. During the five-year after period, there were 5 additional guardrail injuries, 14 property damage only guardrail crashes, and 2 additional fixed object property damage only crashes. Over the design life of 20 years for the guardrail system, the increased cost of crashes would be $2,209,200 (64 PDO = $595,200 and 20 injuries = $1,614,000). Guard rail causes new crashes since it creates a barrier near the roadway. **Figure 3** provide the Benefit/Cost calculations. The B/C ratio for the improvements is 0.71, showing that the improvement may not have been justified.

It should be noted that this location lends itself well to shoulder widening. If 6-foot shoulders and rumble strips are provided the expected crash reduction would be approximately 60%. If $4,000,000 was spent on widening it is estimated the B/C ratio would be 4.00. Additionally, center line rumble strips could be highly effective considering that 2 head-on and 2 sideswipe opposite direction crashes were observed in the after period.

Figure 3 – SH 115A (MP 3.80 to MP 6.80) - Benefit Cost Analysis – Overturning and Fixed Object Off-Road Crash Types Only

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

08/14/2016

Job #: 20160814123740

Location: 115A **Begin:** 3.80 **End:** 6.80 **From:** 01/01/2004 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes				**Projected Crashes and Reduction Factors**			**Other Information**	
PDO:	10		Weighted PDO:	2.46	0%	:CRF for PDO	Cost of PDO:	$ 9,300
INJ:	11	14 :Injured	Weighted INJ:	3.44	57%	:CRF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	100%	:CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	5.00	29%	:Weighted CRF	Interest Rate:	5%
							AADT Growth Factor:	2.0%
							Service Life:	20
							Capital Recovery Factor:	0.080
							Annual Maintenance/Delay Cost:	$ 0

Cost: $ 2,778,329
From: 01/01/2004
To: 12/31/2008 Days: 1827

Benefit Cost Ratio: 0.71 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: GUARDRAIL - INSTALLATION - OFF-ROAD FIXED OBJECT AND OVERTURNING ONLY
Special Notes: COST OF 64 PDO AND 20 INJURIES WERE ADDED TO THE COST OF CONSTRUCTION

Location: 115A **Begin:** 3.80 **End:** 6.80 **From:**01/01/2004 **To:**12/31/2008

Severity

PDO:	32	
INJ:	17	23 :Injured
FAT:	0	0 :Killed
Total:	**49**	

Number of Vehicles

One Vehicle:	40
Two Vehicles:	9
Three or More:	0
Unknown:	0
Total:	**49**

Location

On Road:	25
Off Road Left:	11
Off Road Right:	13
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**49**

Lighting Conditions

Daylight:	23
Dawn or Dusk:	5
Dark - Lighted:	0
Dark - Unlighted:	21
Unknown:	0
Total:	**49**

Weather Conditions

None:	44
Rain:	1
Snow/Sleet/Hail:	1
Fog:	0
Dust:	0
Wind:	1
Unknown:	2
Total:	**49**

Crash Rates

PDO:	0.99 *
INJ:	0.53 *
FAT:	0.00 **
Total:	**1.52** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	3	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	4
Head On:	0	Curb:	0
Rear End:	5	Delineator Post:	0
Sideswipe (Same):	0	Fence:	4
Sideswipe (Opposite):	1	Tree:	1
Approach Turn:	1	Large Boulders or Rocks:	1
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	1	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	1
Domestic Animal:	0	Total Fixed Objects:	20
Wild Animal:	17	Rocks in Roadway:	0
Light/Utility Pole:	6	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	2	Unknown:	0
Cable Rail:	0	**Total:**	**49**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	49
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**49**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	49
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**49**

Road Conditions

Dry:	41
Wet:	2
Muddy:	0
Snowy:	0
Icy:	5
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	1
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**49**

ADT: 5,834 **Length:** 3.02

Location: 115A **Begin:** 3.80 **End:** 6.80 **From:** 01/01/2004 **To:** 12/31/2008

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	37	5	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	6	2	0
Pickup Truck/Utility Van w/Trl:	0	1	0
SUV:	1	0	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	4	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	0	0	0
Other:	0	0	0
Unknown:	0	1	0
Total:	**49**	**9**	**0**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	43	4	0
Slowing:	1	2	0
Stopped in Traffic:	0	1	0
Making Right Turn:	1	0	0
Making Left Turn:	0	0	0
Making U-Turn:	1	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	1	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	0	1	0
Total:	**49**	**9**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	19	3	0
Northeast:	0	0	0
East:	12	0	0
Southeast:	0	0	0
South:	11	3	0
Southwest:	0	0	0
West:	7	2	0
Northwest:	0	0	0
Unknown:	0	1	0
Total:	**49**	**9**	**0**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	32	7	0
Asleep at the Wheel:	1	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	4	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	5	0	0
Driver Unfamilar with Area:	0	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	1	0	0
Unknown:	5	2	0
Total:	**49**	**9**	**0**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	42	9	0
Alcohol Involved:	6	0	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**49**	**9**	**0**

ADT: 5,834 **Length:** 3.02

Location: 115A **Begin:** 3.80 **End:** 6.80 **From:** 01/01/2010 **To:** 12/31/2014

Severity

PDO:	55		
INJ:	22	24	:Injured
FAT:	1	1	:Killed
Total:	**78**		

Number of Vehicles

One Vehicle:	63
Two Vehicles:	14
Three or More:	1
Unknown:	0
Total:	**78**

Location

On Road:	37
Off Road Left:	15
Off Road Right:	26
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**78**

Lighting Conditions

Daylight:	37
Dawn or Dusk:	5
Dark - Lighted:	3
Dark - Unlighted:	33
Unknown:	0
Total:	**78**

Weather Conditions

None:	70
Rain:	3
Snow/Sleet/Hail:	4
Fog:	1
Dust:	0
Wind:	0
Unknown:	0
Total:	**78**

Crash Rates

PDO:	1.77 *
INJ:	0.71 *
FAT:	3.21 **
Total:	**2.51** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	6	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	2	Culvert/Headwall:	1
Broadside:	0	Embankment:	8
Head On:	2	Curb:	0
Rear End:	5	Delineator Post:	2
Sideswipe (Same):	0	Fence:	0
Sideswipe (Opposite):	2	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	1
Domestic Animal:	3	Total Fixed Objects:	35
Wild Animal:	19	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	3
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	1	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	3
Guard Rail:	21	Unknown:	0
Cable Rail:	0	**Total:**	**78**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	78
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**78**

Road Description

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

Road Conditions

Dry:	62
Wet:	7
Muddy:	0
Snowy:	2
Icy:	5
Slushy:	0
Foreign Material:	1
With Road Treatment:	0
Dry w/Icy Road Treatment:	1
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**78**

ADT: 5,633 **Length:** 3.02

Location: 115A **Begin:** 3.80 **End:** 6.80 **From:** 01/01/2010 **To:** 12/31/2014

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	50	6	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	14	8	1
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	7	1	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	1	0	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	1	0	0
Hit and Run - Unknown:	1	0	0
Other:	2	0	0
Unknown:	0	0	0
Total:	**78**	**15**	**1**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	51	14	1
Asleep at the Wheel:	1	0	0
Illness:	5	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	2	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	4	0	0
Driver Unfamilar with Area:	2	0	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	12	1	0
Total:	**78**	**15**	**1**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	69	14	1
Alcohol Involved:	6	1	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	3	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**78**	**15**	**1**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	49	11	1
Slowing:	0	2	0
Stopped in Traffic:	0	0	0
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	1	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	0	0	0
Avoiding Object/Veh in Road:	3	2	0
Weaving:	2	0	0
Other:	22	0	0
Unknown:	1	0	0
Total:	**78**	**15**	**1**

Direction	Veh 1	Veh 2	Veh 3
North:	21	5	0
Northeast:	0	0	0
East:	26	2	0
Southeast:	0	0	0
South:	14	3	1
Southwest:	0	0	0
West:	17	5	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**78**	**15**	**1**

ADT: 5,633 **Length:** 3.02

Project Information

Project Name: I-76 Median Cable Lochbuie North

Project Description: Install Median Cable Rail

CDOT Region: 4 Project Def: 17202 County: Weld

Location: I-76 Mile Points: 25.14 – 32.00 Length: 6.87 miles

Schedule: Work Start Date: 9/5/2009 Completion Date: 1/25/2010

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, the five-year crash history (2000 – 2004) showed that there was a total of 28 crashes that were off-road left or in the median. These 28 crashes included 15 PDO crashes, 11 injury crashes, and two fatal crashes.

Improvement Description: Between September 5, 2009 and January 25, 2010, a cable rail was installed along this section of I-76. The cost of construction was $765,754.43.

The HSIP application anticipated that a 20% reduction in property damage only crashes, 40% reduction in injury crashes, and a 60% reduction in fatal crashes might be realized by the improvement. The initial benefit/cost ratio was estimated to be 7.29.

Summary and Findings

The analysis of safety before and after the cable rail was installed along I-76 showed a reduction in the crashes overturning in the median or crossing into oncoming traffic. However, there also was an increase in fixed object crashes due to the cable rail type crashes. Along this segment of 4-lane divided highway, there were 66 total crashes during the four-year period before the cable rail was installed (2005 – 2008). In the four years after construction (2011 – 2014), the number of crashes increased to 99. This increase in crashes was accompanied by a more modest increase in AADT.

A comparison of overturning, head-on, and sideswipe opposite direction type crashes before and after the installation of the cable rail showed that there was a decrease in injuries and fatalities (from 44 injuries and 4 fatalities in four years before to 34 injuries and 1 fatality in the four years after). The number of PDO crashes was increased from 37 to 72. The ratio of benefits and cost for this project shows that cost paralleled benefits as the B/C ratio was 1.01 to one. The result is an improvement that may have been justified from an economic standpoint.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records shows an increase in the number of crashes; the total number of mainline crashes increased from 66 during the four-year period (2005 to 2008) before the cable rail was installed (see **Table 1** and **Exhibit 1**) to 99 during the four-year after period (2011 to 2014) (see **Table 1** and **Exhibit 2**). Although the total number of crashes increased, the number of injuries and fatalities decreased:

- Before (2005 – 2008) – 3 fatal crashes with 4 fatalities and 26 injury crashes with 44 injuries
- After (2011 – 2014) –1 fatal crashes with 1 fatality and 26 injury crashes with 34 injuries

The cable rail crash type was the primary contributor to the increase in number of crashes with 37 crashes in the after period. There were no cable rail crashes in the before period. It is likely the cable rail prevented more severe crashes by keeping vehicles from traveling into oncoming traffic.

Table 1 – I-76A (MP 25.14 to MP 32.00) - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT	16,354 vpd	17,860 vpd
Filters:	Mainline	Mainline
Total Crashes	**66**	**99**
Fatal Crashes (Fatalities)	3 (4)	1 (1)
Injury Crashes (Injuries)	26 (44)	26 (34)
Property Damage Only	37	72
Crash Types: # (% of total crashes) [cumulative probability]		
Overturning	26 (39.4%) [100.00%]	10 (10.1%)
Fixed Objects	14 (21.2%)	56 (56.6%) [100.00%]
Other Object	6 (9.1%)	2 (2.0%)
Sideswipe Same	6 (9.1%)	5 (5.1%)
Other Non-Collision	4 (6.1%)	6 (6.1%)
Sideswipe Opposite	3 (4.5%)	
Parked Motor Vehicle	3 (4.5%)	
Rear-End	3 (4.5%)	16 (16.2%) [95.97%]
Head-On	1 (1.5%)	
Fixed Object Crashes: # (% of FO) [cumulative probability]		
Guard Rail	4 (28.6%)	5 (8.9%)
Fence	3 (21.4%)	4 (7.1%)
Delineator Post	3 (21.4%)	3 (5.4%)
Cable Rail		37 (66.1%) [100.00%]

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

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

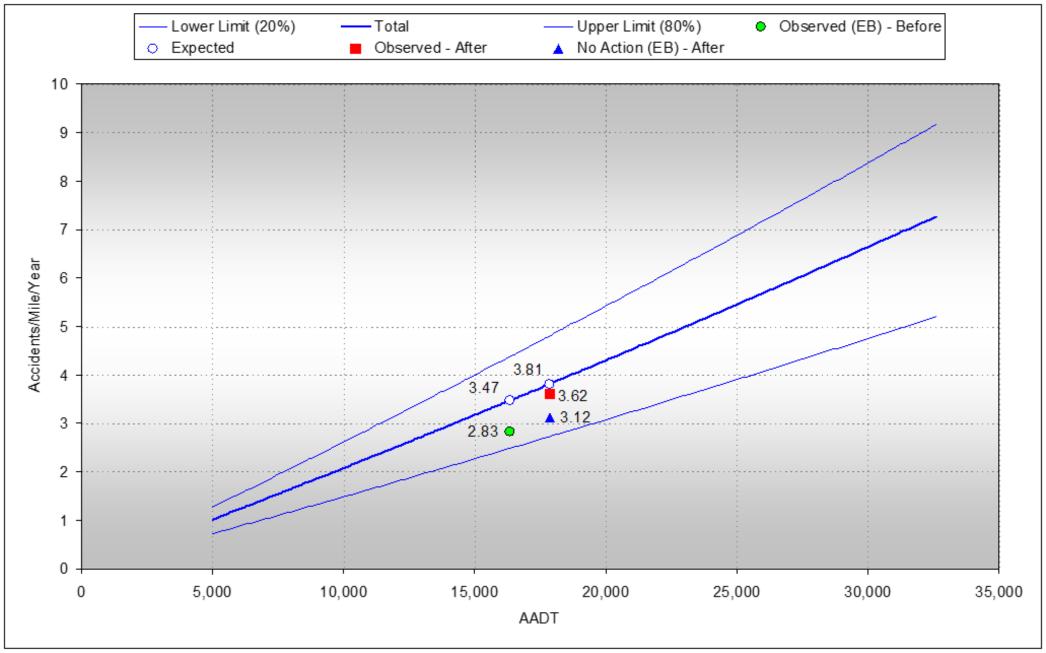
LOSS-I – Indicates low potential for crash reduction
LOSS-II – Indicates low to moderate potential for crash reduction
LOSS-III – Indicates moderate to high potential for crash reduction
LOSS-IV – Indicates high potential for crash reduction

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

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect this change in the crash record. The frequency of crashes increased, although the roadway was in the LOSS II category for both the before and after period. For the severity of crashes, LOSS stayed in the LOSS II range, although there was improvement within the range in the after period. **Table 2** provides the results of the SPF analysis.

Figure 1 - SPF for Total Crashes

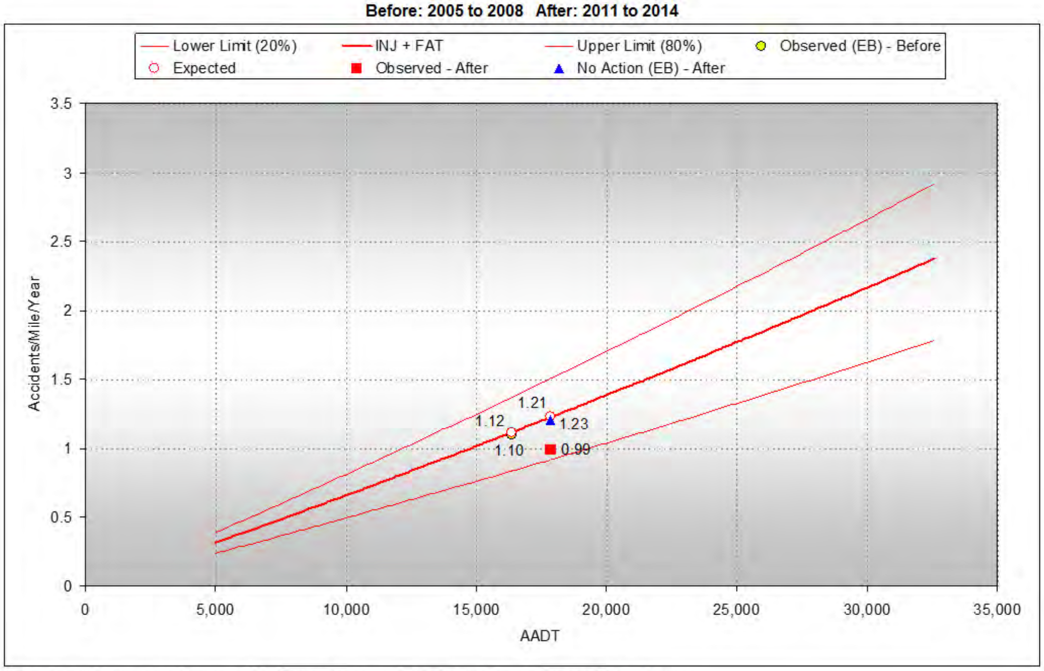
I-76A (MP 25.14 to MP 32.00)
Before: 2005 to 2008 After: 2011 to 2014



Note: Safety Performance Function (SPF) Model: Colorado - Rural Flat and Rolling 4-Lane Divided Freeway

Figure 2 - SPF for Injury and Fatal Crashes

I-76A (MP 25.14 to MP 32.00)
Before: 2005 to 2008 After: 2011 to 2014



Note: Safety Performance Function (SPF) Model: Colorado - Rural Flat and Rolling 4-Lane Divided Freeway

Table 2 – I-76A (MP 25.14 to MP 32.00) - Safety Performance Function (SPF)

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Rural, Flat and Rolling, 4-lane Divided Freeway	Rural, Flat and Rolling, 4-lane Divided Freeway	Rural, Flat and Rolling, 4-lane Divided Freeway
Total Crashes:			
LOSS	LOSS II	LOSS II	LOSS II
CPMPY	2.83	3.62	3.12
Mean CPMPY	3.47	3.81	3.81
Proportion of Mean	0.82	0.95	0.82
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS II	LOSS II
CPMPY	1.10	0.99	1.21
Mean CPMPY	1.12	1.23	1.23
Proportion of Mean	0.98	0.80	0.98

A more detailed review of the before and after crash record reveals that the reduction in head-on and sideswipe opposite direction crashes can be attributed to the installation of the cable rail. **Table 3** provides a comparison of the overturning, sideswipe opposite direction, and head-on crashes. The count of fatal overturning crashes and resulting fatalities occurring in the before period was modified based on the officer narratives documenting the crashes. A motorcycle crash that overturned in the median resulting in a single fatality would likely not have been preventable by a cable rail, so that was removed. A crash that overturned in the median resulting in two fatalities was coded as a guardrail crash, as it eventually crashed with a guardrail. It is likely that this crash could have been prevented by a cable rail in the median, so it was added to the count of overturning fatality crashes.

The No Build After crashes were estimated using the increase in the mean of the SPF for total crashes found in **Table 2** (decrease is 1.12 = 3.85/3.45). **Table 3** shows a decrease in crash types prevented by cable rail. However, there was a large number of cable rail crashes in the after period.

Table 3 – I-76A (MP 25.14 to MP 32.00) - Results of Cable Rail Crash Analyses

	Before	After	No Build After
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
Crash Types:			
Head-On – Total	**1**	**0**	**1**
PDO	1	0	1
% Reduction in Total		100%	
Sideswipe (Opp.)– Total	**3**	**0**	**3**
Injury (injuries)	1 (2)	0	1 (2)
PDO	2	0	2
% Reduction in Total – (Injuries/ PDO)		100% / 100%	
Overturning – Total (off-left/off-median only)	**13**	**5**	**14**
Fatal (fatalities)	1 (2)	0	1 (2)
Injury (injuries)	9 (15)	3 (4)	10 (17)
PDO	3	2	3
% Reduction in Total – (Fatalities/Injuries/ PDO)		100% / 76% / 33%	
Cable Rail – Total (off-left/off-median only)	**0**	**37**	**0**
Fatal (Fatalities)	0	1 (1)	0
Injury (injuries)	0	10 (16)	0
PDO	0	26	0

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for the cable rail improvement. The increase in cable rail crashes was factored into the analysis by increasing the cost of construction for the cable rail. During the four year after period, there were 1 fatality, 16 injuries, and 26 property damage only cable rail crashes. Over the design life of 20 years for the cable rail system, the increased cost of crashes would be $15,165,000 (130 PDO = $1,209,000, 80 injuries = $6,456,000, and 5 fatalities = $7,500,000). Cable rail causes new crashes since it creates a barrier near the roadway. **Figure 3** provide the Benefit/Cost calculations. The B/C ratio for the improvements is 1.01, showing that the improvement may have been justified.

Figure 3 – I-76A (MP 25.14 to MP 32.00) - Benefit Cost Analysis – Overturning, Head-on, Sideswipe Opposite Direction Crash Types Only

COLORADO Department of Transportation

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

09/05/2016

Job #: 20160905162436

Location: 76A **Begin:** 25.14 **End:** 32.00 **From:** 01/01/2005 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Crashes			**Projected Crashes and Reduction Factors**				**Other Information**	
PDO:	6		Weighted PDO:	1.84	33%	:CRF for PDO	Cost of PDO:	$ 9,300
INJ:	11	19:Injured	Weighted INJ:	5.83	76%	:CRF for INJ	Cost of INJ:	$ 80,700
FAT:	1	2:Killed	Weighted FAT:	0.61	100%	:CRF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	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: $ 15,930,755
From: 01/01/2005
To: 12/31/2008 Days: 1461

Benefit Cost Ratio: 1.01 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: CABLE RAIL - HEAD-ON, SIDESWIPE (OPPOSITE), OVERTURNING
Special Notes: COST OF 130 PDO, 80 INJURIES, AND 5 FATALITIES ADDED TO CONSTRUCTION

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

Exhibit 1

08/11/2016

Job #: 20160811150855

Location: 76A **Begin:** 25.14 **End:** 32.00 **From:** 01/01/2005 **To:** 12/31/2008

Severity

PDO:	37		
INJ:	26	44	:Injured
FAT:	3	4	:Killed
Total:	**66**		

Number of Vehicles

One Vehicle:	46
Two Vehicles:	17
Three or More:	3
Unknown:	0
Total:	**66**

Location

On Road:	19
Off Road Left:	17
Off Road Right:	23
Off Road at Tee:	0
Off in Median:	7
Unknown:	0
Total:	**66**

Lighting Conditions

Daylight:	34
Dawn or Dusk:	3
Dark - Lighted:	6
Dark - Unlighted:	23
Unknown:	0
Total:	**66**

Weather Conditions

None:	39
Rain:	4
Snow/Sleet/Hail:	22
Fog:	0
Dust:	0
Wind:	1
Unknown:	0
Total:	**66**

Crash Rates

PDO:	0.23 *
INJ:	0.16 *
FAT:	1.84 **
Total:	**0.40** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	26	Bridge Abutment:	0
Other Non Collision:	4	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	1
Head On:	1	Curb:	0
Rear End:	3	Delineator Post:	3
Sideswipe (Same):	6	Fence:	3
Sideswipe (Opposite):	3	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	3	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	14
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	1
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	2	Involving Other Object:	5
Bridge Rail:	0	Total Other Objects:	6
Guard Rail:	4	Unknown:	0
Cable Rail:	0	**Total:**	**66**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	66
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**66**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	66
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**66**

Road Conditions

Dry:	39
Wet:	6
Muddy:	0
Snowy:	3
Icy:	13
Slushy:	2
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	3
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**66**

ADT: 16,354 **Length:** 6.84

Location: 76A **Begin:** 25.14 **End:** 32.00 **From:** 01/01/2005 **To:** 12/31/2008

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	38	6	2
Passenger Car/Van w/Trl:	1	0	0
Pickup Truck/Utility Van:	9	6	0
Pickup Truck/Utility Van w/Trl:	1	0	0
SUV:	6	1	1
SUV w/Trl:	1	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	6	6	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	1	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	2	0	0
Other:	1	1	0
Unknown:	0	0	0
Total:	**66**	**20**	**3**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	47	16	2
Slowing:	1	1	0
Stopped in Traffic:	0	0	0
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	6	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	3	1
Changing Lanes:	2	0	0
Avoiding Object/Veh in Road:	1	0	0
Weaving:	0	0	0
Other:	9	0	0
Unknown:	0	0	0
Total:	**66**	**20**	**3**

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	2	1	0
East:	30	8	1
Southeast:	0	0	0
South:	2	0	0
Southwest:	2	1	0
West:	30	10	2
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**66**	**20**	**3**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	33	18	3
Asleep at the Wheel:	3	0	0
Illness:	1	0	0
Distracted by Passenger:	2	0	0
Driver Inexperience:	8	0	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	4	0	0
Driver Unfamilar with Area:	3	0	0
Driver Emotionally Upset:	1	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	10	2	0
Total:	**66**	**20**	**3**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	62	20	3
Alcohol Involved:	3	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**66**	**20**	**3**

ADT: 16,354 **Length:** 6.84

Location: 76A **Begin:** 25.14 **End:** 32.00 **From:** 01/01/2011 **To:** 12/31/2014

Severity

PDO:	72		
INJ:	26	34	:Injured
FAT:	1	1	:Killed
Total:	**99**		

Number of Vehicles

One Vehicle:	70
Two Vehicles:	26
Three or More:	3
Unknown:	0
Total:	**99**

Location

On Road:	27
Off Road Left:	53
Off Road Right:	19
Off Road at Tee:	0
Off in Median:	0
Unknown:	0
Total:	**99**

Lighting Conditions

Daylight:	49
Dawn or Dusk:	6
Dark - Lighted:	7
Dark - Unlighted:	36
Unknown:	1
Total:	**99**

Weather Conditions

None:	58
Rain:	9
Snow/Sleet/Hail:	27
Fog:	1
Dust:	0
Wind:	3
Unknown:	1
Total:	**99**

Crash Rates

PDO:	0.40 *
INJ:	0.15 *
FAT:	0.56 **
Total:	**0.55** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	10	Bridge Abutment:	0
Other Non Collision:	6	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	0	Embankment:	1
Head On:	0	Curb:	0
Rear End:	16	Delineator Post:	3
Sideswipe (Same):	5	Fence:	4
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	1	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	1
Domestic Animal:	1	Total Fixed Objects:	56
Wild Animal:	2	Rocks in Roadway:	0
Light/Utility Pole:	1	Vehicle Cargo/Debris:	2
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	2	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	2
Guard Rail:	5	Unknown:	0
Cable Rail:	37	**Total:**	**99**
Concrete Barrier:	2		

Mainline/Ramps/Frontage Roads

Mainline:	99
Crossroad (A):	0

Frontage/Ramp Intersections

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

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**99**

Road Description

At Intersection:	0
At Driveway Access:	0
Intersection Related:	0
Non Intersection:	99
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**99**

Road Conditions

Dry:	49
Wet:	10
Muddy:	0
Snowy:	3
Icy:	26
Slushy:	2
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	1
Icy w/Icy Road Treatment:	6
Slushy w/Icy Road Treatment:	1
Unknown:	1
Total:	**99**

ADT: 17,860 **Length:** 6.84

Location: 76A **Begin:** 25.14 **End:** 32.00 **From:** 01/01/2011 **To:** 12/31/2014

Vehicle Type

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	42	11	1
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	18	7	0
Pickup Truck/Utility Van w/Trl:	2	0	0
SUV:	23	3	2
SUV w/Trl:	1	1	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	8	5	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	2	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	2	0	0
Other:	1	2	0
Unknown:	0	0	0
Total:	**99**	**29**	**3**

Vehicle Movement

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	52	18	2
Slowing:	3	3	1
Stopped in Traffic:	0	0	0
Making Right Turn:	0	0	0
Making Left Turn:	0	0	0
Making U-Turn:	0	0	0
Passing:	6	2	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	1	0
Changing Lanes:	4	1	0
Avoiding Object/Veh in Road:	1	1	0
Weaving:	2	0	0
Other:	31	3	0
Unknown:	0	0	0
Total:	**99**	**29**	**3**

Contributing Factor

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	48	26	2
Asleep at the Wheel:	6	0	0
Illness:	0	0	0
Distracted by Passenger:	0	0	0
Driver Inexperience:	19	2	0
Driver Fatigue:	1	0	0
Driver Preoccupied:	4	0	0
Driver Unfamilar with Area:	1	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	20	1	1
Total:	**99**	**29**	**3**

Direction

Direction	Veh 1	Veh 2	Veh 3
North:	0	0	0
Northeast:	9	3	1
East:	33	10	1
Southeast:	0	0	0
South:	4	2	0
Southwest:	18	4	1
West:	35	10	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**99**	**29**	**3**

Condition of Driver

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	94	28	3
Alcohol Involved:	3	1	0
RX, Medication, or Drugs Involved:	1	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	1	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**99**	**29**	**3**

ADT: 17,860 **Length:** 6.84

Project Information

Project Name: I-76 and 96th Avenue Interchange

Project Description: Roundabouts at Ramp Intersections

CDOT Region: 1 **Project Def**:17249 **County**: Adams

Location: 96th Ave **Mile Points**: 11.45-11.65 (I-76) **Length:** 0.25

Schedule: Work Start Date: 6/22/2009 Completion Date: 6/10/2010

Problem Description: As described in the Highway Safety Improvement Program (HSIP) application for this project, there were safety problems associated with increased vehicle/truck volumes at the unsignalized ramp intersections for the I-76 at 96th Avenue Interchange. The frontage roads also demonstrated need for improved traffic control that could not be achieved efficiently with signalization.

Improvement Description: Between June 2009 and June 2010, roundabouts were installed at each ramp terminal to control both ramp and frontage road traffic and to improve safety by slowing traffic and providing guidance for ramp and frontage road traffic. The cost of construction was $1,959,551.

The HSIP application anticipated that the following reductions in crashes might be realized by the improvement anticipated: accident reduction factor – 60%. The initial benefit/cost ratio was estimated to be 1.78.

Summary and Findings

The analysis of safety before and after the ramp terminals at I-76 and 96th Street were reconstructed as roundabouts showed an increase in number of crashes. For this intersection, there were 56 total crashes (at intersection, intersection related) during the four-year period before the roundabouts were installed (2005 – 2008). In the four years after construction (2011 – 2014), the number of crashes increased to 85. The number of injury crashes remained the same, but the number of injured individuals decreased. Additionally, the number of PDO accidents also increased.

The overall ratio of benefits and cost for this project was 1.60. The result is an improvement that was justified.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records for the ramps and frontage roads shows an increase in the number of crashes; the total number of crashes increased from 56 during the four-year period (2005 to 2008) before the interchange was reconstructed (see **Table 1** and **Exhibit 1**) to 85 during the four-year after period (2011 to 2014) (see **Table 1** and **Exhibit 2**). The number of severe crashes showed a decrease in the number of people injured:

- Before (2005 – 2008) – 11 injury crashes with 17 injuries
- After (2011 – 2014) – 11 injury crashes with 12 injuries

The following summarizes the number of crashes during the four-year after period (2011 to 2014) by year:

- 2011 – 16 Total Crashes (15 PDO, 1 (1) Injury, 0 Fatal)
- 2012 – 14 Total Crashes (13 PDO, 1 (1) Injury, 0 Fatal)
- 2013 – 17 Total Crashes (15 PDO, 2 (2) Injury, 0 Fatal)
- 2014 – 38 Total Crashes (31 PDO, 7 (8) Injury, 0 Fatal)

The large increase in the number of reported crashes in 2014 led to a deeper examination of the 2014 crash records. From 2011 to 2013, approximately 20 percent of crashes involved large vehicles (Vehicle Type – Trucks greater than 10k lbs/buses greater than 15 people). In 2014, the percentage of reported crashes involving large vehicles doubled to approximately 40 percent.

Table 1 - Results of Overall Crash Analyses

	Before	**After**
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT	57,567 vpd on I-76	71,733 vpd on I-76
Filters:	Ramps & Frontage Roads (Mainline excluded)	Ramps & Frontage Roads (Mainline excluded)
Total Crashes	**56**	**85**
Fatal Crashes (Fatalities)	0	0
Injury Crashes (Injuries)	11 (17)	11 (12)
Property Damage Only	45	74
Crash Types: # (%) [significance]		
Rear End	20 (35.71%)	12 (14.12%)
Broadside	22 (39.29%) [100%]	26 (30.59%) [100%]
Sideswipe (Same)	6 (10.71%)	34 (40.00%) [100%]
Approach Turn	5 (8.93%)	0 (0.0%)

Normally, the magnitude of safety problems on highway sections and intersections can be assessed through the use of Safety Performance Function (SPF) methodology. However, in the case of the roundabouts at the I-76 / 96th Avenue Intersection, no SPFs have been developed. However, it is important to note that the AADT on 96th Avenue has increased significantly between the before and after period due to development along the corridor. On I-76, the AADT has increased by nearly 25 percent (approximately 3.73 percent annual growth).

A review of officer narratives indicated that all but three of the crashes coded as "broadside" crashes in the after period should more accurately be coded as "sideswipe (same direction)" crashes. The officer narratives consistently reference vehicles failing to yield right-of-way when entering the roundabout and colliding with a vehicle in the roundabout for both broadside and sideswipe (same direction) crashes. At roundabouts, such as the ones at the I-76 / 96th Avenue interchange, traditional broadside crashes rarely occur with properly designed geometry. Crashes in which vehicles entering the roundabout fail to yield right-of-way to vehicles already in the roundabout may be more accurately described as sideswipe (same direction) crashes.

Table 2 shows a comparison of the total number of crashes including a No Build After scenario. The No Build After crashes were estimated using the increase in AADT along I-76 for total crashes found in **Table 1** (increase is 1.25 = 71,733/57,567).

	Before	**After**	**No Build After**
Time Period:	1/1/2005 to 12/31/2008 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)	1/1/2011 to 12/31/2014 (4 yr.)
AADT	57,567 vpd on I-76	71,733 vpd on I-76	71,733 vpd on I-76
Filters:	Ramps & Frontage Roads (Mainline excluded)	Ramps & Frontage Roads (Mainline excluded)	Ramps & Frontage Roads (Mainline excluded)
Total Crashes	**56**	**85**	**70**
Fatal Crashes (Fatalities)	0	0	0
Injury Crashes (Injuries)	11 (17)	11 (12)	14 (21)
Property Damage Only	45	74	56

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Exhibit 3** based on before/after crashes. The B/C ratio for this project is 1.60, showing that the safety benefits justify the improvement.

Exhibit 3 – Benefit Cost Analysis

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

03/30/2016

Job #: 20160330065928

Location: 76A **Begin:** 11.45 **End:** 11.65 **From:** 01/01/2005 **To:** 12/31/2008

Benefit Cost Ratio Calculations

Accidents			Projected Accidents and Reduction Factors			Other Information	
PDO:	56		Weighted PDO:	20.96	0% :ARF for PDO	Cost of PDO:	$ 9,300
INJ:	14	21 :Injured	Weighted INJ:	7.86	43% :ARF for INJ	Cost of INJ:	$ 80,700
FAT:	0	0 :Killed	Weighted FAT:	0.00	0% :ARF for FAT	Cost of FAT:	$ 1,500,000
			B/C Weighted Year Factor:	4.00	8% :Weighted ARF	Interest Rate:	5%
						ADT Growth Factor:	3.7%
		Cost: $ 2,127,400				Service Life:	20
		From: 01/01/2005				Capital Recovery Factor:	0.080
		To: 12/31/2008	Days: 1461			Annual Maintenance Cost:	$ 0

Benefit Cost Ratio: 1.60 (B/C Based on Injury Numbers : PDO/Injured/Killed)

Type of Improvement: Two Roundabouts on 96th Avenue at I-76

Special Notes: Construction cost increased to include an additional 18 PDO crashes at $9,300 per crash

Location: 76A **Begin:** 11.45 **End:** 11.65 **From:**01/01/2005 **To:**12/31/2008

Before Ramps & Frontage Roads

Severity

PDO:	45	
INJ:	11	17 :Injured
FAT:	0	0 :Killed
Total:	**56**	

Number of Vehicles

One Vehicle:	1
Two Vehicles:	55
Three or More:	0
Unknown:	0
Total:	**56**

Location

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

Lighting Conditions

Daylight:	47
Dawn or Dusk:	3
Dark - Lighted:	6
Dark - Unlighted:	0
Unknown:	0
Total:	**56**

Weather Conditions

None:	52
Rain:	1
Snow/Sleet/Hail:	3
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**56**

Crash Rates

PDO:	2.14 *
INJ:	0.52 *
FAT:	0.00 **
Total:	**2.66** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	1	Bridge Abutment:	0
Other Non Collision:	1	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	22	Embankment:	0
Head On:	1	Curb:	0
Rear End:	20	Delineator Post:	0
Sideswipe (Same):	6	Fence:	0
Sideswipe (Opposite):	0	Tree:	0
Approach Turn:	5	Large Boulders or Rocks:	0
Overtaking Turn:	0	Barricade:	0
Parked Motor Vehicle:	0	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	0
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	0	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**56**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	0
Crossroad (A):	0

Frontage/Ramp Intersections

M:	1	N:	10	O:	45	P:	0

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**56**

Road Description

At Intersection:	52
At Driveway Access:	0
Intersection Related:	4
Non Intersection:	0
In Alley:	0
Roundabout:	0
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**56**

Road Conditions

Dry:	50
Wet:	4
Muddy:	0
Snowy:	0
Icy:	1
Slushy:	1
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**56**

ADT: 57,567 **Length:** 0.25

Location: 76A **Begin:** 11.45 **End:** 11.65 **From:** 01/01/2005 **To:** 12/31/2008

Before Ramps & Frontage Roads

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	32	26	0
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	14	17	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	1	5	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	8	6	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	1	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	0	0	0
Unknown:	0	0	0
Total:	**56**	**55**	**0**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	23	31	0
Slowing:	3	2	0
Stopped in Traffic:	0	17	0
Making Right Turn:	5	2	0
Making Left Turn:	23	3	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	0	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	0	0
Changing Lanes:	1	0	0
Avoiding Object/Veh in Road:	0	0	0
Weaving:	0	0	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**56**	**55**	**0**

Direction	Veh 1	Veh 2	Veh 3
North:	21	2	0
Northeast:	1	0	0
East:	26	37	0
Southeast:	0	0	0
South:	1	1	0
Southwest:	0	0	0
West:	7	15	0
Northwest:	0	0	0
Unknown:	0	0	0
Total:	**56**	**55**	**0**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	41	55	0
Asleep at the Wheel:	0	0	0
Illness:	1	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	1	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	7	0	0
Driver Unfamilar with Area:	3	0	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	2	0	0
Total:	**56**	**55**	**0**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	55	55	0
Alcohol Involved:	1	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**56**	**55**	**0**

ADT: 57,567 **Length:** 0.25

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

02/29/2016

Job #: 20160229110800

Location: 76A **Begin:** 11.45 **End:** 11.65 **From:** 01/01/2011 **To:** 12/31/2014

After Ramps & Frontage

Severity

PDO:	74		
INJ:	11	12	:Injured
FAT:	0	0	:Killed
Total:	**85**		

Number of Vehicles

One Vehicle:	6
Two Vehicles:	77
Three or More:	2
Unknown:	0
Total:	**85**

Location

On Road:	79
Off Road Left:	1
Off Road Right:	4
Off Road at Tee:	0
Off in Median:	0
Unknown:	1
Total:	**85**

Lighting Conditions

Daylight:	64
Dawn or Dusk:	5
Dark - Lighted:	16
Dark - Unlighted:	0
Unknown:	0
Total:	**85**

Weather Conditions

None:	81
Rain:	2
Snow/Sleet/Hail:	2
Fog:	0
Dust:	0
Wind:	0
Unknown:	0
Total:	**85**

Crash Rates

PDO:	2.77 *
INJ:	0.41 *
FAT:	0.00 **
Total:	**3.18** *

* MVMT
** 100 MVMT

Crash Type

Overturning:	2	Bridge Abutment:	0
Other Non Collision:	0	Column/Pier:	0
Pedestrians:	0	Culvert/Headwall:	0
Broadside:	26	Embankment:	1
Head On:	0	Curb:	1
Rear End:	12	Delineator Post:	0
Sideswipe (Same):	34	Fence:	0
Sideswipe (Opposite):	3	Tree:	0
Approach Turn:	0	Large Boulders or Rocks:	0
Overtaking Turn:	2	Barricade:	0
Parked Motor Vehicle:	2	Wall/Building:	0
Railway Vehicle:	0	Crash Cushion:	0
Bicycle:	0	Mailbox:	0
Motorized Bicycle:	0	Other Fixed Object:	0
Domestic Animal:	0	Total Fixed Objects:	4
Wild Animal:	0	Rocks in Roadway:	0
Light/Utility Pole:	0	Vehicle Cargo/Debris:	0
Traffic Signal Pole:	0	Road Maintenance Equipment:	0
Sign:	2	Involving Other Object:	0
Bridge Rail:	0	Total Other Objects:	0
Guard Rail:	0	Unknown:	0
Cable Rail:	0	**Total:**	**85**
Concrete Barrier:	0		

Mainline/Ramps/Frontage Roads

Mainline:	0
Crossroad (A):	0

Frontage/Ramp Intersections

M:	0	N:	41	O:	44	P:	0

Ramps

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

Left Frontage Rd (L):	0
Rt Frontage Rd (R):	0
HOV Lanes (V):	0
Unknown:	0
Total:	**85**

Road Description

At Intersection:	1
At Driveway Access:	0
Intersection Related:	6
Non Intersection:	0
In Alley:	0
Roundabout:	78
Ramp:	0
Parking Lot:	0
Unknown:	0
Total:	**85**

Road Conditions

Dry:	71
Wet:	8
Muddy:	0
Snowy:	2
Icy:	4
Slushy:	0
Foreign Material:	0
With Road Treatment:	0
Dry w/Icy Road Treatment:	0
Wet w/Icy Road Treatment:	0
Snowy w/Icy Road Treatment:	0
Icy w/Icy Road Treatment:	0
Slushy w/Icy Road Treatment:	0
Unknown:	0
Total:	**85**

ADT: 71,733 **Length:** 0.25

Location: 76A **Begin:** 11.45 **End:** 11.65 **From:**01/01/2011 **To:**12/31/2014

After Ramps & Frontage

Vehicle Type	Veh 1	Veh 2	Veh 3
Passenger Car/Van:	26	41	2
Passenger Car/Van w/Trl:	0	0	0
Pickup Truck/Utility Van:	18	16	0
Pickup Truck/Utility Van w/Trl:	0	0	0
SUV:	19	16	0
SUV w/Trl:	0	0	0
Truck 10k lbs or Less:	0	0	0
Trucks > 10k lbs/Bus > 15 People:	20	6	0
School Bus < 15 People:	0	0	0
Non School Bus < 15 People:	0	0	0
Motorhome:	0	0	0
Motorcycle:	0	0	0
Bicycle:	0	0	0
Motorized Bicycle:	0	0	0
Farm Equipment:	0	0	0
Hit and Run - Unknown:	1	0	0
Other:	1	0	0
Unknown:	0	0	0
Total:	**85**	**79**	**2**

Contributing Factor	Veh 1	Veh 2	Veh 3
No Apparent Contributing Factor:	57	78	2
Asleep at the Wheel:	0	0	0
Illness:	0	0	0
Distracted by Passenger:	1	0	0
Driver Inexperience:	3	0	0
Driver Fatigue:	0	0	0
Driver Preoccupied:	4	0	0
Driver Unfamilar with Area:	8	1	0
Driver Emotionally Upset:	0	0	0
Evading Law Enforcement Officier:	0	0	0
Physical Disability:	0	0	0
Unknown:	12	0	0
Total:	**85**	**79**	**2**

Condition of Driver	Veh 1	Veh 2	Veh 3
No Impairment Suspected:	82	79	2
Alcohol Involved:	3	0	0
RX, Medication, or Drugs Involved:	0	0	0
Illegal Drugs Involved:	0	0	0
Alcohol and Drugs Involved:	0	0	0
Driver/Pedestrian not Observed:	0	0	0
Unknown:	0	0	0
Total:	**85**	**79**	**2**

Vehicle Movement	Veh 1	Veh 2	Veh 3
Going Straight:	42	51	1
Slowing:	1	6	0
Stopped in Traffic:	1	8	0
Making Right Turn:	15	6	0
Making Left Turn:	0	1	0
Making U-Turn:	0	0	0
Passing:	0	0	0
Backing:	1	0	0
Enter/Leave Parked Position:	0	0	0
Starting in Traffic:	0	0	0
Parked:	0	2	1
Changing Lanes:	13	1	0
Avoiding Object/Veh in Road:	1	0	0
Weaving:	3	0	0
Other:	8	4	0
Unknown:	0	0	0
Total:	**85**	**79**	**2**

Direction	Veh 1	Veh 2	Veh 3
North:	10	8	1
Northeast:	3	2	0
East:	39	28	0
Southeast:	0	0	0
South:	2	13	0
Southwest:	3	3	0
West:	27	24	1
Northwest:	1	1	0
Unknown:	0	0	0
Total:	**85**	**79**	**2**

ADT: 71,733 **Length:** 0.25