

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

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FHU Reference No. 119009-09

December 2019

INTRODUCTION

The purpose of this study was to continue evaluating the effectiveness of safety improvement projects on safety performance at locations chosen by the Colorado Department of Transportation (CDOT). This report examines the 29 locations that were analyzed and the methodology used in the process. Previously, CDOT completed the analysis of 48 locations throughout the state in 2015 and 2016.

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

ANALYSIS AND RESULTS

The 29 projects chosen by CDOT for analysis are located on state highways and non-state highways and cover a variety of safety improvements to both roadways and intersections. Roadway improvements included median barriers and improvements, guard rail, curve realignment and slope flattening, ITS improvements, wildlife protection, and ramp metering. Intersection improvements analyzed included new signals, signal upgrades (such as larger signal heads and replacing old span-wire signals), geometric improvements, and roundabouts.

Table 1 shows 77 individual projects that have been grouped by type of improvement that was completed. In addition, the table lists the locations, the type of crash(es) that created the safety concerns, the predicted benefit/cost (B/C) ratio, and the observed B/C ratio. Averages and weighted averages for both predicted and observed B/C ratios are also included for each improvement group. As shown, 47 of the projects had B/C ratios that were greater than anticipated at the time of application for funding. Additionally, 11 of the projects had B/C ratios greater than 1.0, showing that the benefits were greater than the costs. The remaining 19 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 from a cost benefit perspective. The following is a summary of the information in **Table 1** and includes a brief description of the 19 projects that resulted in little or no improvement. **Table 2** presents a comparison of average predicted benefit/cost (B/C) ratio, observed B/C ratio, and weighted averages of all projects analyzed during the three studies (2015, 2016, and 2019).

Table 1. Summary of Safety Analyses Locations

| Def. | | Region | Highway/Intersection | MP | Crash Type | Improvement Type | Year Comp. | Predicted B/C | Observed B/C |
|-----------------------------|--|--------|---------------------------------------|------------------------------|-----------------|--------------------------------|-------------------|--------------------|---------------------|
| ROADWAY PROJECTS | | | | | | | | | |
| Median Barriers | | | | | | | | | |
| #15645 ¹ | | 6 | SH 83A – Aurora | 69.39 – 70.57 | Off-Road Median | Concrete Barrier | 2007 | 2.11 | 5.91 |
| #15748 ¹ | | 6 | I-76A – Adams Co | 1.77 – 5.78 | Off-Road Median | Cable Rail | 2007 | 14.36 | 6.16 |
| #15770 ¹ | | 2 | I-25A – Pueblo Co | 102.50 – 107.50 | Off-Road Median | Cable Rail | 2008 | 2.65 | 2.26 |
| #16495 ² | | 6 | I-76A – Commerce City | 17.08 – 22.38 | Off-Road Median | Cable Rail | 2009 | 1.78 | 1.03 |
| #16563 ² | | 1 | I-70A – Clear Creek Co | 221.2 – 224.7 | Off-Road Median | Guard Rail | 2008 | 2.36 | 5.12 |
| #16878 ² | | 6 | I-225A – Aurora SH 83A – Aurora | 4.17 – 6.79 66.98 – 67.98 | Off-Road Median | Cable Rail Concrete Barrier | 2009 | 2.11 | 20.55 |
| #17202 ² | | 4 | I-76A – Weld Co | 25.14 – 32.00 | Off-Road Median | Cable Rail | 2010 | 7.29 | 1.01 |
| #17524 | | 6 | SH 470 between Acres Green Dr. & I-25 | 24.54 – 26.21 | Off-Road Median | Cable Rail | 2012 | 10.43 | 1.58 |
| Range: 1.01 to 20.55 | | | | | | | Avg (WAvg) | 5.39 (3.97) | 5.45 (5.98) |
| Guard Rail | | | | | | | | | |
| #15771 ¹ | | 2 | SH 165A – Pueblo Co | 18.65 – 23.90 | Off-Road | Guard Rail | 2007 | 4.97 | 12.67 |
| #15900 ¹ | | 3 | SH 133A – Pitkin Co | 46.00 – 51.50 | Off-Road | Guard Rail | 2008 | 4.89 | 21.54 |
| #17025 ² | | 2 | US 50A – Fremont Co | 271.00 – 275.00 | Off-Road | Guard Rail | 2009 | 1.26 | 2.12 |
| #17143 ² | | 2 | SH 115A – Fremont Co | 3.80 – 6.80 | Off-Road | Guard Rail | 2009 | 3.28 | 0.71 |
| #17746 | | 2 | I-25A – El Paso Co | 96.36 – 97.25 | Off-Road | Guard Rail | 2011 | 1.32 | 2.63 |
| Range: 0.71 to 21.54 | | | | | | | Avg (WAvg) | 3.14 (3.71) | 7.93 (10.19) |

HSIP Before/After Safety Analysis III

| Def. | Region | Highway/Intersection | MP | Crash Type | Improvement Type | Year Comp. | Predicted B/C | Observed B/C |
|--|--------|---|-----------------|--------------------------------------|---|-------------------|--------------------|---------------------|
| Realignment and Side Slope Flattening | | | | | | | | |
| #17569 | 4 | CR 27 – Larimer Co | 21.8 | Off-Road | Side Slope Flattening – Curve Realignment | 2012 | 2.12 | 5.47 |
| ITS Improvements | | | | | | | | |
| #15828 ¹ | 6 | SH 93A – Jefferson Co | 7.47 – 11.83 | High Winds | Weather Related Road Closures System | 2007 | 1.17 | 1.42 |
| #17014 ² | 1 | I-70A – Clear Creek Co | 215.35 – 229.00 | Downhill Grade | Variable Speed Limit, Descent Speed Warning System | 2010 | 4.24 | 10.52 |
| #17314 | 5 | SH 160A – MP 160.5 | 160.0 – 161.0 | Off-Road | VMS Signing, Barrier Upgrade | 2012 | 1.62 | 0.00 |
| Range: 0.00 to 10.52 | | | | | | Avg (WAvg) | 2.34 (3.07) | 3.98 (6.18) |
| Median Improvements | | | | | | | | |
| #16420 ² | 3 | US 50A – Pueblo | 312.89 – 313.83 | Broadside | Install Median, Extend Turn Lanes | 2008 | 1.54 | 4.06 |
| #17526 | 6 | SH 121A (Wadsworth Blvd) / 9 th Ave | 12.84 | Broadside | Add Raised Median | 2012 | 5.69 | 13.73 |
| #17529 | 6 | SH 121A (Wadsworth Blvd) / 44 th to 45 th Ave | 16.14 – 16.26 | Approach Turn | Add Raised Median | 2011 | 10.27 | 119.12 |
| Range: 4.06 to 119.12 | | | | | | Avg (WAvg) | 5.83 (2.08) | 45.64 (8.71) |
| Wildlife Protection | | | | | | | | |
| #15505 ¹ | 5 | US 550B – Ouray Co | 107.00 – 111.00 | Wild Animal | Cattle Guards | 2008 | 1.81 | 0.24 |
| #15901 ² | 3 | SH 82A | 7.0 – 11.0 | Wild Animal | Deer Fence | 2010 | 1.27 | 5.25 |
| #16453 | 3 | I-70A / Dowd Junction – Eagle Co | 171.00 – 173.5 | Wild Animal, nighttime, ramp-related | Wildlife Fence, Drainage, on-ramp ext., signs, striping, & lighting | 2008 | 2.48 | 16.11 |
| #17656 | 6 | SH 6G – 19 th St to Heritage Rd | 272.64 – 273.96 | Wild Animal | Wildlife Fence | 2011 | 1.47 | 1.70 |
| Range: 0.24 to 16.11 | | | | | | Avg (WAvg) | 1.76 (1.68) | 5.83 (6.46) |

| Def. | Region | Highway/Intersection | MP | Crash Type | Improvement Type | Year Comp. | Predicted B/C | Observed B/C |
|------------------------------|--------|--|-----------------|--------------------------|---|-------------------|--------------------|----------------------|
| Ramp Meters | | | | | | | | |
| #16642 | 6 | SH 270A / Quebec St - WB on-ramp | 4.00 – 5.00 | Read-End, Sideswipe Same | Install Ramp Meter | 2009 | 3.58 | 14.54 |
| #16642 | 6 | SH 36B / 104th Ave - WB on-ramp | 49.64 – 50.64 | Rear-End | Install Ramp Meter | 2009 | 3.69 | 9.40 |
| #16642 | 6 | I-25A / SH 128 - SB on-ramp | 271.00 – 275.00 | Rear-End | Install Ramp Meter | 2009 | 2.31 | 13.70 |
| #16642 | 6 | SH 470A / Lucent Blvd – EB on-ramp | 18.27 – 19.27 | Rear-End | Install Ramp Meter | 2009 | 4.12 | 4.10 |
| #16642 | 6 | SH 470A / Kipling Blvd – EB on-ramp | 12.35 – 13.35 | Rear-End | Install Ramp Meter | 2009 | 0.42 | 9.16 |
| Range: 4.10 to 14.54 | | | | | | Avg (WAvg) | 2.82 (2.82) | 10.18 (10.18) |
| INTERSECTION PROJECTS | | | | | | | | |
| Install Signals | | | | | | | | |
| #16010 ¹ | 2 | Industrial / Purcell – Pueblo | n/a | Broadside | New Signal | 2009 | 1.12 | 0.00 |
| #16380 ² | 4 | US 287 / 19 th St – Larimer Co | 331.65 | Broadside | Install Signal | 2010 | 1.66 | 15.12 |
| #16552 | 3 | SH 82 / Buffalo Valley – Garfield Co | 4.21 – 4.41 | Rear-End | New Signal | 2008 | 1.09 | 0.00 |
| #16595 ² | 4 | SH 50A / 28.5 Rd – Mesa Co | 35.38 | Broadside | Install Signal, Dilemma Zone Preemption | 2008 | 1.23 | 23.89 |
| #16601 ² | 6 | SH 7D / County Line Rd – Erie | 64.14 | Intersection | Install Signal, Geometric Improvements | 2010 | 2.06 | 0.17 |
| #16762 ² | 4 | SH 14C / I-25 East Frontage Rd – Ft. Collins | 139.21 | Broadside | Install Signal | 2010 | 1.14 | 0.44 |
| #16804 ² | 3 | I-70B – Grand Junction | 0.40 – 1.30 | Intersection | Install Signal, Geometric Improvements | 2009 | 1.65 | 5.63 |
| #16814 ² | 3 | I-70B / Peachtree – Grand Junction | 11.72 – 12.17 | Broadside | Install Signal, Consolidate Access | 2008 | 1.88 | 12.44 |
| #17115 ² | 4 | SH 402A / CR 11 – Loveland | 1.00 | Rear-End | Install Signal, Geometric Improvements | 2010 | 1.19 | 0.81 |

HSIP Before/After Safety Analysis III

| Def. | Region | Highway/Intersection | MP | Crash Type | Improvement Type | Year Comp. | Predicted B/C | Observed B/C |
|-----------------------------|--------|--|------------------|---|--|-------------------|--------------------|--------------------|
| #17221 | 2 | SH 21 (Powers Blvd) / Grinnell St | 136.61 | Broadside | New Signal | 2012 | 8.56 | 17.07 |
| #17523 | 6 | SH 7D (160 th Ave) / York St | 69.81 – 68.91 | Broadside | New Signal | 2011 | 2.19 | 1.17 |
| #17577 | 4 | SH 257A / 37 th St | 3.10 – 3.20 | Broadside | New Signal, Turn Lanes | 2011 | 2.44 | 0.69 |
| #17602 | 2 | Purcell Blvd / Spaulding Ave | n/a | Broadside | New Signal | 2011 | 3.55 | 5.01 |
| Range: 0.00 to 23.89 | | | | | | Avg (WAvg) | 2.29 (2.01) | 6.34 (5.79) |
| Signal Upgrades | | | | | | | | |
| #15828 ¹ | 6 | SH 93A / SH 72A – Jefferson Co | 7.57 | Broadside, Rear-end, Approach Turn | Signal Upgrade | 2007 | 1.72 | 14.93 |
| #15862 ¹ | 4 | US 34A / 11th Avenue – Weld Co | 112.23 | Rear-End | Modernize to Current Standards | 2008 | 2.03 | 9.69 |
| #16313 ² | 6 | US 40C / Youngfield St – Lakewood | 289.38 | Rear-End, Broadside | Signal Upgrade, Left-Turn Phasing, Geometric Improvements | 2010 | 1.18 | 3.33 |
| #16314 ² | 6 | SH 391A / 20 th St US 40C / Newland St – both Lakewood | 6.77 293.38 | Broadside, Approach Turn | Upgrade Signals, Left-Turn Phasing | 2010 | 2.47 1.70 | 12.04 |
| #16498 ² | 4 | US 287C / 37 th St - Loveland | 335.75 | Rear-End, Approach Turn | Signal Upgrade, Geometric Improvements | 2010 | 2.69 | 0.57 |
| #16600 ² | 6 | US 285D / Brady Ct – Englewood | 258.69 | Rear-End, Broadside | Signal Upgrade | 2008 | 1.98 | 7.26 |
| #16625 ² | 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, Signal Upgrade, Pedestrian Improvement | 2010 | 4.63 1.09 | 1.14 |
| #16642 ² | 6 | US 285D – Denver | 257.69 – 258.06 | Rear-End, Sideswipe Same Dir | Queue Detection System, Blank-out Warning Sign | 2009 | 2.17 | 6.29 |
| #16941 ² | 6 | SH 121A / Chatfield Ave – Jefferson Co | 1.22 | Broadside | Signal Upgrade, Dilemma Zone Preemption | 2010 | 1.24 | 4.35 |

HSIP Before/After Safety Analysis III

| Def. | | Region | Highway/Intersection | MP | Crash Type | Improvement Type | Year Comp. | Predicted B/C | Observed B/C |
|-------------------------------|--|--------|--|---------------|-----------------------------|--|-------------------|--------------------|--------------------|
| #16957 ² | | 6 | US 285D / Sherman St – Englewood | 260.30 | Approach Turns | Signal Upgrades, Left Turn Phasing | 2010 | 1.42 | 2.32 |
| #17034 ² | | 3 | US 550B / Niagara Rd – Montrose | 128.24 | Intersection | Signal Upgrade, Geometric Improvements | 2010 | 1.55 | 1.30 |
| #17366 | | 3 | SH 40Z (Victory Way) / Ranney St | 0.58 – 0.68 | Broadside | Signal Upgrade, Geometric Improvements | 2010 | 1.07 | 0.61 |
| #17409 | | 2 | SH 45 (Pueblo Blvd) / Goodnight Ave | 5.02 – 5.12 | Broadside, Approach Turn | Signal Upgrade, Geometric Improvements | 2010 | 1.28 | 1.54 |
| #17657 | | 3 | SH 82A / Brush Creek Rd | 35.22 – 35.29 | Rear-End | Signal Upgrade, Geometric Improvements | 2010 | 1.12 | 39.71 |
| #17659 | | 6 | SH 30A (Hampden Ave) / Oneida St | 0.50 – 0.54 | Broadside | Signal Upgrade | 2013 | 4.28 | 0.67 |
| #17659 | | 6 | SH 95A (Sheridan Blvd) / Florida St | 2.51 | Broadside, Pedestrian | Signal Upgrade | 2013 | 2.80 | 2.33 |
| #17659 | | 6 | I-225A / Tamarac St | 0.67 | Broadside | Signal Upgrade | 2013 | 2.63 | 19.14 |
| #17659 | | 6 | SH 2A (Colorado Blvd) / I-70A | 8.82 | Broadside | Signal Upgrade | 2013 | 2.48 | 12.40 |
| #17659 | | 6 | SH 26B (Alameda Ave) / Pecos St | 13.69 – 13.71 | Broadside | Signal Upgrade | 2013 | 2.03 | 3.25 |
| Range: 0.57 to 39.71 | | | | | | | Avg (WAvg) | 2.07 (1.90) | 7.43 (7.13) |
| Geometric Improvements | | | | | | | | | |
| #14963 ² | | 6 | Kipling St / 58 th Ave – Arvada | n/a | Intersection Sight Distance | Geometric Improvements, Dual Left-Turn Lanes | 2008 | 2.50 | 6.41 |
| #15861 ¹ | | 4 | SH 52 / 95th Street – Boulder Co | 3.16 | Broadside, Approach Turn, | Left-Turn Lanes, Protected Left Turns | 2008 | 2.52 | 13.37 |
| #15873 ² | | 3 | SH 82A / Smith Way – Pitkin Co | 34.48 | Broadside | Intersection Improvements, Acceleration Lane | 2009 | 1.06 | 0.05 |
| #16005 ¹ | | 2 | US 50A / Purcell Blvd - Pueblo | 309.78 | Broadside, Approach Turn, | Second Through Lanes, Dual Left-Turn Lanes | 2007 | 1.77 | 4.00 |

HSIP Before/After Safety Analysis III

| Def. | | Region | Highway/Intersection | MP | Crash Type | Improvement Type | Year Comp. | Predicted B/C | Observed B/C |
|-----------------------------|--|--------|--|-----------------|--|---|-------------------|--------------------|--------------------|
| #16006 ¹ | | 2 | SH 45A / Red Creek Springs – Pueblo | 3.95 | Rear-End | Right-Turn Lanes | 2009 | 1.18 | 0.08 |
| #16011 ² | | 6 | El Paso St / Fillmore St – Colorado Springs | n/a | Broadside, Approach Turn, Rear-End, Sideswipe Same Dir, Pedestrian | Geometric Improvements, Pedestrian Improvements | 2010 | 1.31 | 0.00 |
| #16623 ² | | 4 | SH 392B / WCR 31 – Weld Co | 11.54 | Rear-End | Construct Left-Turn Lane | 2008 | 1.44 | 9.02 |
| #17015 ² | | 4 | US 287C / LCR 21C – Larimer Co | 352.35 | Broadside | Geometric Improvements | 2010 | 1.86 | 2.75 |
| #17016 ² | | 4 | SH 392A / LCR 9 – Larimer Co | 98.50 | Rear-End | Construct Left-Turn Lane | 2009 | 1.42 | 0.42 |
| #17116 ² | | 4 | SH 119A / Hover St – Longmont | 54.41 | Rear-End, Sideswipe Same Dir | Left-Turn Lane Extension, Acceleration Lane | 2009 | 0.76 | 15.77 |
| #17410 | | 2 | SH 50B / Bonforte Blvd | 316.30 – 316.70 | Rear-End, Sideswipe Same Dir | Acceleration Lane Extension, New Guardrail | 2010 | 1.36 | 0.35 |
| #17528 | | 6 | 64 th Ave / Simms St (Arvada) | n/a | Approach Turn | Realign Left Turn Lanes | 2011 | 4.73 | 0.00 |
| #17574 | | 4 | SH 287C (Main St) / Pike Rd | 313.85 – 313.95 | Rear-End | Right-Turn Lane, Acceleration Lane | 2012 | 2.04 | 2.48 |
| Range: 0.00 to 15.77 | | | | | | | Avg (WAvg) | 1.84 (1.64) | 4.21 (2.92) |
| Roundabout | | | | | | | | | |
| #15367 ² | | 4 | US 6D / 9 th St – Silt | 99.24 | Broadside | Roundabout | 2009 | 1.53 | 0.67 |
| #16730 ² | | 3 | 23 Rd / G Rd – Grand Junction | n/a | Injury, Fatal | Roundabout | 2012 | 2.54 | 15.36 |
| #17249 ² | | 1 | I-76A / 96 th Ave Interchange – Commerce City | 11.45 – 11.65 | Intersection | Roundabouts | 2010 | 1.78 | 1.60 |
| Range: 0.67 to 15.36 | | | | | | | Avg (WAvg) | 1.95 (1.89) | 5.88 (4.58) |

¹ Project descriptions can be found in the 2015 report.

² Project descriptions can be found in the 2016 report, revision 1.

Table 2. Summary of Benefit/Cost Ratios for All Projects

| Study Number | Report Year | Number of Projects | Predicted B/C Average (& Weighted) | Observed B.C Average (& Weighted) |
|-------------------------------------|--------------------|---------------------------|---|--|
| 1 | 2015 | 13 | 3.25 (3.14) | 7.10 (6.53) |
| 2 | 2016 | 35 | 2.01 (2.01) | 5.75 (5.35) |
| 3 | 2019 | 29 | 3.21 (2.87) | 10.95 (6.86) |
| Running B/C (& Weighted) | | | 2.65 (2.40) | 7.88 (5.89) |

ROADWAY PROJECTS

Median Barriers – All eight 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 at 1.03 and #17202 at 1.01). These results show that barriers help reduce severe crashes and are generally cost-effective.

Guard Rail – Four of the five projects where guard rail was installed 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.

Realignment & Side Slope Flattening – There has been only one project evaluated (#17569) to date for this type of improvement. The curve between MP 21.76 and 21.84 on Larimer County CR 27 was realigned to a condition of mild curvature and side slopes were flattened. The analysis of safety performance showed an 80 percent reduction in all crashes (from five to one). The resulting B/C ratio was 5.47 to one, showing that the improvement was cost-effective in terms of safety benefits.

ITS Improvements – Three projects added Intelligent Transportation Systems (ITS) devices along an existing roadway. Two of the projects had B/C ratios greater than 1.0. 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 4.24 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 were 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.

#17314 – This project along SH 160A at MP 160.5 involved adding VMS signing and upgrading the truck ramp and barrier near a hairpin curve. After improvements were completed, the number of PDO crashes went down (25 to 18), but the number of injury crashes increased (11 to 14). There were no fatal crashes in the before period but one in the after period. As a result, of the overall increase in crash severity, there was no attempt to calculate a ratio.

Median Improvements – Three projects involved installing median improvements. These projects resulted in B/C ratios of 4.06 to 119.12, all of which were better than predicted.

Wildlife Protection – Four wildlife protection projects were analyzed. Three of the four projects resulted in B/C ratios that exceeded their predicted ratios, ranging from 1.70 to 16.11. 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.

Ramp Meters – Five projects that installed ramp meters on freeway on-ramps were analyzed. Four of the five projects resulted in B/C ratios that exceeded their predicted ratios, ranging from 9.26 to 14.54. One project (#16642, SH 470A at Lucent Boulevard) performed very close in the after period to what was predicted (4.12 predicted versus 4.10 observed).

INTERSECTION PROJECTS

Install New Signals – Of the thirteen projects that included signaling an intersection, six had B/C ratios less than one, indicating that signaling an intersection may not always be justifiable from a safety perspective. The seven 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.

#16552 – New signal constructed at SH 82A and Buffalo Valley in Garfield County. The installation of the signal reduced the number of broadside crashes but increased the number of rear-ends (and resulting injuries). Unfortunately, one broadside crash in the after period resulted in a fatality, which was likely a random event. There was no measurable safety benefit realized from the construction.

#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 in the before period to zero 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 a benefit that was less than the cost 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

#17577 – Signal installation at the intersection of SH 257A and 37th Street in Weld County. The safety analysis of the improvements at this intersection shows a reduction in the total number of crashes and the number of injury crashes and injuries, but the number of fatalities increased, which could be random considering that an overall decrease in severe (injury) crashes was realized.

Upgrade Existing Signals – Of the nineteen intersection projects that included upgrading the signals (such as replacing signal heads, installing new signal poles, etc., usually with geometric or phasing improvements), sixteen had B/C ratios greater than one, ranging from 1.14 to 39.71. Three projects (#16625, #17034, and #17659) had observed B/C ratios that did not exceed their predicted ratios (1.14, 1.30, and 2.33, respectively). Three projects had a B/C ratio less than one. It is not known if signal timings or phasing were updated after all of these signals were upgraded, but they should be reviewed and adjusted as appropriate after construction is completed to maximize potential safety benefits.

#16498 – Signal upgrade and geometric improvements at the intersection of US 287 and 37th Street in Loveland resulted in an observed B/C ratio of 0.57. There was almost no change in the overall number of crashes or in the number of injury crashes after this improvement.

#17366 – The signal upgrade at the intersection of SH 40Z (Victory Way) and Ranney Street in Moffat County resulted in an observed B/C ratio of 0.61. There were eleven total crashes before the improvements, and the crashes in the after period decreased to two, a reduction of 82 percent. Since all crashes in the before and after period were property damage only, the overall costs of the project outweighed the benefits.

#17659 – The signal upgrade at the intersection of US 30A (Hampden Avenue) and Oneida Street resulted in an observed B/C ratio of 0.67. The crash analysis shows no overall change in crashes with a slight decrease in injuries. A comparison of all crash types (before and after the improvements were made) showed that there was a decrease in the number of broadside crashes after the completion of the project. The number of approach turn and rear-end crashes increased in the after period.

Geometric Improvements – Seven of the thirteen geometric improvements had positive results with B/C ratios ranging from 2.48 to 15.77. These improvements included modifying geometry to improve sight distance 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. Six 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

affected the B/C ratio, it should be noted that the number of people injured is subject to chance, as the quantity of vehicle occupants cannot be predicted.

#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 as previously noted.

#17410 – The westbound acceleration lane was extended and guardrail installed at the intersection of SH 50B and Bonforte Boulevard in Pueblo. A comparison of all crash types showed that there was a slight decrease in the total number of crashes for any related crash type after the completion of the project. There was also a slight decrease in injury crashes.

#17528 – The median was removed and the left turn lanes were shifted to allow more sight distance at the intersection of 64th Avenue and Simms Street in Arvada. The crash analyses showed that there was an increase in the number of rear-end and approach turn crashes while there was a decrease in the number of broadside crashes after the completion of the project. There was an increase in injury crashes. The number of PDO increased from 22 in the before period to 32 in the after period. Since there were no decreases in overall crash numbers, it was not meaningful to attempt to derive a benefit cost ratio for this project.

Roundabouts – There were three roundabout construction projects analyzed. 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 conduct Before/After Safety Analyses to understand what safety improvements are most effective. While many of the projects analyzed in the study have shown significant safety benefits, some showed deterioration in safety. It is essential to complete these studies to understand the impacts of different improvement types and why the initially predicted safety improvements are not always observed following construction. It is recommended that CDOT institutionalize this process and perform a before/after safety analysis evaluation of safety performance for all projects constructed when after period crash data becomes available. Analyzing safety performance of projects before and after completion will allow CDOT to make better and more informed decisions for future projects, thereby maximizing the positive impact of the limited safety improvement funding that is available.

SAFETY REPORTS

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

- #16453 – I-70A – Dowd Junction
- #16552 – SH 82A – Buffalo Valley
- #16642 – SH 270A / Quebec St
- #16642 – SH 36B / 104th Ave
- #16642 – I-25A / SH 138
- #16642 – SH 470A / Lucent Blvd
- #16642 – SH 470A / Kipling Blvd
- #17221 – SH 21A (Powers Blvd) / Grinnell St
- #17314 – SH 160A – MP 160.5
- #17366 – SH 40Z (Victory Way) / Ranney St
- #17409 – SH 45A (Pueblo Blvd) / Goodnight Ave
- #17410 – SH 50B / Bonforte Blvd
- #17523 – SH 7D (160th Ave) / York St
- #17524 – SH 470A between Acres Green Dr & I-25
- #17526 – SH 121A (Wadsworth Blvd) / 9th Ave
- #17528 – 64th Ave / Simms St
- #17529 – SH 121A (Wadsworth Blvd) / 44th Ave to 45th Ave
- #17569 – CR 27 – MP 21.8

- #17574 – SH 287C (Main St) / Pike Rd
- #17577 – SH 257A / 37th St
- #17602 – Purcell Blvd / Spaulding Ave
- #17656 – SH 6G / 19th St to Heritage Rd
- #17657 – SH 82A / Brush Creek Rd
- #17659 – SH 30A (Hampden Ave) / Oneida St
- #17659 – SH 95A (Sheridan Blvd) / Florida St
- #17659 – I-225A / Tamarac St
- #17659 – SH 2A (Colorado Blvd) / I-70
- #17659 – SH 26B (Alameda Ave) / Pecos St
- #17746 – I-25A – MP 96.36 to 97.25

Project Information

Project Name: I-70 Vail East & West

Project Description: Wildlife Fence, Drainage Improvements, Extension of EB On Ramp, Signing, Striping and Lighting

CDOT Region: 3 Project Def: 16453 County: Mesa

Location: I-70, in Dowd Canyon West of Vail Mile Points: 171.00 to 173.50
Length: 2.5 miles

Schedule: Work Start Date: 5/19/2008 Completion Date: 9/2/2008

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 48 injury crashes, 136 PDO crashes, and one fatal crash. I-70A is a four lane Interstate Freeway through this section with two interchanges (Dowd Junction at MP 171.11 and West Vail at MP 173.32).

Improvement Description: Between May 19, 2008 and September 2, 2008, one of the eastbound on-ramps was extended, wildlife fence was installed and improvements were made to the drainage, lighting and signing. The cost of construction was \$600,000.

The FHEP application anticipated that a 30% reduction in all types of crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 2.48.

Summary and Findings

The analysis of safety before and after the improvements were made on this portion of the corridor shows a reduction in the number and severity of all crash types. In this segment of 4-lane divided freeway, there were 167 total crashes during the three-year period before the improvements were made (2005 – 2007). In the three years after construction (2009 – 2011), the number of crashes decreased to 103, a reduction of 38%. The ADT did not appear to significantly increase or decrease from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a 22% decrease in injury crashes, from 27 crashes (40 injuries) in the three years before construction to 21 crashes (27 injuries) in the three years after construction. The number of PDO crashes was reduced from 140 to 82. There were no fatalities in either the before or the after period. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 20 years for this project is **16.11** to one. The result is an improvement that certainly was justified from the safety improvement as well as cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 171.00 to 173.50 shows a decrease in the number of crashes from 167 during the three-year period (2005 to 2007) before the improvements to 103 during the three-year after period (2009 to 2011) (Table 1). The number of serious crashes also showed a decrease in the after period:

- Before (2005 – 2007) – No fatal crashes and 27 injury crashes with 40 injuries
- After (2009 – 2011) – No fatal crashes and 21 injury crashes with 27 injuries

It is reasonable to conclude that the observed decrease in the frequency and severity of crashes is related to the various safety improvements constructed on this project.

Table 1 – I-70, in Dowd Canyon West of Vail (MP 171.00 – 173.50) - 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 | 34,329 vpd | 31,861 vpd |
| Filters: | All Non-Intersection Related Mainline Crashes | All Non-Intersection Related Mainline Crashes |
| Total Crashes | 167 | 103 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 27 (40) | 21 (27) |
| Property Damage Only | 140 | 82 |

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 of safety uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 (**Figure 1**) and for fatal and injury crashes (**Figure 2**) reflect an improvement in the crash record for this project. LOSS improved from very high in the LOSS IV range for total crashes in the before period to LOSS III in the after period. Injury/Fatal crashes also improved to LOSS III in the after period from LOSS IV in the before period. **Figures 1 and 2** also show that the number and severity of crashes during the period after construction improved in comparison to what it could have been without this safety improvement project. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes

I-70A, MP 171.00 to 173.50

Before: 2005 to 2007 After: 2009 to 2011

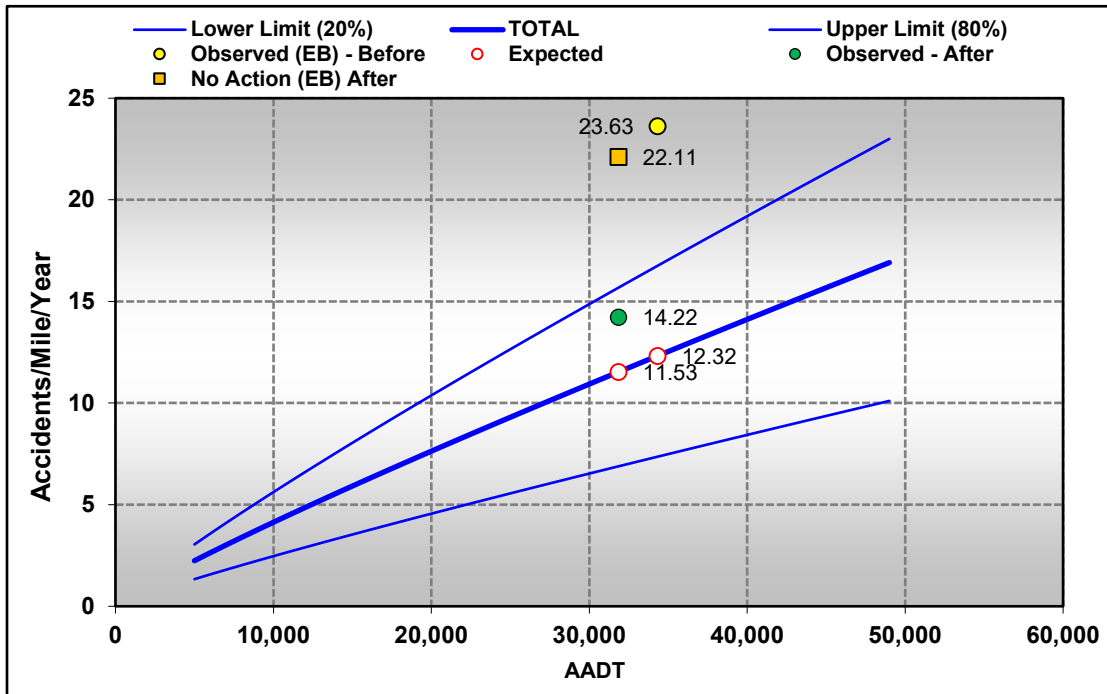


Figure 2 – SPF for Injury and Fatal Crashes

I-70A, MP 171.00 to 173.50

Before: 2005 to 2007 After: 2009 to 2011

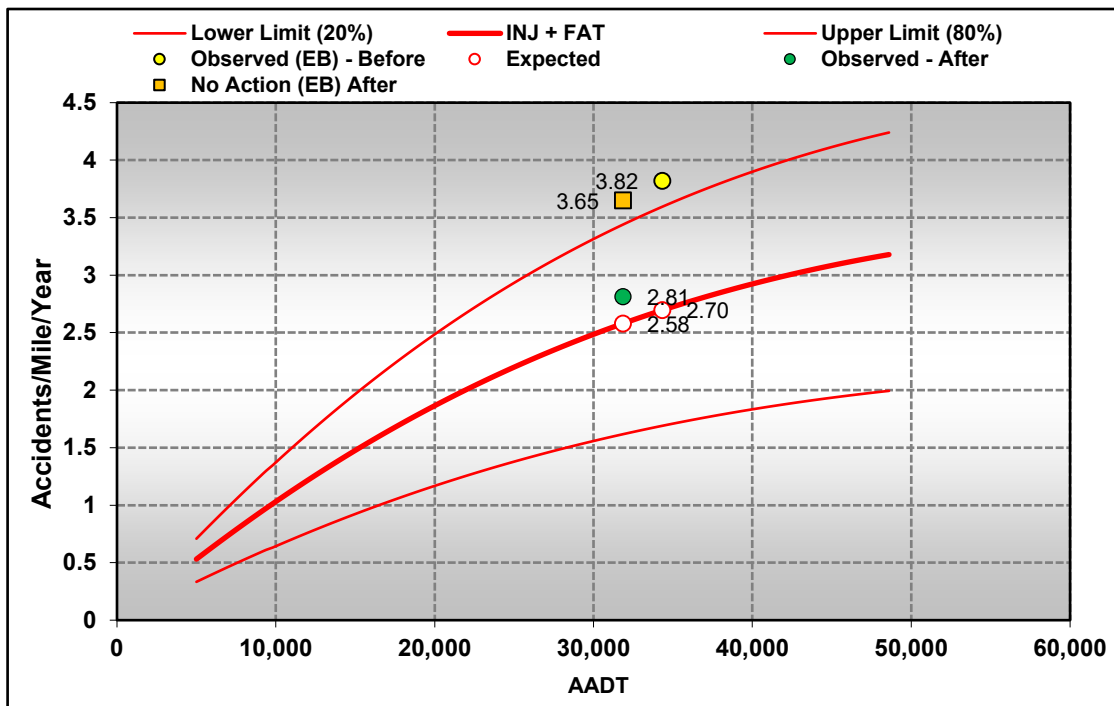
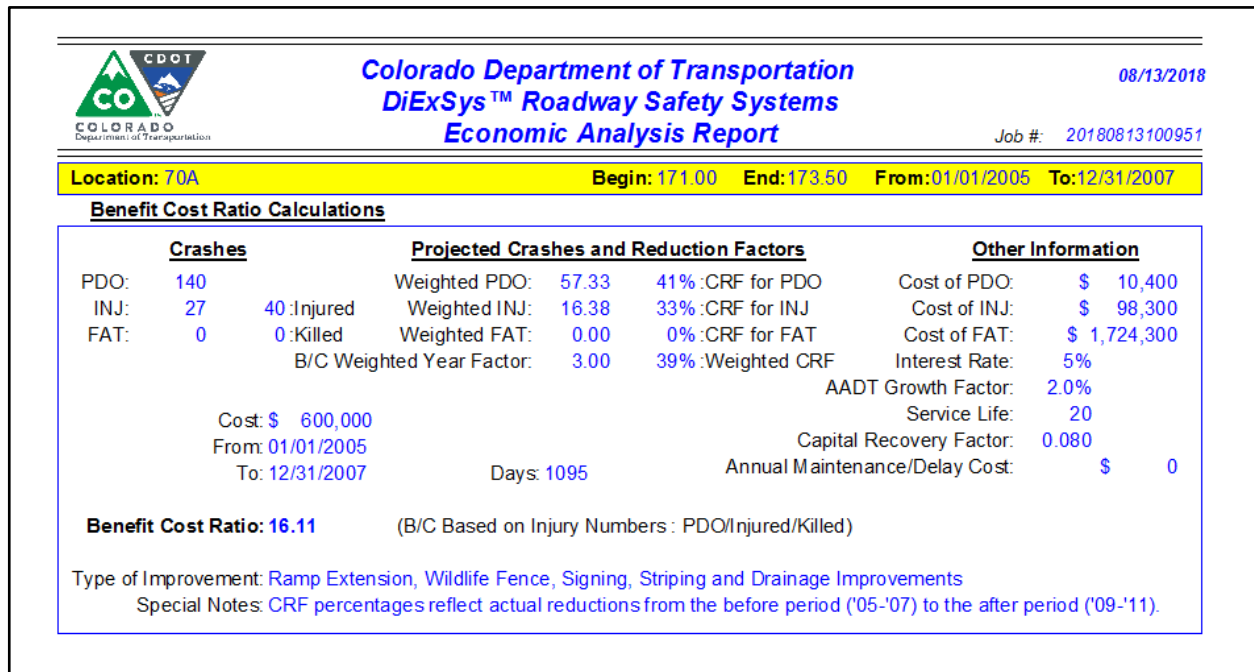


Table 2 – I-70, in Dowd Canyon West of Vail (MP 171.00 – 173.50) - Safety Performance Function (SPF)

| | Before | After | No Action After |
|------------------------------------|--|--|--|
| EB Correction: | Yes | No | Yes |
| SPF Graph | Rural Mountainous 4-Lane Divided Freeway | Rural Mountainous 4-Lane Divided Freeway | Rural Mountainous 4-Lane Divided Freeway |
| Total Crashes: | | | |
| LOSS | LOSS IV | LOSS III | LOSS IV |
| CPY | 23.63 | 14.22 | 22.11 |
| Mean CPY | 12.32 | 11.53 | 11.53 |
| Proportion of Mean | 1.92 | 1.23 | 1.92 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS IV | LOSS III | LOSS IV |
| CPY | 3.82 | 2.81 | 3.65 |
| Mean CPY | 2.70 | 2.56 | 2.56 |
| Proportion of Mean | 1.41 | 1.10 | 1.43 |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes in the segment. **A calculated B/C ratio of 16.11 was ultimately realized.** This outcome displays that this safety improvement project was justified from a cost-effectiveness standpoint.

Figure 3 – I-70, in Dowd Canyon West of Vail (MP 171.00 – 173.50) – Benefit Cost Analysis





Location: 70A **Begin: 171.00** **End: 173.50** **From: 01/01/2005** **To: 12/31/2007**

I-70 - Dowd Junction

| Severity | |
|---------------|---------------------|
| PDO: | 140 |
| INJ: | 27 40 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 167 |

| Number of Vehicles | |
|--------------------|------------|
| One Vehicle: | 114 |
| Two Vehicles: | 46 |
| Three or More: | 7 |
| Unknown: | 0 |
| Total: | 167 |

| Location | |
|------------------|------------|
| On Road: | 68 |
| Off Road Left: | 48 |
| Off Road Right: | 50 |
| Off Road at Tee: | 0 |
| Off in Median: | 1 |
| Unknown: | 0 |
| Total: | 167 |

| Lighting Conditions | |
|---------------------|------------|
| Daylight: | 105 |
| Dawn or Dusk: | 4 |
| Dark - Lighted: | 25 |
| Dark - Unlighted: | 33 |
| Unknown: | 0 |
| Total: | 167 |

| Weather Conditions | |
|--------------------|------------|
| None: | 90 |
| Rain: | 16 |
| Snow/Sleet/Hail: | 61 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 167 |

| Crash Rates | |
|---------------|------------------------|
| PDO: | 1.58* * MVMT |
| INJ: | 0.30* ** 100 MVMT |
| FAT: | 0.00** |
| Total: | 1.89* |

| Crash Type | | | |
|-----------------------|----|-----------------------------|------------|
| Overtuning: | 9 | Bridge Abutment: | 0 |
| Other Non Collision: | 4 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 0 | Embankment: | 5 |
| Head On: | 0 | Curb: | 0 |
| Rear End: | 13 | Delineator Post: | 0 |
| Sideswipe (Same): | 24 | Fence: | 0 |
| Sideswipe (Opposite): | 0 | Tree: | 0 |
| Approach Turn: | 0 | Large Boulders or Rocks: | 4 |
| Overtaking Turn: | 0 | Barricade: | 3 |
| Parked Motor Vehicle: | 3 | Wall/Building: | 0 |
| Railway Vehicle: | 0 | Crash Cushion: | 0 |
| Bicycle: | 0 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 1 |
| Domestic Animal: | 0 | Total Fixed Objects: | 92 |
| Wild Animal: | 17 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 1 | Vehicle Cargo/Debris: | 2 |
| Traffic Signal Pole: | 0 | Road Maintenance Equipment: | 0 |
| Sign: | 1 | Involving Other Object: | 3 |
| Bridge Rail: | 6 | Total Other Objects: | 5 |
| Guard Rail: | 23 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 167 |
| Concrete Barrier: | 48 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | | | |
|-------------------------------|------|-----------------------------|-----------------------|----|-------------------|
| Mainline: | 167 | M: | 0 | N: | 0 |
| Crossroad (A): | 0 | O: | 0 | P: | 0 |
| Ramps | | | | | |
| B: 0 | F: 0 | J: 0 | Left Frontage Rd (L): | 0 | |
| C: 0 | G: 0 | K: 0 | Rt Frontage Rd (R): | 0 | |
| D: 0 | H: 0 | T: 0 | HOV Lanes (V): | 0 | |
| E: 0 | I: 0 | | Unknown: | 0 | Total: 167 |

| Road Description | |
|-----------------------|------------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 167 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 167 |

| Road Conditions | |
|------------------------------|------------|
| Dry: | 53 |
| Wet: | 22 |
| Muddy: | 0 |
| Snowy: | 27 |
| Icy: | 38 |
| Slushy: | 9 |
| Foreign Material: | 0 |
| With Road Treatment: | 0 |
| Dry w/Icy Road Treatment: | 0 |
| Wet w/Icy Road Treatment: | 0 |
| Snowy w/Icy Road Treatment: | 4 |
| Icy w/Icy Road Treatment: | 10 |
| Slushy w/Icy Road Treatment: | 4 |
| Unknown: | 0 |
| Total: | 167 |

ADT: 34,329 **Length: 2.35**



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

CDOT Project #16453 06/26/2019
Exhibit 1

Job #: 20190626104327

Location: 70A **Begin: 171.00** **End: 173.50** **From: 01/01/2005** **To: 12/31/2007**

I-70 - Dowd Junction

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 | Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-------|-------|-------|------------------------------|------------|-----------|----------|
| Passenger Car/Van: | 103 | 28 | 4 | Going Straight: | 99 | 34 | 4 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 | Slowing: | 7 | 2 | 0 |
| Pickup Truck/Utility Van: | 29 | 8 | 1 | Stopped in Traffic: | 0 | 5 | 3 |
| Pickup Truck/Utility Van w/Trl: | 4 | 1 | 0 | Making Right Turn: | 2 | 0 | 0 |
| SUV: | 15 | 6 | 1 | Making Left Turn: | 0 | 0 | 0 |
| SUV w/Trl: | 0 | 0 | 0 | Making U-Turn: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 | Passing: | 14 | 1 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 14 | 7 | 0 | Backing: | 1 | 0 | 0 |
| School Bus < 15 People: | 0 | 0 | 0 | Enter/Leave Parked Position: | 0 | 0 | 0 |
| Non School Bus < 15 People: | 0 | 2 | 0 | Starting in Traffic: | 0 | 0 | 0 |
| Motorhome: | 1 | 0 | 0 | Parked: | 0 | 2 | 0 |
| Motorcycle: | 0 | 0 | 0 | Changing Lanes: | 8 | 0 | 0 |
| Bicycle: | 0 | 0 | 0 | Avoiding Object/Veh in Road: | 4 | 6 | 0 |
| Motorized Bicycle: | 0 | 0 | 0 | Weaving: | 3 | 0 | 0 |
| Farm Equipment: | 0 | 0 | 0 | Wrong Way: | 0 | 0 | 0 |
| Hit and Run - Unknown: | 0 | 1 | 0 | Other: | 28 | 1 | 0 |
| Other: | 1 | 0 | 1 | Unknown: | 1 | 2 | 0 |
| Unknown: | 0 | 0 | 0 | Total: | 167 | 53 | 7 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 | Direction | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-------|-------|-------|---------------|------------|-----------|----------|
| No Apparent Contributing Factor: | 125 | 47 | 7 | North: | 0 | 0 | 0 |
| Asleep at the Wheel: | 0 | 0 | 0 | Northeast: | 0 | 0 | 0 |
| Illness: | 1 | 0 | 0 | East: | 80 | 28 | 4 |
| Distracted by Passenger: | 0 | 0 | 0 | Southeast: | 0 | 0 | 0 |
| Driver Inexperience: | 13 | 1 | 0 | South: | 0 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 | Southwest: | 0 | 1 | 0 |
| Driver Preoccupied: | 6 | 0 | 0 | West: | 87 | 23 | 3 |
| Driver Unfamiliar with Area: | 7 | 0 | 0 | Northwest: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 1 | 0 | 0 | Unknown: | 0 | 1 | 0 |
| Evading Law Enforcement Officer: | 1 | 0 | 0 | Total: | 167 | 53 | 7 |
| Physical Disability: | 0 | 0 | 0 | | | | |
| Unknown: | 13 | 5 | 0 | | | | |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|------------|-----------|----------|
| No Impairment Suspected: | 155 | 53 | 7 |
| Alcohol Involved: | 10 | 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: | 167 | 53 | 7 |

ADT: 34,329 **Length: 2.35**



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

CDOT Project #16453 06/26/2019
Exhibit 2

Job #: 20190626104549

Location: 70A Begin: 171.00 End: 173.50 From: 01/01/2009 To: 12/31/2011

I-70 - Dowd Junction

Severity

PDO: 82
 INJ: 21 27 :Injured
 FAT: 0 0 :Killed

Total: 103

Number of Vehicles

One Vehicle: 76
 Two Vehicles: 25
 Three or More: 2
 Unknown: 0

Total: 103

Location

On Road: 34
 Off Road Left: 37
 Off Road Right: 32
 Off Road at Tee: 0
 Off in Median: 0
 Unknown: 0

Total: 103

Lighting Conditions

Daylight: 51
 Dawn or Dusk: 9
 Dark - Lighted: 19
 Dark - Unlighted: 24
 Unknown: 0

Total: 103

Weather Conditions

None: 48
 Rain: 4
 Snow/Sleet/Hail: 51
 Fog: 0
 Dust: 0
 Wind: 0
 Unknown: 0

Total: 103

Crash Rates

PDO: 1.00* * MVMT
 INJ: 0.26* ** 100 MVMT
 FAT: 0.00** **Total: 1.25***

Crash Type

| | |
|-------------------------|-------------------------------|
| Overtuning: 0 | Bridge Abutment: 0 |
| Other Non Collision: 0 | Column/Pier: 0 |
| Pedestrians: 0 | Culvert/Headwall: 0 |
| Broadside: 0 | Embankment: 7 |
| Head On: 0 | Curb: 0 |
| Rear End: 10 | Delineator Post: 2 |
| Sideswipe (Same): 8 | Fence: 0 |
| 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: 0 |
| Domestic Animal: 0 | Total Fixed Objects: 70 |
| Wild Animal: 12 | 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: 1 |
| Bridge Rail: 0 | Total Other Objects: 2 |
| Guard Rail: 17 | Unknown: 0 |
| Cable Rail: 0 | Total: 103 |
| Concrete Barrier: 43 | |

Mainline/Ramps/Frontage Roads

Mainline: 103
 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 T: 0
 E: 0 I: 0

Left Frontage Rd (L): 0
 Rt Frontage Rd (R): 0
 HOV Lanes (V): 0

Unknown: 0

Total: 103

Road Description

At Intersection: 0
 At Driveway Access: 0
 Intersection Related: 0
 Non Intersection: 103
 In Alley: 0
 Roundabout: 0
 Ramp: 0
 Parking Lot: 0
 Unknown: 0

Total: 103

Road Conditions

Dry: 27
 Wet: 8
 Muddy: 0
 Snowy: 22
 Icy: 28
 Slushy: 12
 Foreign Material: 0
 With Road Treatment: 0
 Dry w/Icy Road Treatment: 0
 Wet w/Icy Road Treatment: 1
 Snowy w/Icy Road Treatment: 3
 Icy w/Icy Road Treatment: 2
 Slushy w/Icy Road Treatment: 0
 Unknown: 0

Total: 103

ADT: 31,861 Length: 2.35



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

CDOT Project #16453 06/26/2019
Exhibit 2

Job #: 20190626104549

Location: 70A **Begin: 171.00** **End: 173.50** **From: 01/01/2009** **To: 12/31/2011**

I-70 - Dowd Junction

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 | Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|------------|-----------|----------|------------------------------|------------|-----------|----------|
| Passenger Car/Van: | 54 | 11 | 2 | Going Straight: | 33 | 15 | 0 |
| Passenger Car/Van w/Trl: | 1 | 0 | 0 | Slowing: | 6 | 8 | 1 |
| Pickup Truck/Utility Van: | 11 | 9 | 0 | Stopped in Traffic: | 1 | 2 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 | Making Right Turn: | 0 | 0 | 0 |
| SUV: | 34 | 5 | 0 | Making Left Turn: | 0 | 0 | 0 |
| SUV w/Trl: | 0 | 0 | 0 | Making U-Turn: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 | Passing: | 4 | 1 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 1 | 1 | 0 | Backing: | 0 | 0 | 0 |
| School Bus < 15 People: | 0 | 0 | 0 | Enter/Leave Parked Position: | 0 | 0 | 0 |
| Non School Bus < 15 People: | 0 | 1 | 0 | Starting in Traffic: | 0 | 0 | 0 |
| Motorhome: | 0 | 0 | 0 | Parked: | 1 | 0 | 0 |
| Motorcycle: | 0 | 0 | 0 | Changing Lanes: | 4 | 0 | 0 |
| Bicycle: | 0 | 0 | 0 | Avoiding Object/Veh in Road: | 5 | 1 | 1 |
| Motorized Bicycle: | 0 | 0 | 0 | Weaving: | 1 | 0 | 0 |
| Farm Equipment: | 0 | 0 | 0 | Wrong Way: | 1 | 0 | 0 |
| Hit and Run - Unknown: | 2 | 0 | 0 | Other: | 47 | 0 | 0 |
| Other: | 0 | 0 | 0 | Unknown: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 | Total: | 103 | 27 | 2 |
| Total: | 103 | 27 | 2 | | | | |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 | Direction | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|------------|-----------|----------|---------------|------------|-----------|----------|
| No Apparent Contributing Factor: | 79 | 25 | 2 | North: | 0 | 0 | 0 |
| Asleep at the Wheel: | 0 | 0 | 0 | Northeast: | 0 | 0 | 0 |
| Illness: | 0 | 0 | 0 | East: | 53 | 12 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 | Southeast: | 0 | 0 | 0 |
| Driver Inexperience: | 9 | 1 | 0 | South: | 0 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 | Southwest: | 0 | 0 | 0 |
| Driver Preoccupied: | 0 | 0 | 0 | West: | 50 | 15 | 2 |
| Driver Unfamiliar with Area: | 2 | 0 | 0 | Northwest: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 | Unknown: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 | Total: | 103 | 27 | 2 |
| Physical Disability: | 0 | 0 | 0 | | | | |
| Unknown: | 13 | 1 | 0 | | | | |
| Total: | 103 | 27 | 2 | | | | |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|------------|-----------|----------|
| No Impairment Suspected: | 93 | 27 | 2 |
| Alcohol Involved: | 9 | 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: | 103 | 27 | 2 |

ADT: 31,861 **Length: 2.35**

Project Information

Project Name: Signal at Intersection of SH 82 & CR 154

Project Description: New Signal Installation

CDOT Region: 3 Project Def: 16552 County: Garfield

Location: SH 82 Mile Points: 3.55 Length: Spot Location

Schedule: Work Start Date: 4/1/2008 Completion Date: 5/7/2008

Problem Description: The crash history from VZS for the evaluation period of 2000 to 2004 shows four fixed object and two broadside crashes. Of the six crashes, one resulted in an injury to one person. The application data references 28 crashes with 15 of them being injury crashes. That data also cited eight rear end crashes out a total of 18 crashes. We were not able to identify the source of either of these conflicting references and find no rear end crashes occurring during the pre-construction evaluation period.

Improvement Description: Between April 1, 2008 and May 7, 2008 the intersection was signalized. The cost of construction was \$232,735.

The FHEP application anticipated that rear-end crashes would be impacted by this improvement. It was anticipated that there would be a 20% crash reduction for these crashes. The expected benefit/cost ratio was estimated to be 1.09.

Summary and Findings

The analysis of safety performance before and after signalization of the intersection of SH 82 and County Road 154 at MP 3.55 showed a reduction of the affected crash types, specifically broadside and approach turn, however overall frequency as well as severity of crashes has increased. At this intersection, there were 14 total crashes and six injury crashes during the five-year period before construction (2003 – 2007). In the five years after construction (2009 – 2013), the number of all crashes increased to 18 and the number of injury crashes increased to seven. The number of fatal crashes increased to 1.

The signalization project did not appear to improve the safety at this location in the short term, with increases in all three severity categories. However, the percentage of broadside crashes decreased from 36% to 17%. Unfortunately, the broadside crashes that did occur in the after period were all in severe categories with one being a fatality. However, with only three crashes of this type, this pattern of severity is more likely random than reflective of an actual increase in the probability of broadsides to be injurious. The most significant increase was in rear-end crashes from two crashes in the before period to ten in the after period. An increase in rear-end crashes is not unexpected when signalizing an intersection. Since there were no decreases in overall crash numbers in any of the severity categories, it is not meaningful to attempt to derive a benefit cost ratio for this project as doing so would result in negative values. These findings suggest that it may not have been justified to install a signal for the purpose of improving safety at this location.

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 14 during the five-year period (2003 to 2007) before the intersection was signalized and 18 during the five-year after period (2009 to 2013) (**Table 1**). The number of severe crashes increased in the five-year period after the improvements, and there was a fatal crash in the after period when there was no fatal crash in the before period.

- Before (2003 – 2007) – No fatal crashes and 6 injury crashes with 10 people injured
- After (2009 – 2013) – 1 fatal crash with 1 fatality and 7 injury crashes with 10 people injured

There was a small decrease in traffic volume at the intersection from the before period to the after period. As a result, the proportional increase in crash rates is slightly higher than the increase in the number of crashes.

- Before (2003 – 2007): 0.30 crashes per million entering vehicles (cpmev)
- After (2009 – 2013): 0.45 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 82/CR 154) | 23,258/estimated 2,326 vpd | 21,780/estimated 2,178 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 14 | 18 |
| Fatal Crashes (Fatalities) | 0 (0) | 1 (1) |
| Injury Crashes (Injuries) | 6 (10) | 7 (10) |
| Property Damage Only | 8 | 10 |
| Crash Types: # (%) [cumulative probability] | | |
| Broadside | 5 (35.7%) | 3 (16.7%) |
| Fixed Object | 5 (35.7%) [99.99%] | 1 (5.6%) |
| Rear-End | 2 (14.3%) | 13 (55.6%) |

The magnitude of safety problems on selected 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 of safety uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and

severity. If the level of service 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 (**Figure 1**) and for fatal and injury crashes (**Figure 2**) 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 (**Table 2**).

Figure 1 – SPF for Total Crashes – Before/After/No Action After
 SH 82A (MP 3.55)
 Before:2003 to 2007 After:2009 to 2013

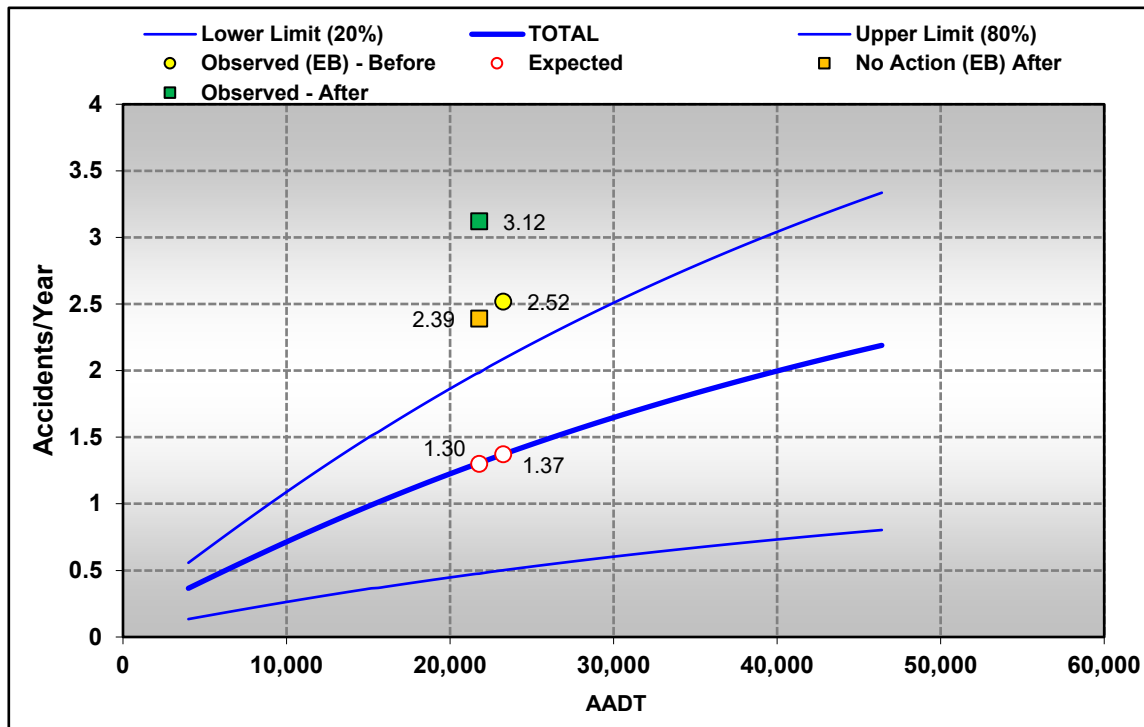


Figure 2 – SPF for Injury and Fatal Crashes – Before/After/No Action After
 SH 82A (MP 3.55)
 Before:2003 to 2007 After:2009 to 2013

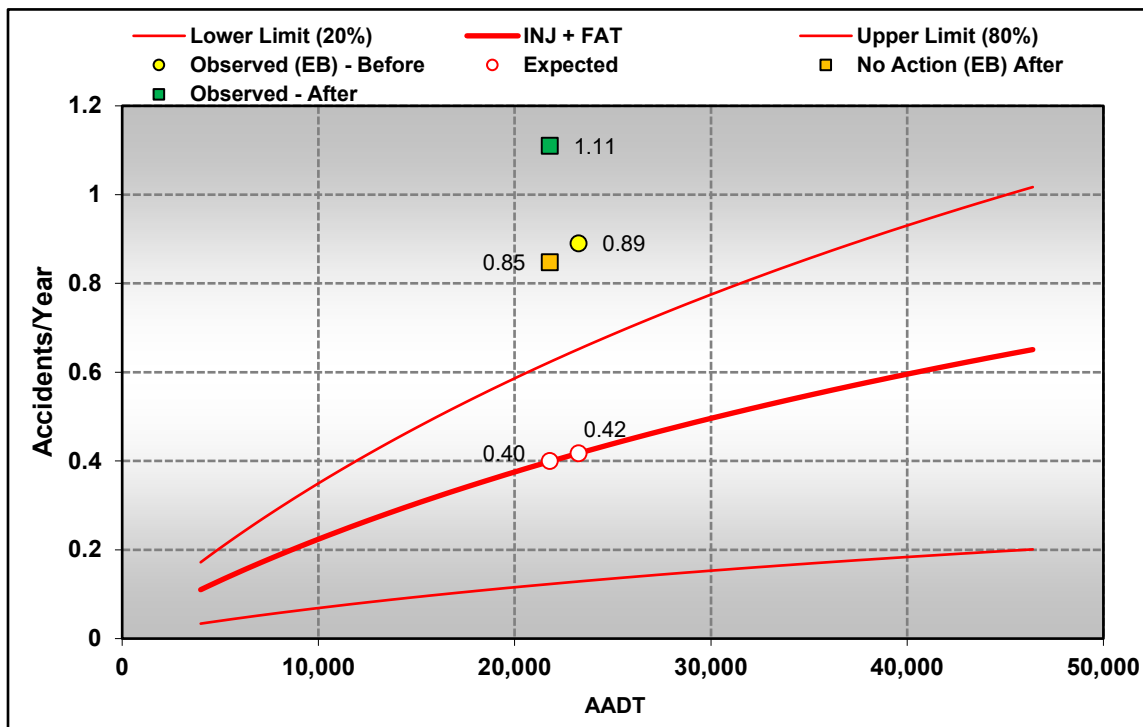


Table 2 – Safety Performance Function (SPF)

| | 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 IV | LOSS IV |
| CPY | 2.52 | 3.12 | 2.39 |
| Mean CPY | 1.37 | 1.30 | 1.30 |
| Proportion of Mean | 1.84 | 2.40 | 1.84 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS IV | LOSS IV | LOSS IV |
| CPY | 0.89 | 1.11 | .85 |
| Mean CPY | 0.42 | 0.40 | 0.40 |
| Proportion of Mean | 2.12 | 2.78 | 2.13 |

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

A more detailed review of the before and after crash record shows the crash types that were most affected by the signal installation. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: broadside, and rear-end. The installation of the signal reduced the number of broadside crashes, but increased the number of rear-ends. This is an expected outcome when signaling 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 (in this case there were no approach turn crashes in either the before or after periods). However, there was one broadside fatality that was likely random, which occurred in the after period. The No-Build After crashes were estimated using the change in SH 82 traffic volumes between the before and after period, as found in **Table 1** (decrease is $0.936 = 21,780/23,258$).

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 | 18 | 13 |
| Fatal (fatalities) | 0 (0) | 1 (1) | 0 (0) |
| Injury (injuries) | 6 (10) | 7 (10) | 6 (9) |
| PDO | 8 | 10 | 7 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | N/A (All Increased) | |
| Broadside – Total | 5 | 3 | 5 |
| Fatal (fatalities) | 0 (0) | 1 (1) | 0 (0) |
| Injury (injuries) | 3 (7) | 2 (5) | 3 (7) |
| PDO | 2 | 0 | 2 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | (Increase/33% /100%) | |
| Rear Ends – Total | 2 | 10 | 2 |
| Injury (injuries) | 1(1) | 3 (3) | 1(1) |
| PDO | 1 | 7 | 1 |
| % Reduction in Total (Injuries/PDO) | | N/A (All Increased) | |

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. However, as previously mentioned, it is not meaningful to provide benefit to cost analysis for this case because there was no measurable safety benefit realized from the construction since the crash numbers increased across all of the severity categories following construction. Therefore no B/C report is provided for this location.



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

CDOT Project #16552 06/26/2019
Exhibit 1

Job #: 20190626105125

Location: 82A **Begin: 3.53** **End: 3.57** **From:01/01/2003** **To:12/31/2007**

SH 82A at CR 154 (Buffalo Valley)

Severity

PDO: 8
 INJ: 6 10 :Injured
 FAT: 0 0 :Killed

Total: 14

Number of Vehicles

One Vehicle: 5
 Two Vehicles: 9
 Three or More: 0
 Unknown: 0

Total: 14

Location

On Road: 10
 Off Road Left: 0
 Off Road Right: 4
 Off Road at Tee: 0
 Off in Median: 0
 Unknown: 0

Total: 14

Lighting Conditions

Daylight: 8
 Dawn or Dusk: 1
 Dark - Lighted: 5
 Dark - Unlighted: 0
 Unknown: 0

Total: 14

Weather Conditions

None: 14
 Rain: 0
 Snow/Sleet/Hail: 0
 Fog: 0
 Dust: 0
 Wind: 0
 Unknown: 0

Total: 14

Crash Rates

PDO: 4.71 * * MVMT
 INJ: 3.53 * ** 100 MVMT
 FAT: 0.00 ** **Total: 8.24 ***

Crash Type

| | |
|-------------------------|-------------------------------|
| Overtuning: 0 | Bridge Abutment: 0 |
| Other Non Collision: 0 | Column/Pier: 0 |
| Pedestrians: 1 | Culvert/Headwall: 0 |
| Broadside: 5 | Embankment: 0 |
| Head On: 0 | Curb: 0 |
| Rear End: 2 | 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: 3 |
| 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: 0 |
| Bridge Rail: 0 | Total Other Objects: 0 |
| Guard Rail: 2 | 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 T: 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: 10
 At Driveway Access: 0
 Intersection Related: 4
 Non Intersection: 0
 In Alley: 0
 Roundabout: 0
 Ramp: 0
 Parking Lot: 0
 Unknown: 0

Total: 14

Road Conditions

Dry: 13
 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: 14

ADT: 23,258 **Length: 0.04**



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

CDOT Project #16552 06/26/2019
Exhibit 1

Job #: 20190626105125

Location: 82A Begin: 3.53 End: 3.57 From:01/01/2003 To:12/31/2007

SH 82A at CR 154 (Buffalo Valley)

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 | Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-------|-------|-------|------------------------------|-----------|----------|----------|
| Passenger Car/Van: | 9 | 4 | 0 | Going Straight: | 5 | 4 | 0 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 | Slowing: | 0 | 1 | 0 |
| Pickup Truck/Utility Van: | 2 | 2 | 0 | Stopped in Traffic: | 0 | 1 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 | Making Right Turn: | 7 | 1 | 0 |
| SUV: | 1 | 2 | 0 | Making Left Turn: | 2 | 0 | 0 |
| SUV w/Trl: | 0 | 0 | 0 | Making U-Turn: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 | Passing: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 1 | 1 | 0 | Backing: | 0 | 0 | 0 |
| School Bus < 15 People: | 0 | 0 | 0 | Enter/Leave Parked Position: | 0 | 0 | 0 |
| Non School Bus < 15 People: | 0 | 0 | 0 | Starting in Traffic: | 0 | 0 | 0 |
| Motorhome: | 0 | 0 | 0 | Parked: | 0 | 0 | 0 |
| Motorcycle: | 0 | 0 | 0 | Changing Lanes: | 0 | 0 | 0 |
| Bicycle: | 0 | 0 | 0 | Avoiding Object/Veh in Road: | 0 | 1 | 0 |
| Motorized Bicycle: | 0 | 0 | 0 | Weaving: | 0 | 0 | 0 |
| Farm Equipment: | 0 | 0 | 0 | Wrong Way: | 0 | 0 | 0 |
| Hit and Run - Unknown: | 0 | 0 | 0 | Other: | 0 | 1 | 0 |
| Other: | 1 | 0 | 0 | Unknown: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 | Total: | 14 | 9 | 0 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 | Direction | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|----------|----------|---------------|-----------|----------|----------|
| No Apparent Contributing Factor: | 6 | 9 | 0 | North: | 6 | 2 | 0 |
| Asleep at the Wheel: | 0 | 0 | 0 | Northeast: | 0 | 0 | 0 |
| Illness: | 0 | 0 | 0 | East: | 8 | 7 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 | Southeast: | 0 | 0 | 0 |
| Driver Inexperience: | 1 | 0 | 0 | South: | 0 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 | Southwest: | 0 | 0 | 0 |
| Driver Preoccupied: | 2 | 0 | 0 | West: | 0 | 0 | 0 |
| Driver Unfamiliar with Area: | 2 | 0 | 0 | Northwest: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 | Unknown: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 | Total: | 14 | 9 | 0 |
| Physical Disability: | 0 | 0 | 0 | | | | |
| Unknown: | 3 | 0 | 0 | | | | |
| Total: | 14 | 9 | 0 | | | | |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|----------|----------|
| No Impairment Suspected: | 13 | 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: | 14 | 9 | 0 |

ADT: 23,258 Length: 0.04



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

CDOT Project #16552 06/26/2019
Exhibit 2

Job #: 20190626105403

Location: 82A **Begin: 3.53** **End: 3.57** **From:01/01/2009** **To:12/31/2013**

SH 82A at CR 154 (Buffalo Valley)

Severity

PDO: 10
 INJ: 7 10 :Injured
 FAT: 1 1 :Killed

Total: 18

Number of Vehicles

One Vehicle: 3
 Two Vehicles: 13
 Three or More: 2
 Unknown: 0

Total: 18

Location

On Road: 16
 Off Road Left: 0
 Off Road Right: 2
 Off Road at Tee: 0
 Off in Median: 0
 Unknown: 0

Total: 18

Lighting Conditions

Daylight: 14
 Dawn or Dusk: 2
 Dark - Lighted: 1
 Dark - Unlighted: 1
 Unknown: 0

Total: 18

Weather Conditions

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

Total: 18

Crash Rates

PDO: 6.29* * MVMT
 INJ: 4.40* ** 100 MVMT
 FAT: 62.86** **Total: 11.31***

Crash Type

| | |
|-------------------------|-------------------------------|
| Overtuning: 1 | 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: 10 | 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: 1 | 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: 0 | Involving Other Object: 0 |
| Bridge Rail: 0 | Total Other Objects: 0 |
| Guard Rail: 0 | Unknown: 0 |
| Cable Rail: 0 | Total: 18 |
| Concrete Barrier: 0 | |

Mainline/Ramps/Frontage Roads

Mainline: 18
 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 T: 0
 E: 0 I: 0

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

Total: 18

Road Description

At Intersection: 10
 At Driveway Access: 0
 Intersection Related: 8
 Non Intersection: 0
 In Alley: 0
 Roundabout: 0
 Ramp: 0
 Parking Lot: 0
 Unknown: 0

Total: 18

Road Conditions

Dry: 14
 Wet: 1
 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: 0
 Snowy w/Icy Road Treatment: 0
 Icy w/Icy Road Treatment: 1
 Slushy w/Icy Road Treatment: 0
 Unknown: 0

Total: 18

ADT: 21,780 **Length: 0.04**



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

CDOT Project #16552 06/26/2019
Exhibit 2

Job #: 20190626105403

Location: 82A Begin: 3.53 End: 3.57 From:01/01/2009 To:12/31/2013

SH 82A at CR 154 (Buffalo Valley)

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 | Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-------|-------|-------|------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 6 | 5 | 1 | Going Straight: | 12 | 2 | 0 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 | Slowing: | 1 | 1 | 0 |
| Pickup Truck/Utility Van: | 1 | 3 | 0 | Stopped in Traffic: | 0 | 8 | 2 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 | Making Right Turn: | 2 | 0 | 0 |
| SUV: | 9 | 6 | 1 | Making Left Turn: | 1 | 3 | 0 |
| SUV w/Trl: | 0 | 0 | 0 | Making U-Turn: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 | Passing: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 1 | 0 | 0 | Backing: | 0 | 0 | 0 |
| School Bus < 15 People: | 0 | 0 | 0 | Enter/Leave Parked Position: | 0 | 0 | 0 |
| Non School Bus < 15 People: | 0 | 0 | 0 | Starting in Traffic: | 0 | 0 | 0 |
| Motorhome: | 0 | 0 | 0 | Parked: | 0 | 0 | 0 |
| Motorcycle: | 1 | 0 | 0 | Changing Lanes: | 0 | 0 | 0 |
| Bicycle: | 0 | 1 | 0 | Avoiding Object/Veh in Road: | 1 | 0 | 0 |
| Motorized Bicycle: | 0 | 0 | 0 | Weaving: | 0 | 0 | 0 |
| Farm Equipment: | 0 | 0 | 0 | Wrong Way: | 0 | 0 | 0 |
| Hit and Run - Unknown: | 0 | 0 | 0 | Other: | 1 | 1 | 0 |
| Other: | 0 | 0 | 0 | Unknown: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 | Total: | 18 | 15 | 2 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 | Direction | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-------|-------|-------|---------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 7 | 14 | 2 | North: | 0 | 2 | 0 |
| Asleep at the Wheel: | 0 | 0 | 0 | Northeast: | 1 | 0 | 0 |
| Illness: | 0 | 0 | 0 | East: | 10 | 6 | 1 |
| Distracted by Passenger: | 0 | 0 | 0 | Southeast: | 0 | 0 | 0 |
| Driver Inexperience: | 2 | 0 | 0 | South: | 0 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 | Southwest: | 0 | 0 | 0 |
| Driver Preoccupied: | 3 | 0 | 0 | West: | 7 | 6 | 1 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 | Northwest: | 0 | 1 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 | Unknown: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 | Total: | 18 | 15 | 2 |
| Physical Disability: | 1 | 0 | 0 | | | | |
| Unknown: | 4 | 1 | 0 | | | | |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 16 | 14 | 2 |
| Alcohol Involved: | 2 | 0 | 0 |
| RX, Medication, or Drugs Involved: | 0 | 1 | 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: | 18 | 15 | 2 |

ADT: 21,780 Length: 0.04

Project Information

Project Name: I 270 at Quebec (WB), Ramp Metering

Project Description: Ramp Metering

CDOT Region: 6 Project Def: 16642 County: Denver & Adams

Location: I 270 at WB Quebec Entrance Ramp Mile Points: 4.00 to 5.00
Length: 1 Mile

Schedule: Work Start Date: 10/13/2008 Completion Date: 8/5/2009

Problem Description: The crash history showed a high number of rear end and same direction sideswipe type crashes near the westbound ramp entry from Quebec St.

Improvement Description: Between October 2008 and August 2009 ramp metering was installed. Upon completion, the meters were activated during the peak period hours of 6:30 A.M. to 9:30 A.M. and from 3:00 P.M. to 6:00 P.M. The cost of construction was \$90,000.

The HSIP application anticipated that rear end and sideswipe crashes would be impacted by this improvement. It was anticipated that there would be a 20% crash reduction for these crashes. The initial benefit/cost ratio was estimated to be 3.58.

Summary and Findings

The analysis considered only those crashes that occurred in the westbound direction during the hours that the ramp metering was in effect. The analysis of safety before and after the ramp metering at westbound I-270 and Quebec showed safety measurably improved in terms of total crashes and rear end crashes. There were 24 total crashes including two (2) injury crashes during the three-year period before the improvement (2005 – 2007). In the three years after construction (2010 – 2012), the number of crashes decreased to 17 with one (1) injury crash. This 27% reduction in total crashes occurred against a 13% increase in traffic volume from an average AADT of 69,571 to 78,772. There was a 33% reduction in rear end crashes (from 15 crashes to 10 crashes). The number of same direction sideswipe crashes remained unchanged with six (6) crashes in both periods.

The ramp metering has likely contributed to decreases in the number of rear end crashes and total crashes. We have provided a benefit/cost analysis based on the comparison of crashes in the before period to those in the after period. The cost associated with the improvement was \$90,000. The ratio of benefits and cost for this project shows that benefits outweigh the costs with a B/C ratio of 14.54 to one, showing that the improvement was cost effective in terms of safety benefits. It is noted that it is conservative to compare the benefits to the total project cost since ramp metering is expected to generate an operational benefit as well.

Results of Safety Analyses

Using VZS, the review of before and after crash records showed the number of crashes decreased between the two study periods. The total number of crashes was 24 during the three-year period (2005 to 2007) before the ramp metering and 17 during the three-year after period (2010 to 2012) (see **Table 1**). The number of injury crashes decreased from two (2) crashes to one (1) crash.

- Before (2005 – 2007) – no fatal crashes and 2 injury crashes with 3 injuries
- After (2010 – 2012) – no fatal crashes and 1 injury crash with 1 injury

With a 13% increase in traffic volumes in the segment, the crash rates at the intersection decreased as well. To estimate crash rates, we multiplied the average AADT for the period by 0.185. This multiplier is based on multiplying the total ADT by 0.50 for the directional component and by 0.37 for the proportion of the ADT component that occurs during ramp metering, which was calculated using hourly volume data at the ramp ($0.50 \times 0.37 = 0.185$).

- Before (2005 – 2007): 1.67 crashes per million entering vehicles (cpmev)
- After (2010 – 2012): 1.08 cpmev

Table 1 - Results of Overall Crash Analyses

| | Before | After |
|----------------------------|---|---|
| Time Period: | 1/1/2005 to 12/31/2007 (3 yr.) | 1/1/2010 to 12/31/2012 (3 yr.) |
| AADT (I-270) | 69,571 | 78,772 |
| Filters: | Westbound 6:30 AM to 9:30 AM and 3:00 PM to 6:00 PM Mainline Non Intersection | Westbound 6:30 AM to 9:30 AM and 3:00 PM to 6:00 PM Mainline Non Intersection |
| Total Crashes | 24 | 17 |
| Fatal Crashes (Fatalities) | 0 | 0 |
| Injury Crashes (Injuries) | 2 (3) | 1 (1) |
| Property Damage Only | 22 | 16 |
| Crash Types: # (%) | | |
| Rear-End | 15 (63%) | 10 (59%) |
| Sideswipe Same Direction | 6 (25%) | 6 (35%) |

The magnitude of safety problems on select highway sections and intersections can often be assessed through the use of Safety Performance Function (SPF) methodology. However, it is not as feasible to derive meaningful SPF relationships for cases like this one where we are observing only those crashes that occurred during certain hours of the day in one direction because the predictive functions were developed using the entire traffic volumes and all crashes for the locations under consideration. Therefore we will dispense with SPF analyses for this project location and focus on crash numbers, crash rates and benefit to cost analysis.

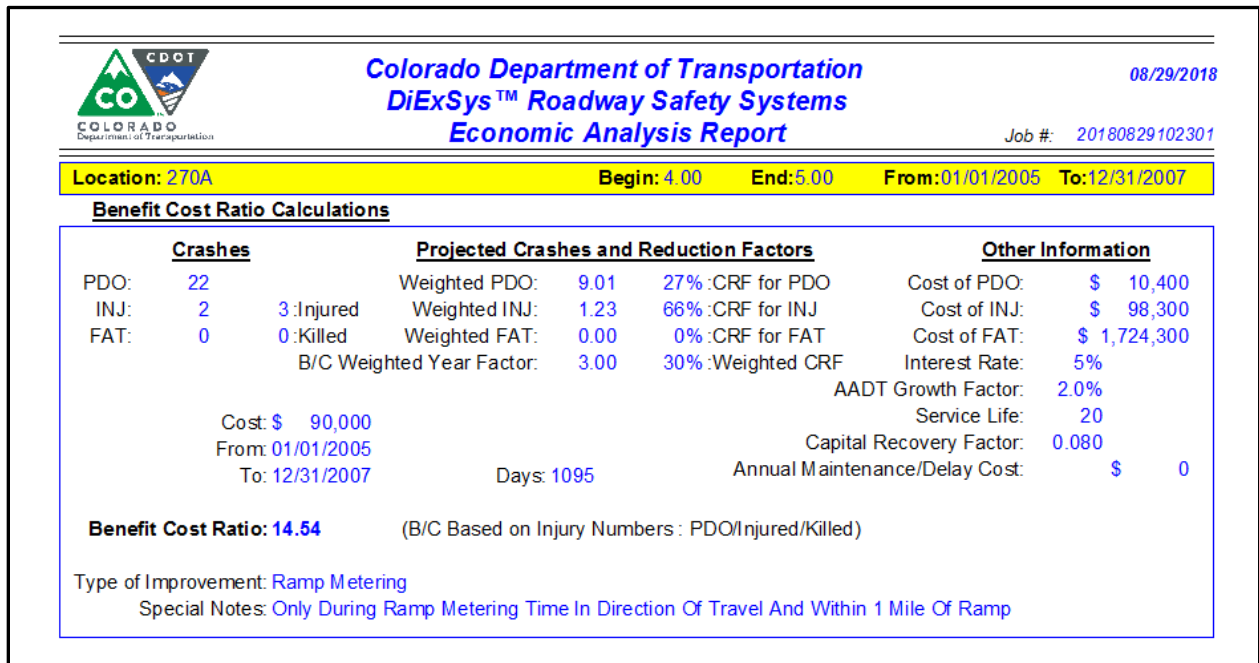
A more detailed review of the before and after crash record further suggests that some improvement in safety can be attributed to the ramp metering for westbound I-270 at Quebec. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that are most directly affected by the improvement: rear-end and same direction sideswipes. The installation of the ramp metering appears to have reduced the number of rear-ends but not affected the sideswipes. The No Build After crashes were estimated using the change in I-270 traffic volumes between the before and after period, as found in **Table 1** (increase is 1.13 = 78,772/69,571).

Table 3 – Results of Crash Analyses

| | Before | After | No Build After |
|--|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2005 to 12/31/2007 (3 yr.) | 1/1/2010 to 12/31/2012 (3 yr.) | 1/1/2010 to 12/31/2012 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 24 | 17 | 26 |
| Fatal (fatalities) | 0 | 0 | 0 |
| Injury (injuries) | 2 (3) | 1 (1) | 2 (3) |
| PDO | 22 | 16 | 24 |
| % Change in Total (Fatalities/Injuries/PDO) | | NA / -50% / -27% | |
| Rear Ends – Total | 15 | 10 | 17 |
| Injury (injuries) | 2 (3) | 1 (1) | 2 (3) |
| PDO | 13 | 9 | 15 |
| % Change in Total (Injuries/PDO) | | -50% / -31% | |
| Same Dir. Sideswipe - Total | 6 | 6 | 7 |
| Fatal (fatalities) | 0 | 0 | 0 |
| Injury (injuries) | 0 | 0 | 0 |
| PDO | 6 | 6 | 7 |
| % Change in Total (Fatalities/Injuries/PDO) | | NA / NA / 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 this ramp. As shown, using the full \$90,000 project cost as the cost basis, the safety related B/C ratio for the improvement is 14.54, showing that the improvement was cost effective from the safety standpoint. This calculation is conservative since additional benefit was also likely gained for this cost from an operational standpoint.

Figure 3 – Benefit Cost Analysis –Crashes During Metering Hours Only



Figures 4 and 5 show the location of the westbound crashes in the before and after periods respectively. The comparison illustrates a conspicuous dispersion of the cluster of rear-end crashes approaching the ramp gore.

Figure 4 – Westbound Crashes in Before Period (2005-2007) Ramp Metering Hours Only

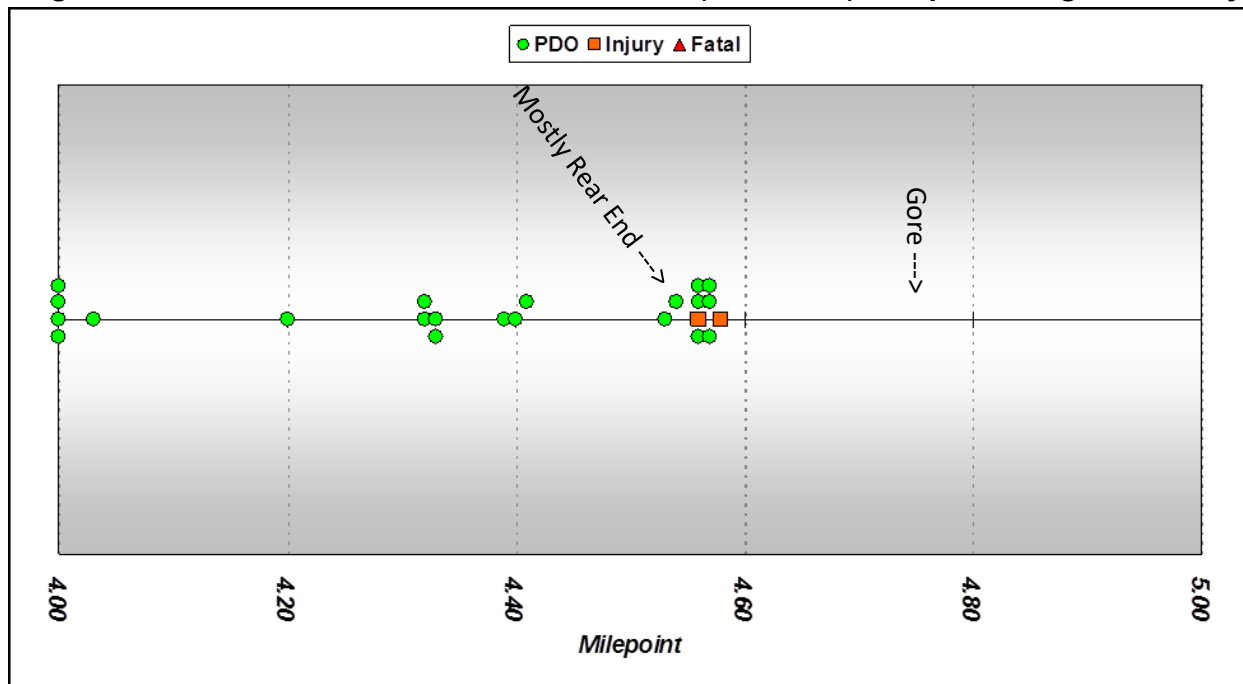
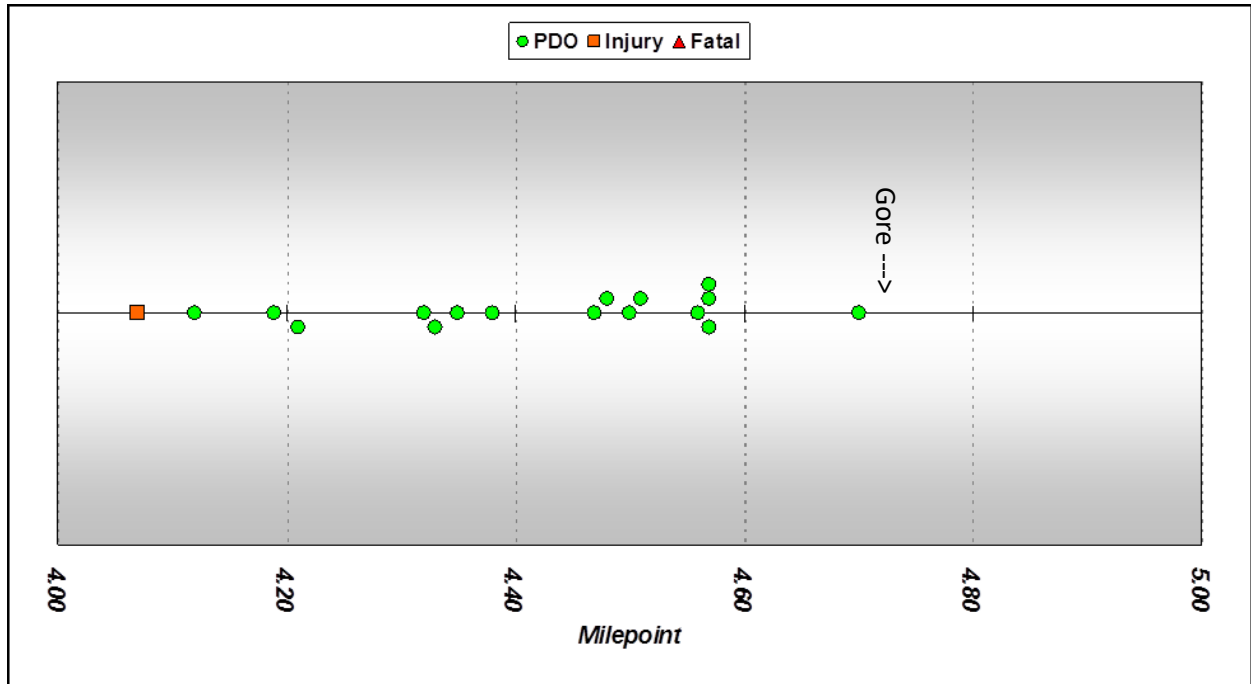


Figure 5 – Westbound Crashes in After Period (2010-2012) Ramp Metering Hours Only





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

CDOT Project #16642 06/17/2019
 Exhibit 1

Job #: 20190617120913

Location: 270A **Begin: 4.00** **End: 5.00** **From:01/01/2003** **To:12/31/2007**

| Severity | |
|---------------|---------------------|
| PDO: | 36 |
| INJ: | 11 18 :Injured |
| FAT: | 1 1 :Killed |
| Total: | 48 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 9 |
| Two Vehicles: | 35 |
| Three or More: | 4 |
| Unknown: | 0 |
| Total: | 48 |

| Location | |
|------------------|-----------|
| On Road: | 40 |
| Off Road Left: | 3 |
| Off Road Right: | 3 |
| Off Road at Tee: | 0 |
| Off in Median: | 2 |
| Unknown: | 0 |
| Total: | 48 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 32 |
| Dawn or Dusk: | 2 |
| Dark - Lighted: | 10 |
| Dark - Unlighted: | 4 |
| Unknown: | 0 |
| Total: | 48 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 39 |
| Rain: | 4 |
| Snow/Sleet/Hail: | 4 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 1 |
| Unknown: | 0 |
| Total: | 48 |

| Crash Rates | |
|---------------|------------------------|
| PDO: | 0.30* * MVMT |
| INJ: | 0.09* ** 100 MVMT |
| FAT: | 0.83** |
| Total: | 0.40* |

| Crash Type | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 1 | Bridge Abutment: | 0 |
| Other Non Collision: | 1 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 0 | Embankment: | 0 |
| Head On: | 1 | Curb: | 0 |
| Rear End: | 24 | Delineator Post: | 0 |
| Sideswipe (Same): | 12 | 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: | 4 |
| Wild Animal: | 2 | 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: | 1 |
| Bridge Rail: | 1 | Total Other Objects: | 2 |
| Guard Rail: | 0 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 48 |
| Concrete Barrier: | 3 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | |
|-------------------------------|----|------------------------------|------------------|
| Mainline: | 48 | M: | 0 N: 0 O: 0 P: 0 |
| Crossroad (A): | 0 | | |
| Ramps | | Left Frontage Rd (L): | 0 |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 |
| D: 0 H: 0 T: 0 | | Unknown: | 0 |
| E: 0 I: 0 | | Total: | 48 |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 48 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 48 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 41 |
| 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: | 1 |
| Icy w/Icy Road Treatment: | 0 |
| Slushy w/Icy Road Treatment: | 1 |
| Unknown: | 0 |
| Total: | 48 |

ADT: 65,914 **Length: 1.00**



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

CDOT Project #16642 06/17/2019
 Exhibit 1

Job #: 20190617120913

Location: 270A **Begin: 4.00** **End: 5.00** **From:01/01/2003** **To:12/31/2007**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 33 | 18 | 3 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 5 | 10 | 0 |
| Pickup Truck/Utility Van w/Trl: | 2 | 0 | 0 |
| SUV: | 0 | 0 | 1 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 6 | 8 | 0 |
| School Bus < 15 People: | 0 | 0 | 0 |
| Non School Bus < 15 People: | 0 | 0 | 0 |
| Motorhome: | 0 | 0 | 0 |
| Motorcycle: | 1 | 2 | 0 |
| Bicycle: | 0 | 0 | 0 |
| Motorized Bicycle: | 0 | 0 | 0 |
| Farm Equipment: | 0 | 0 | 0 |
| Hit and Run - Unknown: | 1 | 1 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 48 | 39 | 4 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 27 | 21 | 0 |
| Slowing: | 4 | 7 | 3 |
| Stopped in Traffic: | 0 | 10 | 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: | 1 | 0 | 0 |
| Starting in Traffic: | 0 | 0 | 0 |
| Parked: | 0 | 1 | 0 |
| Changing Lanes: | 10 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 4 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 48 | 39 | 4 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 31 | 39 | 4 |
| 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: | 8 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 7 | 0 | 0 |
| Total: | 48 | 39 | 4 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 0 | 0 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 1 | 0 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 0 | 0 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 35 | 30 | 1 |
| Northwest: | 12 | 9 | 3 |
| Unknown: | 0 | 0 | 0 |
| Total: | 48 | 39 | 4 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 46 | 39 | 4 |
| 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: | 48 | 39 | 4 |

ADT: 65,914 **Length: 1.00**



Location: 270A **Begin: 4.00** **End: 5.00** **From:01/01/2010** **To:12/31/2014**

| Severity | |
|---------------|---------------------|
| PDO: | 48 |
| INJ: | 18 25 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 66 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 7 |
| Two Vehicles: | 53 |
| Three or More: | 6 |
| Unknown: | 0 |
| Total: | 66 |

| Location | |
|------------------|-----------|
| On Road: | 61 |
| Off Road Left: | 2 |
| Off Road Right: | 3 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 66 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 48 |
| Dawn or Dusk: | 5 |
| Dark - Lighted: | 11 |
| 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: | 0.33* * MVMT |
| INJ: | 0.12* ** 100 MVMT |
| FAT: | 0.00** |
| Total: | 0.45* |

| Crash Type | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 2 | Bridge Abutment: | 0 |
| Other Non Collision: | 1 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 0 | Embankment: | 0 |
| Head On: | 0 | Curb: | 0 |
| Rear End: | 35 | Delineator Post: | 0 |
| Sideswipe (Same): | 19 | Fence: | 0 |
| Sideswipe (Opposite): | 0 | Tree: | 0 |
| Approach Turn: | 1 | Large Boulders or Rocks: | 0 |
| Overtaking Turn: | 0 | Barricade: | 0 |
| Parked Motor Vehicle: | 1 | Wall/Building: | 0 |
| Railway Vehicle: | 0 | Crash Cushion: | 0 |
| Bicycle: | 0 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 1 |
| Domestic Animal: | 0 | Total Fixed Objects: | 3 |
| Wild Animal: | 1 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 0 | Vehicle Cargo/Debris: | 2 |
| Traffic Signal Pole: | 0 | Road Maintenance Equipment: | 1 |
| Sign: | 0 | Involving Other Object: | 0 |
| Bridge Rail: | 0 | Total Other Objects: | 3 |
| Guard Rail: | 0 | Unknown: | 0 |
| Cable Rail: | 1 | Total: | 66 |
| Concrete Barrier: | 1 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | |
|-------------------------------|----|-----------------------------|-----------|
| Mainline: | 66 | M: | 0 |
| Crossroad (A): | 0 | N: | 0 |
| | | O: | 0 |
| | | P: | 0 |
| Ramps | | Left Frontage Rd (L): | 0 |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 |
| D: 0 H: 0 T: 0 | | Unknown: | 0 |
| E: 0 I: 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: | 55 |
| Wet: | 3 |
| Muddy: | 0 |
| Snowy: | 2 |
| Icy: | 3 |
| 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: | 66 |

ADT: 79,081 **Length: 1.01**



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

CDOT Project #16642 06/17/2019
 Exhibit 2

Job #: 20190617120826

Location: 270A **Begin: 4.00** **End: 5.00** **From:01/01/2010** **To:12/31/2014**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 30 | 27 | 6 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 12 | 13 | 0 |
| Pickup Truck/Utility Van w/Trl: | 2 | 0 | 0 |
| SUV: | 10 | 10 | 0 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 4 | 8 | 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: | 8 | 0 | 0 |
| Other: | 0 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 66 | 59 | 6 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 37 | 27 | 1 |
| Slowing: | 4 | 14 | 3 |
| Stopped in Traffic: | 0 | 13 | 2 |
| Making Right Turn: | 0 | 0 | 0 |
| Making Left Turn: | 0 | 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 | 1 | 0 |
| Changing Lanes: | 14 | 3 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 10 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 66 | 59 | 6 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 38 | 59 | 6 |
| 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: | 6 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 19 | 0 | 0 |
| Total: | 66 | 59 | 6 |

| 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: | 60 | 52 | 6 |
| Northwest: | 6 | 6 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 66 | 59 | 6 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 63 | 59 | 6 |
| Alcohol Involved: | 2 | 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 | 59 | 6 |

ADT: 79,081 **Length: 1.01**

Project Information

Project Name: SH 36 at 104th (WB), Ramp Metering

Project Description: Ramp Metering

CDOT Region: 6 Project Def: 16642 County: Jefferson

Location: SH 36 at WB 104th Ave Entrance Ramp Mile Points: 49.64 to 50.64
Length: 1 Mile

Schedule: Work Start Date: 10/13/2008 Completion Date: 8/5/2009

Problem Description: The crash history showed a high number of rear end and same direction sideswipe type crashes near the westbound ramp entry from 104th Ave.

Improvement Description: Between October 2008 and August 2009 ramp metering was installed. Upon completion, the meters were activated during the peak period hours of 6:30 A.M. to 9:30 A.M. and from 3:00 P.M. to 6:00 P.M. The cost of construction was \$90,000.

The HSIP application anticipated that rear end crashes would be impacted by this improvement. It was anticipated that there would be a 20% crash reduction for these crashes. The initial benefit/cost ratio was estimated to be 3.69.

Summary and Findings

The analysis considered only those crashes that occurred in the westbound direction during the hours that the ramp metering was in effect. The analysis of safety before and after the ramp metering at westbound SH 36 and 104th Ave showed safety measurably improved in terms of total crashes and rear end crashes. There were 42 total crashes including four (4) injury crashes during the three-year period before the improvement (2005 – 2007). In the three years after construction (2010 – 2012), the number of crashes decreased to 27 with a slight increase in injury crashes from four to five. This 36% reduction in total crashes occurred against a slight decrease (1.3%) in traffic volume from an average AADT of 82,403 to 81,333. There was a 40% reduction in rear end crashes (from 37 crashes to 22 crashes). There were three (3) same direction sideswipe crashes in the after period whereas there had been none in the before period.

The ramp metering may have been responsible for decreases in the number of rear end crashes and total crashes. We have provided a benefit/cost analysis based on the comparison of crashes in the before period to those in the after period. The cost associated with the improvement was \$90,000. In this particular case the number of injury crashes increased by one, but the number of people injured decreased by one. Because the actual number of injury crashes did not decrease we did not include the decrease in injured persons in benefit component of the analysis. The ratio of benefits and cost for this project shows that benefits outweigh the costs with a B/C ratio of 9.4 to one, showing that the improvement was cost effective in terms of safety benefits. It is noted that it is conservative to compare the benefits to the total project cost since ramp metering is expected to incorporate an operational benefit as well.

Results of Safety Analyses

Using VZS, the review of before and after crash records showed the number of crashes decreased between the two study periods. The total number of crashes was 42 during the three-year period (2005 to 2007) before the ramp metering and 27 during the three-year after period (2010 to 2012) (see **Table 1**). The number of injury crashes increased from four (4) crashes to five (5) crashes, but the number of injured people decreased from six (6) to five (5).

- Before (2005 – 2007) – no fatal crashes and 4 injury crashes with 6 injuries
- After (2010 – 2012) – no fatal crashes and 5 injury crashes with 5 injuries

With a 1.3% decrease in traffic volumes in the segment, the crash rates at the intersection decreased as well. To estimate crash rates, we multiplied the average AADT for the period by 0.221. This multiplier is based on using 50% for the directional component and 44% for the time of day component. The time of day component was calculated using hourly volume data at the ramp.

- Before (2005 – 2007): 2.19 crashes per million entering vehicles (cpmev)
- After (2010 – 2012): 1.37 cpmev

Table 1 - Results of Overall Crash Analyses

| | Before | After |
|----------------------------|---|---|
| Time Period: | 1/1/2005 to 12/31/2007 (3 yr.) | 1/1/2010 to 12/31/2012 (3 yr.) |
| AADT (SH 36) | 82,403 | 81,333 |
| Filters: | Westbound 6:30 AM to 9:30 AM and 3:00 PM to 6:00 PM Mainline Non Intersection | Westbound 6:30 AM to 9:30 AM and 3:00 PM to 6:00 PM Mainline Non Intersection |
| Total Crashes | 42 | 27 |
| Fatal Crashes (Fatalities) | 0 | 0 |
| Injury Crashes (Injuries) | 4 (6) | 5 (5) |
| Property Damage Only | 38 | 22 |
| Crash Types: # (%) | | |
| Rear-End | 37 (88%) | 22 (81%) |
| Sideswipe Same Direction | 0 (0%) | 3 (11%) |

The magnitude of safety problems on select highway sections and intersections can often be assessed through the use of Safety Performance Function (SPF) methodology. However, it is not as feasible to derive meaningful SPF relationships for cases like this one where we are observing only those crashes that occurred during certain hours of the day in one direction because the predictive functions were developed using the entire traffic volumes and all crashes for the locations under consideration. Therefore we will dispense with SPF analyses for this project location and focus on crash numbers, crash rates and benefit to cost analysis.

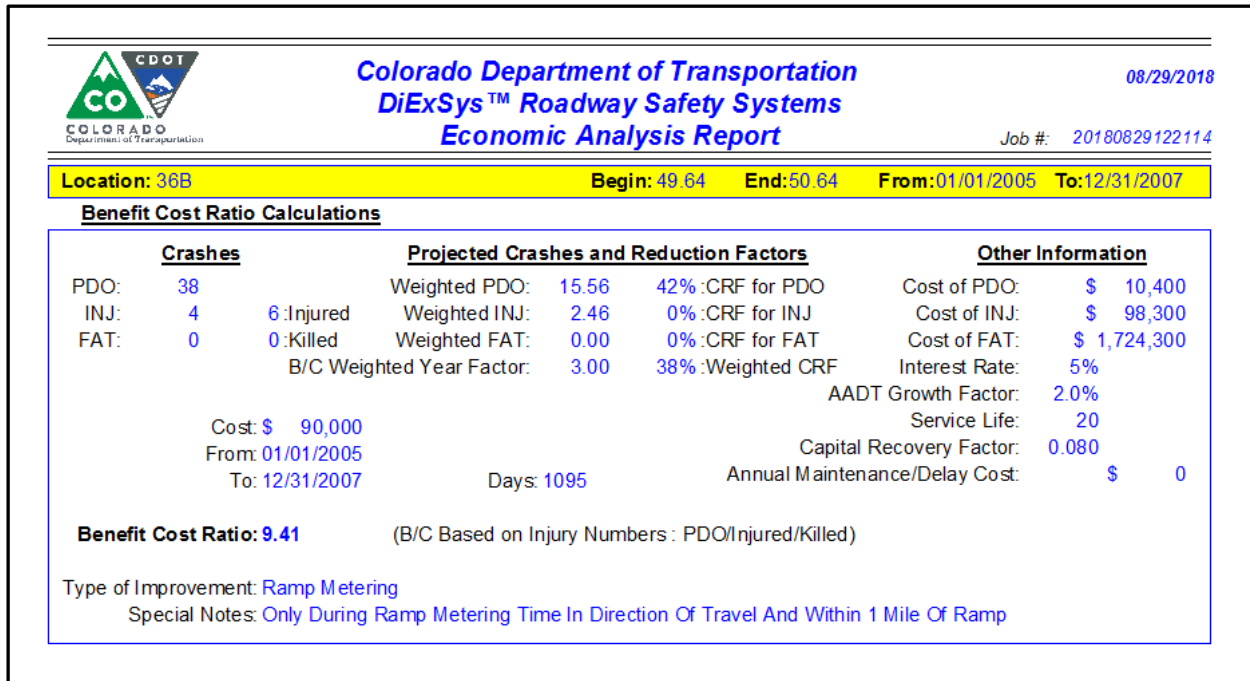
A more detailed review of the before and after crash record reveals that some improvement in safety can be attributed to the ramp metering for westbound SH 36 at 104th Ave. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that are most directly affected by the improvement: rear-end and same direction sideswipes. The installation of the ramp metering appears to have reduced the number of rear-ends. The No Build After crashes were estimated using the change in SH 36 traffic volumes between the before and after period, as found in **Table 1** (decrease is $0.987 = 81,333/82403$).

Table 3 – Results of Crash Analyses

| | Before | After | No Build After |
|--|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2005 to 12/31/2007 (3 yr.) | 1/1/2010 to 12/31/2012 (3 yr.) | 1/1/2010 to 12/31/2012 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 42 | 27 | 42 |
| Fatal (fatalities) | 0 | 0 | 0 |
| Injury (injuries) | 4 (6) | 5 (5) | 4 (6) |
| PDO | 38 | 22 | 38 |
| % Change in Total (Fatalities/Injuries/PDO) | | NA / +25% / -36% | |
| Rear Ends – Total | 37 | 22 | 37 |
| Injury (injuries) | 4 (6) | 5 (5) | 4 (6) |
| PDO | 33 | 17 | 33 |
| % Change in Total (Injuries/PDO) | | +25% / -40% | |
| Same Dir. Sideswipe - Total | 0 | 3 | 0 |
| Fatal (fatalities) | 0 | 0 | 0 |
| Injury (injuries) | 0 | 0 | 0 |
| PDO | 6 | 6 | 7 |
| % Change in Total (Fatalities/Injuries/PDO) | | NA / NA / 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 this ramp. As shown, using the full \$90,000 project cost as the cost basis, the safety related B/C ratio for the improvement is 9.41, showing that the improvement was cost effective from the safety standpoint. This calculation is conservative since additional benefit was also likely gained for this cost from an operational standpoint.

Figure 3 – Benefit Cost Analysis –Crashes During Metering Hours Only



Figures 4 and 5 show the location of the westbound crashes in the before and after periods respectively. The comparison illustrates a conspicuous dispersion of the cluster of rear-end crashes just beyond the ramp gore.

Figure 4 – Westbound Crashes in Before Period (2005-2007) Ramp Metering Hours Only

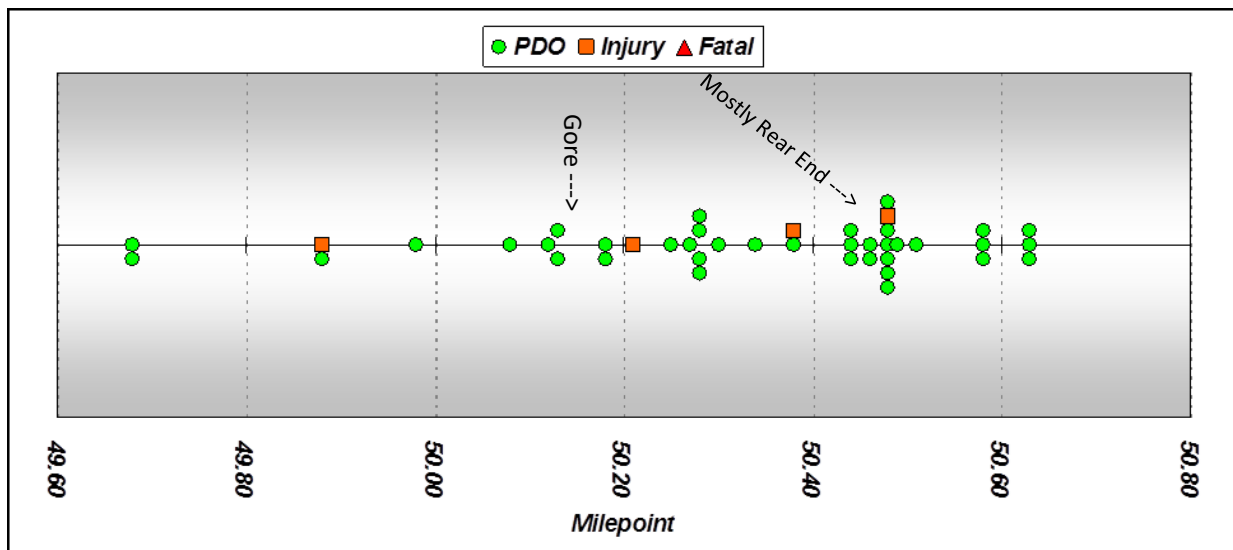
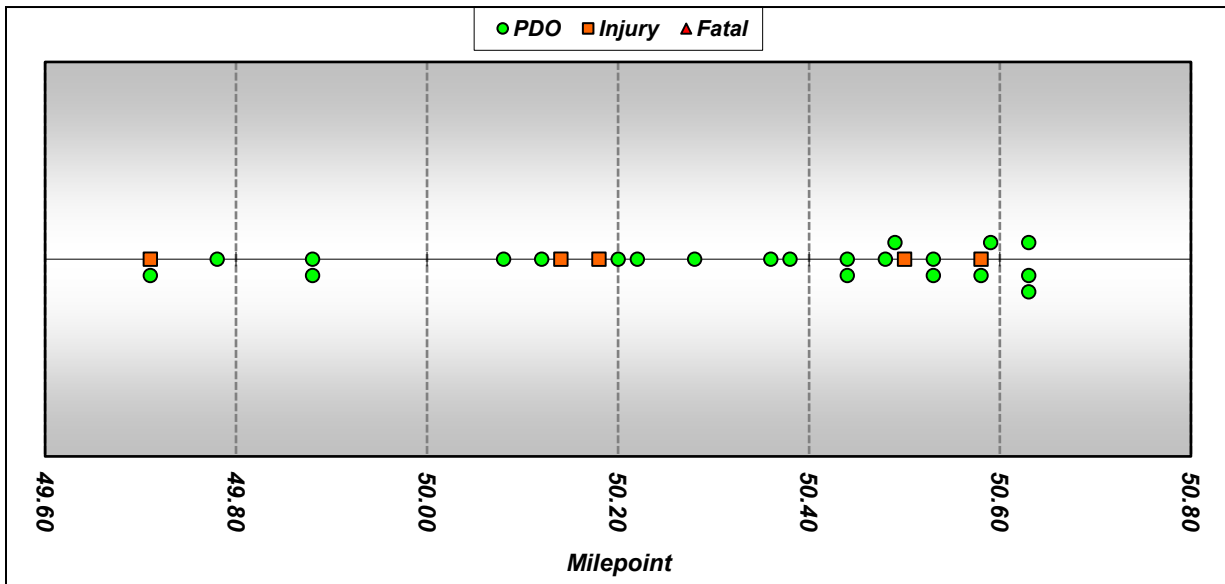


Figure 5 – Westbound Crashes in After Period (2010-2012) Ramp Metering Hours Only





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

CDOT Project #16642 06/17/2019
Exhibit 1

Job #: 20190617121103

Location: 36B Begin: 49.64 End: 50.64 From:01/01/2003 To:12/31/2007

Severity

| | | |
|---------------|------------|-------------|
| PDO: | 103 | |
| INJ: | 17 | 21 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 120 | |

Number of Vehicles

| | |
|----------------|------------|
| One Vehicle: | 21 |
| Two Vehicles: | 79 |
| Three or More: | 20 |
| Unknown: | 0 |
| Total: | 120 |

Location

| | |
|------------------|------------|
| On Road: | 96 |
| Off Road Left: | 19 |
| Off Road Right: | 5 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 120 |

Lighting Conditions

| | |
|-------------------|------------|
| Daylight: | 86 |
| Dawn or Dusk: | 11 |
| Dark - Lighted: | 12 |
| Dark - Unlighted: | 11 |
| Unknown: | 0 |
| Total: | 120 |

Weather Conditions

| | |
|------------------|------------|
| None: | 101 |
| Rain: | 8 |
| Snow/Sleet/Hail: | 7 |
| Fog: | 3 |
| Dust: | 0 |
| Wind: | 1 |
| Unknown: | 0 |
| Total: | 120 |

Crash Rates

| | | |
|---------------|---------------|-------------|
| PDO: | 0.70 * | * MVMT |
| INJ: | 0.12 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 0.81 * | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|------------|
| Overturning: | 1 | Bridge Abutment: | 0 |
| Other Non Collision: | 3 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 0 | Embankment: | 1 |
| Head On: | 0 | Curb: | 0 |
| Rear End: | 83 | Delineator Post: | 0 |
| Sideswipe (Same): | 9 | Fence: | 0 |
| 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: | 24 |
| 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: | 3 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 120 |
| Concrete Barrier: | 18 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----|------------------------------------|
| Mainline: | 120 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | | Left Frontage Rd (L): 0 |
| C: 0 G: 0 K: 0 | | Rt Frontage Rd (R): 0 |
| D: 0 H: 0 T: 0 | | HOV Lanes (V): 0 |
| E: 0 I: 0 | | Unknown: 0 |
| | | Total: 120 |

Road Description

| | |
|-----------------------|------------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 120 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 120 |

Road Conditions

| | |
|------------------------------|------------|
| Dry: | 89 |
| Wet: | 14 |
| Muddy: | 0 |
| Snowy: | 0 |
| Icy: | 7 |
| Slushy: | 5 |
| Foreign Material: | 0 |
| With Road Treatment: | 0 |
| Dry w/Icy Road Treatment: | 0 |
| Wet w/Icy Road Treatment: | 1 |
| Snowy w/Icy Road Treatment: | 2 |
| Icy w/Icy Road Treatment: | 1 |
| Slushy w/Icy Road Treatment: | 1 |
| Unknown: | 0 |
| Total: | 120 |

ADT: 80,496 Length: 1.00



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

CDOT Project #16642 06/17/2019
Exhibit 1

Job #: 20190617121103

Location: 36B Begin: 49.64 End: 50.64 From:01/01/2003 To:12/31/2007

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|------------|-----------|-----------|
| Passenger Car/Van: | 86 | 69 | 14 |
| Passenger Car/Van w/Trl: | 1 | 0 | 0 |
| Pickup Truck/Utility Van: | 18 | 22 | 5 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 11 | 4 | 1 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 3 | 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 | 1 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 120 | 99 | 20 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|------------|-----------|-----------|
| Going Straight: | 96 | 28 | 6 |
| Slowing: | 4 | 28 | 3 |
| Stopped in Traffic: | 0 | 42 | 11 |
| 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: | 12 | 0 | 0 |
| Avoiding Object/Veh in Road: | 1 | 1 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 7 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 120 | 99 | 20 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|------------|-----------|-----------|
| No Apparent Contributing Factor: | 46 | 95 | 20 |
| Asleep at the Wheel: | 1 | 0 | 0 |
| Illness: | 1 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 7 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 52 | 0 | 0 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 12 | 4 | 0 |
| Total: | 120 | 99 | 20 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|------------|-----------|-----------|
| North: | 0 | 0 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 0 | 1 | 1 |
| Southeast: | 0 | 0 | 0 |
| South: | 0 | 0 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 119 | 97 | 19 |
| Northwest: | 1 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 120 | 99 | 20 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|------------|-----------|-----------|
| No Impairment Suspected: | 116 | 99 | 20 |
| Alcohol Involved: | 4 | 0 | 0 |
| RX, Medication, or Drugs Involved: | 0 | 0 | 0 |
| Illegal Drugs Involved: | 0 | 0 | 0 |
| Alcohol and Drugs Involved: | 0 | 0 | 0 |
| Driver/Pedestrian not Observed: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 120 | 99 | 20 |

ADT: 80,496 Length: 1.00



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

CDOT Project #16642 06/17/2019
Exhibit 2

Job #: 20190617121134

Location: 36B **Begin: 49.64** **End: 50.64** **From:01/01/2010** **To:12/31/2014**

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 77 | |
| INJ: | 19 | 23 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 96 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 12 |
| Two Vehicles: | 64 |
| Three or More: | 20 |
| Unknown: | 0 |
| Total: | 96 |

Location

| | |
|------------------|-----------|
| On Road: | 81 |
| Off Road Left: | 8 |
| Off Road Right: | 7 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 96 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 76 |
| Dawn or Dusk: | 4 |
| Dark - Lighted: | 6 |
| Dark - Unlighted: | 10 |
| Unknown: | 0 |
| Total: | 96 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 85 |
| Rain: | 2 |
| Snow/Sleet/Hail: | 8 |
| Fog: | 1 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 96 |

Crash Rates

| | | |
|---------------|---------------|-------------|
| PDO: | 0.51 * | * MVMT |
| INJ: | 0.13 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 0.64 * | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 2 | Culvert/Headwall: | 0 |
| Broadside: | 0 | Embankment: | 1 |
| Head On: | 0 | Curb: | 0 |
| Rear End: | 64 | Delineator Post: | 0 |
| Sideswipe (Same): | 14 | Fence: | 1 |
| 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: | 1 |
| Bicycle: | 0 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 0 |
| Domestic Animal: | 0 | Total Fixed Objects: | 15 |
| 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: | 2 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 96 |
| Concrete Barrier: | 9 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|----|------------------------------------|
| Mainline: | 96 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | | Left Frontage Rd (L): 0 |
| C: 0 G: 0 K: 0 | | Rt Frontage Rd (R): 0 |
| D: 0 H: 0 T: 0 | | HOV Lanes (V): 0 |
| E: 0 I: 0 | | Unknown: 0 |
| | | Total: 96 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 96 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 96 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 81 |
| Wet: | 5 |
| Muddy: | 0 |
| Snowy: | 1 |
| Icy: | 7 |
| 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: | 96 |

ADT: 80,400 **Length: 1.02**



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

CDOT Project #16642 06/17/2019
 Exhibit 2

Job #: 20190617121134

Location: 36B **Begin: 49.64** **End: 50.64** **From:01/01/2010** **To:12/31/2014**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|-----------|
| Passenger Car/Van: | 56 | 43 | 9 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 13 | 10 | 2 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 23 | 25 | 7 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 0 | 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: | 0 | 0 | 0 |
| Hit and Run - Unknown: | 3 | 3 | 2 |
| Other: | 1 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 96 | 84 | 20 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|-----------|
| Going Straight: | 59 | 20 | 2 |
| Slowing: | 14 | 20 | 6 |
| Stopped in Traffic: | 0 | 41 | 12 |
| Making Right Turn: | 0 | 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: | 8 | 1 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 1 | 1 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 11 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 96 | 84 | 20 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|-----------|
| No Apparent Contributing Factor: | 25 | 83 | 20 |
| Asleep at the Wheel: | 2 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 29 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 13 | 0 | 0 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 26 | 1 | 0 |
| Total: | 96 | 84 | 20 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|-----------|
| North: | 0 | 1 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 1 | 0 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 0 | 0 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 70 | 63 | 14 |
| Northwest: | 25 | 20 | 6 |
| Unknown: | 0 | 0 | 0 |
| Total: | 96 | 84 | 20 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|-----------|
| No Impairment Suspected: | 91 | 84 | 20 |
| Alcohol Involved: | 5 | 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: | 96 | 84 | 20 |

ADT: 80,400 **Length: 1.02**

Project Information

Project Name: I-25 at SH 128 (120th Ave) (SB), Ramp Metering

Project Description: Ramp Metering

CDOT Region: 6 Project Def: 16642 County: Denver

Location: I-25 at SH 128 SB Entrance Ramp Mile Points: 222.37 to 223.37
Length: 1 Mile

Schedule: Work Start Date: 10/13/2008 Completion Date: 8/5/2009

Problem Description: The crash history showed a high number of rear end and same direction sideswipe type crashes near the southbound ramp entry from SH 128.

Improvement Description: Between October 2008 and August 2009 ramp metering was installed and activated from the hours of 6:30 A.M. to 9:30 A.M. and from 3:00 P.M. to 6:00 P.M. The cost of construction was \$90,000.

The HSIP application anticipated that rear end crashes would be impacted by this improvement. It was anticipated that there would be a 20% crash reduction for these crashes. The initial benefit/cost ratio was estimated to be 2.31.

Summary and Findings

This analysis considers only those crashes that occurred in the southbound direction during the hours that the ramp metering was in effect. There were 51 total crashes including 11 injury crashes during the five-year period before the improvement (2003 – 2007). In the five years after construction (2010 – 2014), the number of crashes increased to 61 with 7 injury crashes. However, this 19.6% increase in total crashes occurred against a 21.3% increase in traffic volume from an average AADT of 103,102 to 125,099, resulting in small reduction in the rate of crashes per vehicle mile travelled. There was a 60.7% increase in rear end crashes (from 28 crashes to 45 crashes) and a 9.1% increase in same direction sideswipe crashes (from 11 crashes to 12 crashes).

The analysis showed marked improvement in safety in terms of crash severity. There was a 36.4% reduction in injury related crashes with 7 injury related crashes in the after period compared to 11 in the before period. When viewed against the 21.3% increase in traffic the reduction in injury crashes per vehicle mile travelled is approximately 48%.

The installation of ramp metering appears to have been cost effective from the safety standpoint with a benefit to cost ratio of 13.70 based on the comparison of the 5-year crash history for the before and after periods. Additional benefit has likely been obtained since ramp metering is expected to improve operations as well as safety. The cost associated with the improvement was \$90,000.

Results of Safety Analyses

Using VZS, the review of before and after crash records showed that total number of crashes increased between the two study periods. The total number of crashes was 51 during the five-year period (2003 to 2007) before the ramp metering and 61 during the five-year after period (2010 to 2014) (see **Table 1**). The number of injury crashes decreased from 11 to 7, with the number of people injured decreasing from 11 to 9. There were no fatal crashes in either time period.

- Before (2003 – 2007) – no fatal crashes and 11 injury crashes with 11 injuries
- After (2010 – 2014) – no fatal crashes and 7 injury crashes with 9 injuries

With a 21.3% increase in traffic volumes in the segment, the overall crash rate in the section decreased slightly, while the rate of injury crashes decreased significantly. To estimate crash rates, we multiplied the average AADT for the period by 0.195. This multiplier is based on multiplying the total ADT by 0.50 for the directional component and by 0.39 for the proportion of the ADT component that occurs during ramp metering, which was calculated using hourly volume data at the ramp (0.50 x 0.39 = 0.195).

- Before (2003 – 2007): 1.39 total crashes per million entering vehicles (cpmev), 0.30 injury cpmev
- After (2010 – 2014): 1.37 total cpmev, 0.16 injury cpmev

Table 1 - 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 (I-25) | 103,102 | 125,099 |
| Filters: | Southbound 6:30 AM to 9:30 AM and 3:00 PM to 6:00 PM Mainline Non Intersection | Southbound 6:30 AM to 9:30 AM and 3:00 PM to 6:00 PM Mainline Non Intersection |
| Total Crashes | 51 | 61 |
| Fatal Crashes (Fatalities) | 0 | 0 |
| Injury Crashes (Injuries) | 11 (11) | 7 (9) |
| Property Damage Only | 40 | 54 |
| Crash Types: # (%) | | |
| Rear-End | 28 (70%) | 45 (74%) |
| Sideswipe Same Direction | 11 (27%) | 12 (20%) |

A detailed review of the before and after crash record indicate that an improvement in safety is likely attributable to the ramp metering for southbound I-25 at SH 128 in terms of a reduction in injuries in all categories even though there is no pronounced reduction in total crashes. **Table 2** shows a comparison of the total crashes as well as the primary types of crashes that are most directly affected by the improvement: rear-end and same direction sideswipes. While there was no reduction in the total number of either rear-ends or same direction sideswipes, there was a notable decrease in injuries for both crash types. The No Build After crashes were proportionally estimated using the change in I-25 traffic volumes between the before and after period, as found in **Table 1** (increase is 1.213 = 125,099 / 103,102).

Table 2 – Results of 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: | | | |
| Total Crashes | 51 | 61 | 62 |
| Fatal (fatalities) | 0 | 0 | 0 |
| Injury (injuries) | 11 (11) | 7 (9) | 13 (13) |
| PDO | 40 | 54 | 49 |
| % Change in Total /Injury (Injuries)/PDO | | +20% / -36% (-18%) / +35% | |
| Rear Ends – Total | 28 | 45 | 34 |
| Injury (injuries) | 7 (8) | 6 (6) | 8 (10) |
| PDO | 21 | 39 | 25 |
| % Change in Total /Injury (Injuries)/PDO | | +61% / -14% (-25%) / +86% | |
| Same Dir. Sideswipe - Total | 11 | 12 | 13 |
| Fatal (fatalities) | 0 | 0 | 0 |
| Injury (injuries) | 2 (3) | 1 (1) | 2 (3) |
| PDO | 9 | 11 | 11 |
| % Change in Total /Injury (Injuries)/PDO | | +9% / -50% (-67%) / +22% | |

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. Due to the significant increase in traffic volume between the before and after periods, crash reduction calculations are based on a comparison of the no-build crash projections compared to the actual crash numbers that occurred. The results of the B/C analysis are shown in **Table 3** for the intersection. As shown, using the \$90,000 project cost as the cost basis, the safety related B/C ratio for the improvement is 13.70, showing that the improvement was cost effective from the safety standpoint. This calculation is conservative since additional benefit was presumably gained for this cost from an operational standpoint.


| | | | | | | | |
|--|----|---|--------------------|-------------------------------------|--------------------------------|--------------|--------------|
|  | | Colorado Department of Transportation DiExSys™ Roadway Safety Systems Economic Analysis Report | | 06/12/2019 Job #: 20190612104704 | | | |
| Location: 25A | | Begin: 222.37 | End: 223.37 | From: 01/01/2003 | To: 12/31/2007 | | |
| Benefit Cost Ratio Calculations | | | | | | | |
| Crashes | | Projected Crashes and Reduction Factors | | | Other Information | | |
| PDO: | 62 | Weighted PDO: | 15.23 | 1% :CRF for PDO | Cost of PDO: | \$ 10,400 | |
| INJ: | 13 | 13 :Injured | Weighted INJ: | 3.19 | 31% :CRF for INJ | Cost of INJ: | \$ 98,300 |
| FAT: | 0 | 0 :Killed | Weighted FAT: | 0.00 | 0% :CRF for FAT | Cost of FAT: | \$ 1,724,300 |
| | | B/C Weighted Year Factor: | 5.00 | 6% :Weighted CRF | Interest Rate: | 5% | |
| | | | | | AADT Growth Factor: | 2.0% | |
| | | | | | Service Life: | 20 | |
| | | | | | Capital Recovery Factor: | 0.080 | |
| | | | | | Annual Maintenance/Delay Cost: | \$ 0 | |
| | | Cost: \$ | 90,000 | | | | |
| | | From: | 01/01/2003 | | | | |
| | | To: | 12/31/2007 | | | | |
| | | | Days: 1826 | | | | |
| Benefit Cost Ratio: 13.70 | | (B/C Based on Injury Numbers : PDO/Injured/Killed) | | | | | |
| Type of Improvement: Ramp Metering | | | | | | | |
| Special Notes: Southbound Crashes During Ramp Metering Hours (6:30 AM to 9:30 AM and 3:00 PM to 6:00 PM) | | | | | | | |

Table 3: Benefit Cost Analysis –Crashes During Metering Hours Only

The magnitude of safety problems on select highway sections and intersections can often be assessed through the use of Safety Performance Function (SPF) methodology. However, it is not as feasible to derive meaningful SPF relationships for cases like this one where we are observing only those crashes that occurred during certain hours of the day in one direction because the predictive functions were developed using the entire traffic volumes and all crashes for the locations under consideration. Therefore we dispensed with SPF analyses for this report and focused on crash numbers, crash rates and benefit to cost analysis. **Figures 1 and 2** show the location of the southbound crashes in the before and after periods respectively.

Figure 1 – Southbound Crashes in Before Period (2003-2007) Ramp Metering Hours Only

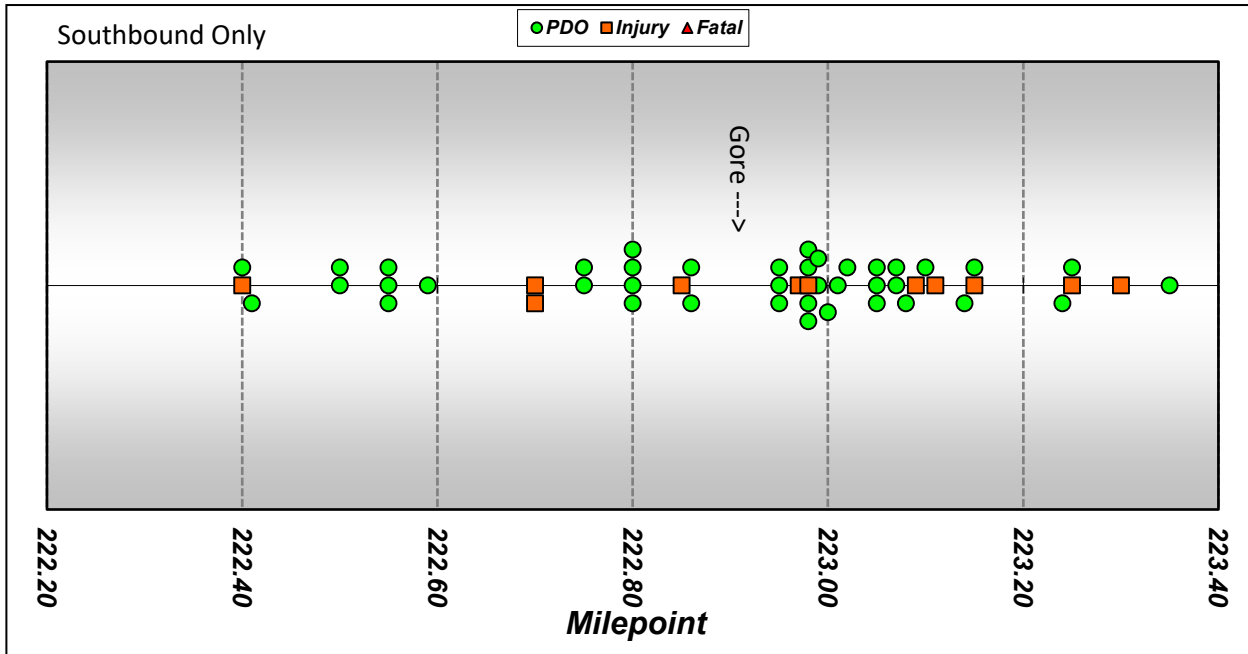
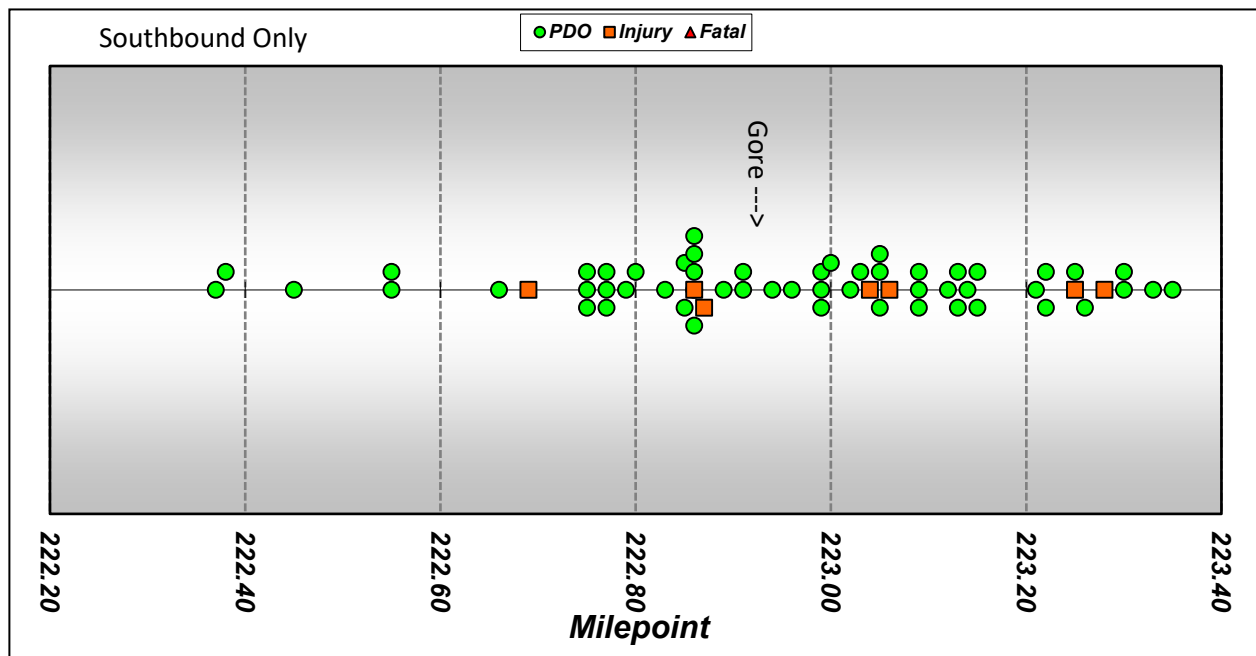


Figure 2 – Southbound Crashes in After Period (2010-2014) Ramp Metering Hours Only





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

CDOT Project #16642 06/17/2019
Exhibit 1

Job #: 20190617112410

Location: 25A Begin: 222.37 End: 223.37 From: 01/01/2003 To: 12/31/2007

Severity

| | | |
|---------------|------------|-------------|
| PDO: | 102 | |
| INJ: | 30 | 37 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 132 | |

Number of Vehicles

| | |
|----------------|------------|
| One Vehicle: | 40 |
| Two Vehicles: | 77 |
| Three or More: | 15 |
| Unknown: | 0 |
| Total: | 132 |

Location

| | |
|------------------|------------|
| On Road: | 91 |
| Off Road Left: | 17 |
| Off Road Right: | 20 |
| Off Road at Tee: | 0 |
| Off in Median: | 4 |
| Unknown: | 0 |
| Total: | 132 |

Lighting Conditions

| | |
|-------------------|------------|
| Daylight: | 89 |
| Dawn or Dusk: | 3 |
| Dark - Lighted: | 24 |
| Dark - Unlighted: | 15 |
| Unknown: | 1 |
| Total: | 132 |

Weather Conditions

| | |
|------------------|------------|
| None: | 88 |
| Rain: | 33 |
| Snow/Sleet/Hail: | 10 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 1 |
| Total: | 132 |

Crash Rates

| | | |
|---------------|--------------|-------------|
| PDO: | 0.52* | * MVMT |
| INJ: | 0.15* | ** 100 MVMT |
| FAT: | 0.00** | |
| Total: | 0.67* | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|------------|
| Overtuning: | 3 | Bridge Abutment: | 0 |
| Other Non Collision: | 5 | Column/Pier: | 0 |
| Pedestrians: | 1 | Culvert/Headwall: | 0 |
| Broadside: | 0 | Embankment: | 1 |
| Head On: | 1 | Curb: | 0 |
| Rear End: | 51 | Delineator Post: | 0 |
| Sideswipe (Same): | 23 | Fence: | 0 |
| Sideswipe (Opposite): | 0 | Tree: | 0 |
| Approach Turn: | 0 | Large Boulders or Rocks: | 0 |
| Overtaking Turn: | 0 | Barricade: | 3 |
| Parked Motor Vehicle: | 1 | Wall/Building: | 0 |
| Railway Vehicle: | 0 | Crash Cushion: | 2 |
| Bicycle: | 0 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 2 |
| Domestic Animal: | 0 | Total Fixed Objects: | 38 |
| Wild Animal: | 0 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 1 | Vehicle Cargo/Debris: | 2 |
| Traffic Signal Pole: | 0 | Road Maintenance Equipment: | 0 |
| Sign: | 0 | Involving Other Object: | 7 |
| Bridge Rail: | 0 | Total Other Objects: | 9 |
| Guard Rail: | 8 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 132 |
| Concrete Barrier: | 21 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----|------------------------------------|
| Mainline: | 132 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | | Left Frontage Rd (L): 0 |
| C: 0 G: 0 K: 0 | | Rt Frontage Rd (R): 0 |
| D: 0 H: 0 T: 0 | | HOV Lanes (V): 0 |
| E: 0 I: 0 | | Unknown: 0 |
| | | Total: 132 |

Road Description

| | |
|-----------------------|------------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 132 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 132 |

Road Conditions

| | |
|------------------------------|------------|
| Dry: | 80 |
| Wet: | 37 |
| Muddy: | 0 |
| Snowy: | 3 |
| Icy: | 7 |
| Slushy: | 1 |
| Foreign Material: | 0 |
| With Road Treatment: | 0 |
| Dry w/Icy Road Treatment: | 0 |
| Wet w/Icy Road Treatment: | 1 |
| Snowy w/Icy Road Treatment: | 2 |
| Icy w/Icy Road Treatment: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 1 |
| Total: | 132 |

ADT: 103,102 Length: 1.04



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

CDOT Project #16642 06/17/2019
Exhibit 1

Job #: 20190617112410

Location: 25A Begin: 222.37 End: 223.37 From: 01/01/2003 To: 12/31/2007

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|------------|-----------|-----------|
| Passenger Car/Van: | 74 | 57 | 12 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 30 | 20 | 3 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 8 | 4 | 0 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 12 | 8 | 0 |
| School Bus < 15 People: | 0 | 1 | 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: | 6 | 0 | 0 |
| Other: | 0 | 1 | 0 |
| Unknown: | 1 | 1 | 0 |
| Total: | 132 | 92 | 15 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|------------|-----------|-----------|
| Going Straight: | 89 | 49 | 4 |
| Slowing: | 4 | 13 | 2 |
| Stopped in Traffic: | 0 | 25 | 8 |
| Making Right Turn: | 0 | 0 | 0 |
| Making Left Turn: | 0 | 0 | 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 | 2 | 0 |
| Changing Lanes: | 17 | 1 | 0 |
| Avoiding Object/Veh in Road: | 3 | 0 | 0 |
| Weaving: | 4 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 9 | 2 | 1 |
| Unknown: | 2 | 0 | 0 |
| Total: | 132 | 92 | 15 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|------------|-----------|-----------|
| No Apparent Contributing Factor: | 84 | 86 | 15 |
| Asleep at the Wheel: | 4 | 0 | 0 |
| Illness: | 1 | 0 | 0 |
| Distracted by Passenger: | 1 | 0 | 0 |
| Driver Inexperience: | 9 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 20 | 1 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 1 | 1 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 12 | 4 | 0 |
| Total: | 132 | 92 | 15 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|------------|-----------|-----------|
| North: | 2 | 2 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 0 | 0 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 128 | 90 | 15 |
| Southwest: | 0 | 0 | 0 |
| West: | 0 | 0 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 2 | 0 | 0 |
| Total: | 132 | 92 | 15 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|------------|-----------|-----------|
| No Impairment Suspected: | 127 | 91 | 15 |
| 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: | 132 | 92 | 15 |

ADT: 103,102 Length: 1.04



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

CDOT Project #16642 06/17/2019
Exhibit 2

Job #: 20190617112335

Location: 25A Begin: 222.37 End: 223.37 From: 01/01/2010 To: 12/31/2014

Severity

| | | |
|---------------|------------|-------------|
| PDO: | 129 | |
| INJ: | 17 | 26 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 146 | |

Number of Vehicles

| | |
|----------------|------------|
| One Vehicle: | 13 |
| Two Vehicles: | 113 |
| Three or More: | 20 |
| Unknown: | 0 |
| Total: | 146 |

Location

| | |
|------------------|------------|
| On Road: | 137 |
| Off Road Left: | 4 |
| Off Road Right: | 5 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 146 |

Lighting Conditions

| | |
|-------------------|------------|
| Daylight: | 100 |
| Dawn or Dusk: | 10 |
| Dark - Lighted: | 28 |
| Dark - Unlighted: | 8 |
| Unknown: | 0 |
| Total: | 146 |

Weather Conditions

| | |
|------------------|------------|
| None: | 128 |
| Rain: | 9 |
| Snow/Sleet/Hail: | 8 |
| Fog: | 0 |
| Dust: | 1 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 146 |

Crash Rates

| | | |
|---------------|---------------|-------------|
| PDO: | 0.56 * | * MVMT |
| INJ: | 0.07 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 0.63 * | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|------------|
| Overtuning: | 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: | 89 | Delineator Post: | 0 |
| Sideswipe (Same): | 43 | 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: | 8 |
| Wild Animal: | 0 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 0 | Vehicle Cargo/Debris: | 2 |
| Traffic Signal Pole: | 0 | Road Maintenance Equipment: | 0 |
| Sign: | 1 | Involving Other Object: | 3 |
| Bridge Rail: | 0 | Total Other Objects: | 5 |
| Guard Rail: | 3 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 146 |
| Concrete Barrier: | 4 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----|------------------------------------|
| Mainline: | 146 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | | Left Frontage Rd (L): 0 |
| C: 0 G: 0 K: 0 | | Rt Frontage Rd (R): 0 |
| D: 0 H: 0 T: 0 | | HOV Lanes (V): 0 |
| E: 0 I: 0 | | Unknown: 0 |
| | | Total: 146 |

Road Description

| | |
|-----------------------|------------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 146 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 146 |

Road Conditions

| | |
|------------------------------|------------|
| Dry: | 125 |
| Wet: | 12 |
| Muddy: | 0 |
| Snowy: | 1 |
| Icy: | 3 |
| Slushy: | 1 |
| Foreign Material: | 1 |
| With Road Treatment: | 0 |
| Dry w/Icy Road Treatment: | 2 |
| 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: | 146 |

ADT: 125,099 Length: 1.00



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

CDOT Project #16642 06/17/2019

Exhibit 2

Job #: 20190617112335

Location: 25A **Begin: 222.37** **End: 223.37** **From: 01/01/2010** **To: 12/31/2014**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|------------|------------|-----------|
| Passenger Car/Van: | 85 | 68 | 4 |
| Passenger Car/Van w/Trl: | 1 | 0 | 0 |
| Pickup Truck/Utility Van: | 16 | 18 | 5 |
| Pickup Truck/Utility Van w/Trl: | 2 | 4 | 0 |
| SUV: | 25 | 33 | 9 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 9 | 8 | 1 |
| School Bus < 15 People: | 0 | 0 | 0 |
| Non School Bus < 15 People: | 3 | 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: | 5 | 0 | 1 |
| Other: | 0 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 146 | 133 | 20 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|------------|------------|-----------|
| Going Straight: | 66 | 60 | 3 |
| Slowing: | 21 | 26 | 1 |
| Stopped in Traffic: | 1 | 41 | 15 |
| Making Right Turn: | 0 | 0 | 0 |
| Making Left Turn: | 0 | 0 | 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: | 39 | 4 | 0 |
| Avoiding Object/Veh in Road: | 3 | 0 | 0 |
| Weaving: | 1 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 11 | 2 | 1 |
| Unknown: | 0 | 0 | 0 |
| Total: | 146 | 133 | 20 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|------------|------------|-----------|
| No Apparent Contributing Factor: | 42 | 129 | 20 |
| Asleep at the Wheel: | 1 | 0 | 0 |
| Illness: | 2 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 9 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 29 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 63 | 4 | 0 |
| Total: | 146 | 133 | 20 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|------------|------------|-----------|
| North: | 0 | 0 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 0 | 0 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 146 | 133 | 20 |
| Southwest: | 0 | 0 | 0 |
| West: | 0 | 0 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 146 | 133 | 20 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|------------|------------|-----------|
| No Impairment Suspected: | 143 | 133 | 20 |
| 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: | 146 | 133 | 20 |

ADT: 125,099 **Length: 1.00**

Project Information

Project Name: C-470 at Lucent (EB), Ramp Metering

Project Description: Ramp Metering

CDOT Region: 6 Project Def: 16642 County: Douglas

Location: C-470 at EB Lucent Entrance Ramp Mile Points: 18.27 to 19.27
Length: 1 Mile

Schedule: Work Start Date: 10/13/2008 Completion Date: 8/5/2009

Problem Description: The crash history showed a high number of rear end and same direction sideswipe type crashes near the eastbound ramp entry from Lucent.

Improvement Description: Between October 2008 and August 2009 ramp metering was installed. Upon completion, the meters were activated during the peak period hours of 6:30 A.M. to 9:30 A.M. and from 3:00 P.M. to 6:00 P.M. The cost of construction was \$90,000.

The HSIP application anticipated that rear end crashes would be impacted by this improvement. It was anticipated that there would be a 20% crash reduction for these crashes. The anticipated benefit/cost ratio was estimated to be 4.12.

Summary and Findings

The analysis considered only those crashes that occurred in the eastbound direction during the hours that the ramp metering was in effect. The analysis of safety before and after the ramp metering at eastbound C-470 and Lucent showed safety measurably improved in terms of total crashes and rear end crashes. There were 30 total crashes including nine (9) injury crashes during the three-year period before the improvement (2005 – 2007). In the three years after construction (2010 – 2012), the number of crashes decreased to 21 with a small decrease in injury crashes from nine (9) to seven (7) as well. This 30% reduction in total crashes occurred against a small increase (3.2%) in traffic volume from an average AADT of 76,587 to 79,061. There was a 29% reduction in rear end crashes (from 24 crashes to 17 crashes). There were three (3) same direction sideswipe crashes in the before period and two (2) in the after period.

The ramp metering likely has contributed to decreases in the number of rear end crashes and total crashes. We have provided a benefit/cost analysis based on the comparison of crashes in the before period to those in the after period. The cost associated with the improvement was \$90,000. In this case, the number of injury crashes decreased from nine (9) to seven (7), but the number of people injured increased from nine (9) to 12. It would seem somewhat arbitrary to assert that safety worsened in terms of injury crashes when there were fewer of those crashes in the after period than in the before period even though the number of injured people, which is typically the component we measure, happened to increase. Therefore, since both the change in number of injury crashes and number of people injured are small enough to be random and are opposite in effect, we are excluding injury crashes from the benefit to cost calculations altogether. The resulting ratio of benefits and cost for this project, which considers only the 33% reduction in PDO crashes shows that benefits outweigh the costs with a B/C ratio of 4.1 to one, showing that the improvement was cost effective in terms of safety benefits. It is noted that it is

conservative to compare the benefits to the total project cost since ramp metering is expected to produce an operational benefit as well.

Results of Safety Analyses

Using VZS, the review of before and after crash records showed the number of crashes decreased between the two study periods. The total number of crashes was 30 during the three-year period (2005 to 2007) before the ramp metering and 21 during the three-year after period (2010 to 2012) (see **Table 1**). The number of injury crashes decreased from nine (9) crashes to seven (7) crashes, but the number of injured people increased from nine (9) to (12).

- Before (2005 – 2007) – no fatal crashes and 9 injury crashes with 9 injuries
- After (2010 – 2012) – no fatal crashes and 7 injury crashes with 12 injuries

With a 3.2% increase in traffic volumes in the segment, the crash rates at the intersection decreased as well. To estimate crash rates, we multiplied the average AADT for the period by 0.235. To estimate crash rates, we multiplied the average AADT for the period by 0.235. This multiplier is based on multiplying the total ADT by 0.50 for the directional component and by 0.47 for the proportion of the ADT component that occurs during ramp metering, which was calculated using hourly volume data at the ramp (0.50 x 0.47 = 0.235).

- Before (2005 – 2007): 1.52 crashes per million entering vehicles (cpmev)
- After (2010 – 2012): 1.03 cpmev

Table 1 - Results of Overall Crash Analyses

| | Before | After |
|----------------------------|---|---|
| Time Period: | 1/1/2005 to 12/31/2007 (3 yr.) | 1/1/2010 to 12/31/2012 (3 yr.) |
| AADT (C-470) | 76,587 | 79,061 |
| Filters: | Eastbound 6:30 AM to 9:30 AM and 3:00 PM to 6:00 PM Mainline Non Intersection | Eastbound 6:30 AM to 9:30 AM and 3:00 PM to 6:00 PM Mainline Non Intersection |
| Total Crashes | 30 | 21 |
| Fatal Crashes (Fatalities) | 0 | 0 |
| Injury Crashes (Injuries) | 9 (9) | 7 (12) |
| Property Damage Only | 21 | 14 |
| Crash Types: # (%) | | |
| Rear-End | 24 (80%) | 17 (81%) |
| Sideswipe Same Direction | 3 (10%) | 1 (5%) |

The magnitude of safety problems on select highway sections and intersections can often be assessed through the use of Safety Performance Function (SPF) methodology. However, it is not as feasible to derive meaningful SPF relationships for cases like this one where we are observing only those crashes that occurred during certain hours of the day in one direction because the predictive functions were developed using the entire traffic volumes and all crashes for the locations under consideration. Therefore we will dispense with SPF analyses for this project location and focus on crash numbers, crash rates and benefit to cost analysis.

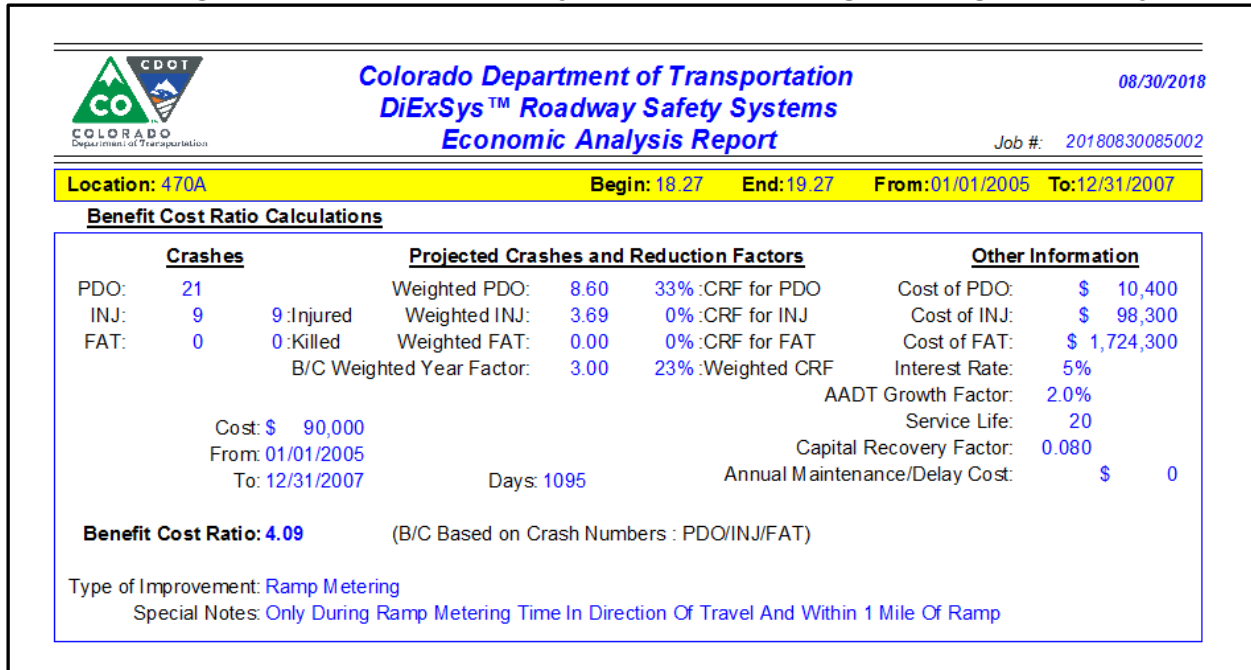
A more detailed review of the before and after crash record further suggests that some improvement in safety can be attributed to the ramp metering for eastbound C-470 at Lucent. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that are most directly affected by the improvement: rear-end and same direction sideswipes. The installation of the ramp metering appears to have reduced the number of both rear-ends and same direction sideswipes, although the quantity of sideswipes is so small overall that the observed difference could be random. The No Build After crashes were estimated using the change in C-470 traffic volumes between the before and after period, as found in **Table 1** (increase is $1.032 = 79,061/76,587$).

Table 3 – Results of Crash Analyses

| | Before | After | No Build After |
|---|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2005 to 12/31/2007 (3 yr.) | 1/1/2010 to 12/31/2012 (3 yr.) | 1/1/2010 to 12/31/2012 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 30 | 21 | 31 |
| Fatal (fatalities) | 0 | 0 | 0 |
| Injury (injuries) | 9 (9) | 7 (12) | 9 (9) |
| PDO | 21 | 14 | 22 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | NA / -33% / 30% | |
| Rear Ends – Total | 24 | 17 | 25 |
| Injury (injuries) | 9 (9) | 5 (8) | 9 (9) |
| PDO | 15 | 12 | 16 |
| % Reduction in Total (Injuries/PDO) | | 11% / 20% | |
| Same Dir. Sideswipe - Total | 3 | 1 | 3 |
| Fatal (fatalities) | 0 | 0 | 0 |
| Injury (injuries) | 0 | 0 | 0 |
| PDO | 3 | 1 | 3 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | NA / NA / 67% | |

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 this ramp. As shown, using the full \$90,000 project cost as the cost basis, the safety related B/C ratio for the improvement is 4.09, showing that the improvement was cost effective from the safety standpoint. This calculation is conservative since additional benefit was also likely gained for this cost from an operational standpoint.

Figure 3 – Benefit Cost Analysis –Crashes During Metering Hours Only



Figures 4 and 5 show the location of the eastbound crashes in the before and after periods respectively.

Figure 4 – Eastbound Crashes in Before Period (2005-2007) Ramp Metering Hours Only

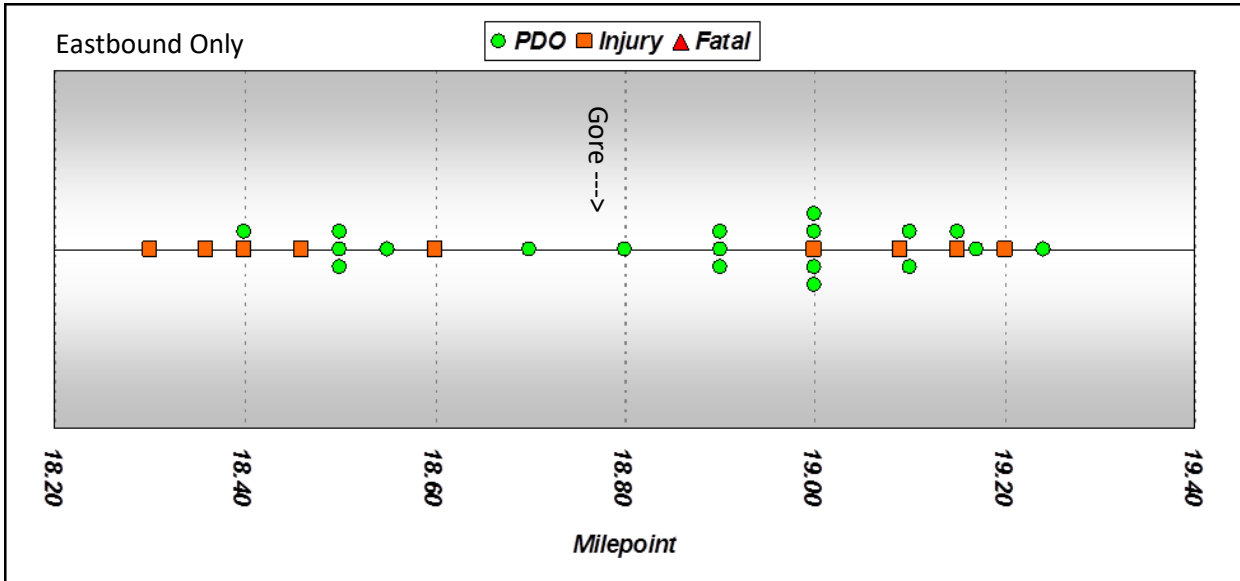
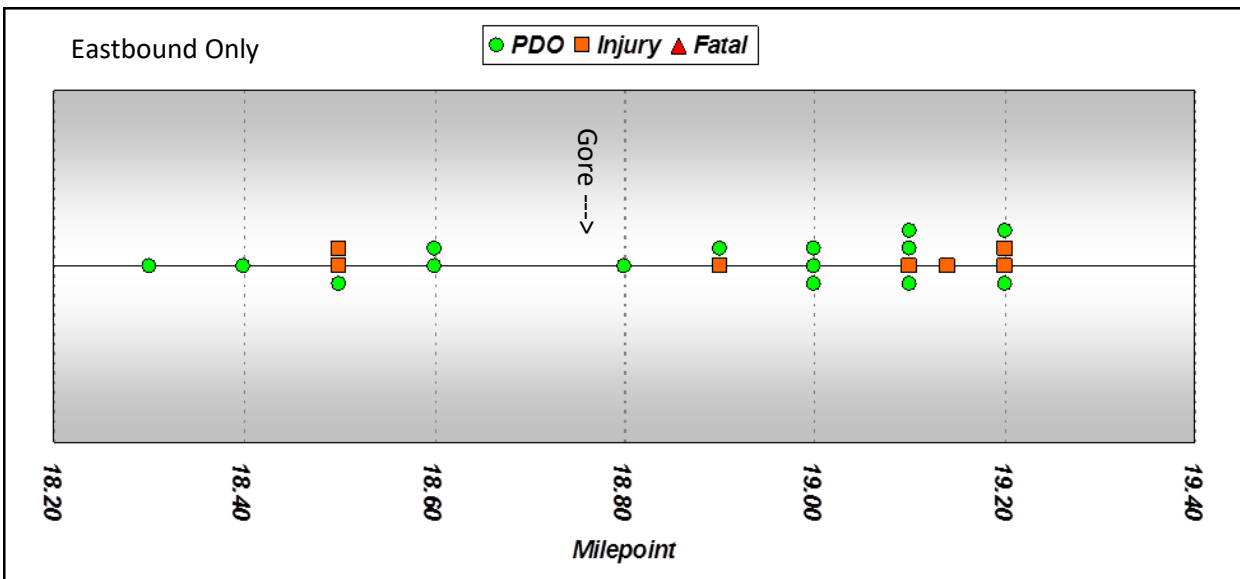


Figure 4 – Eastbound Crashes in After Period (2010-2012) Ramp Metering Hours Only





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

CDOT Project #16642 06/17/2019
Exhibit 1

Job #: 20190617112202

Location: 470A Begin: 18.27 End: 19.27 From:01/01/2010 To:12/31/2014

| Severity | |
|---------------|---------------------|
| PDO: | 55 |
| INJ: | 21 30 :Injured |
| FAT: | 1 1 :Killed |
| Total: | 77 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 20 |
| Two Vehicles: | 43 |
| Three or More: | 14 |
| Unknown: | 0 |
| Total: | 77 |

| Location | |
|------------------|-----------|
| On Road: | 57 |
| Off Road Left: | 14 |
| Off Road Right: | 6 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 77 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 62 |
| Dawn or Dusk: | 4 |
| Dark - Lighted: | 2 |
| Dark - Unlighted: | 9 |
| Unknown: | 0 |
| Total: | 77 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 67 |
| Rain: | 4 |
| Snow/Sleet/Hail: | 5 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 1 |
| Unknown: | 0 |
| Total: | 77 |

| Crash Rates | |
|---------------|------------------------|
| PDO: | 0.36* * MVMT |
| INJ: | 0.14* ** 100 MVMT |
| FAT: | 0.65** |
| Total: | 0.50* |

| Crash Type | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 5 | 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: | 44 | Delineator Post: | 3 |
| Sideswipe (Same): | 7 | Fence: | 1 |
| 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: | 17 |
| Wild Animal: | 1 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 0 | Vehicle Cargo/Debris: | 2 |
| Traffic Signal Pole: | 0 | Road Maintenance Equipment: | 0 |
| Sign: | 0 | Involving Other Object: | 0 |
| Bridge Rail: | 0 | Total Other Objects: | 2 |
| Guard Rail: | 2 | Unknown: | 0 |
| Cable Rail: | 11 | Total: | 77 |
| Concrete Barrier: | 0 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | | | |
|-------------------------------|----|-----------------------------|---|---------------|-----------|
| Mainline: | 77 | M: | 0 | N: | 0 |
| Crossroad (A): | 0 | O: | 0 | P: | 0 |
| Ramps | | Left Frontage Rd (L): | 0 | | |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 | | |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 | | |
| D: 0 H: 0 T: 0 | | Unknown: | 0 | Total: | 77 |
| E: 0 I: 0 | | | | | |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 77 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 77 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 64 |
| Wet: | 11 |
| 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: | 77 |

ADT: 80,904 Length: 1.04



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

CDOT Project #16642 06/17/2019
 Exhibit 1

Job #: 20190617112202

Location: 470A **Begin: 18.27** **End: 19.27** **From:01/01/2010** **To:12/31/2014**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|-----------|
| Passenger Car/Van: | 42 | 26 | 6 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 9 | 5 | 4 |
| Pickup Truck/Utility Van w/Trl: | 4 | 0 | 0 |
| SUV: | 18 | 26 | 3 |
| 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: | 2 | 0 | 1 |
| 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: | 77 | 57 | 14 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|-----------|
| Going Straight: | 56 | 10 | 2 |
| Slowing: | 4 | 21 | 2 |
| Stopped in Traffic: | 0 | 23 | 10 |
| Making Right Turn: | 0 | 0 | 0 |
| Making Left Turn: | 0 | 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: | 7 | 1 | 0 |
| Avoiding Object/Veh in Road: | 1 | 1 | 0 |
| Weaving: | 2 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 6 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 77 | 57 | 14 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|-----------|
| No Apparent Contributing Factor: | 42 | 57 | 14 |
| Asleep at the Wheel: | 4 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 2 | 0 | 0 |
| Driver Inexperience: | 6 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 19 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 1 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 3 | 0 | 0 |
| Total: | 77 | 57 | 14 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|-----------|
| North: | 0 | 0 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 77 | 56 | 14 |
| 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: | 77 | 57 | 14 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|-----------|
| No Impairment Suspected: | 73 | 57 | 14 |
| 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: | 77 | 57 | 14 |

ADT: 80,904 **Length: 1.04**



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

CDOT Project #16642 06/17/2019
Exhibit 2

Job #: 20190617112128

Location: 470A Begin: 18.27 End: 19.27 From:01/01/2003 To:12/31/2007

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 42 | |
| INJ: | 21 | 29 :Injured |
| FAT: | 2 | 3 :Killed |
| Total: | 65 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 10 |
| Two Vehicles: | 43 |
| Three or More: | 12 |
| Unknown: | 0 |
| Total: | 65 |

Location

| | |
|------------------|-----------|
| On Road: | 52 |
| Off Road Left: | 6 |
| Off Road Right: | 3 |
| Off Road at Tee: | 0 |
| Off in Median: | 4 |
| Unknown: | 0 |
| Total: | 65 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 53 |
| Dawn or Dusk: | 2 |
| Dark - Lighted: | 7 |
| Dark - Unlighted: | 3 |
| Unknown: | 0 |
| Total: | 65 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 53 |
| Rain: | 5 |
| Snow/Sleet/Hail: | 7 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 65 |

Crash Rates

| | | |
|---------------|---------------|-------------|
| PDO: | 0.31 * | * MVMT |
| INJ: | 0.16 * | ** 100 MVMT |
| FAT: | 1.49 ** | |
| Total: | 0.48 * | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 7 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 0 | Embankment: | 0 |
| Head On: | 4 | Curb: | 0 |
| Rear End: | 39 | Delineator Post: | 0 |
| Sideswipe (Same): | 6 | 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: | 3 |
| 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: | 4 |
| Bridge Rail: | 0 | Total Other Objects: | 5 |
| Guard Rail: | 0 | Unknown: | 0 |
| Cable Rail: | 3 | Total: | 65 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|----|------------------------------------|
| Mainline: | 65 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | | Left Frontage Rd (L): 0 |
| C: 0 G: 0 K: 0 | | Rt Frontage Rd (R): 0 |
| D: 0 H: 0 T: 0 | | HOV Lanes (V): 0 |
| E: 0 I: 0 | | Unknown: 0 |
| | | Total: 65 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 65 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 65 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 48 |
| Wet: | 10 |
| Muddy: | 0 |
| Snowy: | 5 |
| 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: | 65 |

ADT: 73,132 Length: 1.00



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

CDOT Project #16642 06/17/2019
 Exhibit 2

Job #: 20190617112128

Location: 470A **Begin: 18.27** **End: 19.27** **From:01/01/2003** **To:12/31/2007**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|-----------|
| Passenger Car/Van: | 44 | 34 | 8 |
| Passenger Car/Van w/Trl: | 1 | 0 | 0 |
| Pickup Truck/Utility Van: | 8 | 11 | 4 |
| Pickup Truck/Utility Van w/Trl: | 2 | 1 | 0 |
| SUV: | 4 | 7 | 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: | 1 | 0 | 0 |
| Bicycle: | 0 | 0 | 0 |
| Motorized Bicycle: | 0 | 0 | 0 |
| Farm Equipment: | 0 | 0 | 0 |
| Hit and Run - Unknown: | 1 | 1 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 65 | 55 | 12 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|-----------|
| Going Straight: | 50 | 18 | 5 |
| Slowing: | 5 | 15 | 2 |
| Stopped in Traffic: | 0 | 21 | 5 |
| 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 | 0 | 0 |
| Changing Lanes: | 3 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 1 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 2 | 0 | 0 |
| Unknown: | 3 | 0 | 0 |
| Total: | 65 | 55 | 12 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|-----------|
| No Apparent Contributing Factor: | 32 | 54 | 11 |
| Asleep at the Wheel: | 0 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 2 | 0 | 0 |
| Driver Inexperience: | 9 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 20 | 0 | 1 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 1 | 1 | 0 |
| Total: | 65 | 55 | 12 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|-----------|
| North: | 0 | 0 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 59 | 52 | 11 |
| Southeast: | 0 | 0 | 0 |
| South: | 0 | 0 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 3 | 3 | 1 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 3 | 0 | 0 |
| Total: | 65 | 55 | 12 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|-----------|
| No Impairment Suspected: | 64 | 55 | 12 |
| 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: | 65 | 55 | 12 |

ADT: 73,132 **Length: 1.00**

Project Information

Project Name: C-470 at Kipling (EB), Ramp Metering

Project Description: Ramp Metering

CDOT Region: 6 Project Def: 16642 County: Jefferson

Location: C-470 at EB Kipling Entrance Ramp Mile Points: 12.35 to 13.35
Length: 1 Mile

Schedule: Work Start Date: 10/13/2008 Completion Date: 8/5/2009

Problem Description: The crash history showed a high number of rear end and same direction sideswipe type crashes near the eastbound ramp entry from Kipling.

Improvement Description: Between October 2008 and August 2009 ramp metering was installed. Upon completion, the meters were activated during the peak period hours of 6:30 A.M. to 9:30 A.M. and from 3:00 P.M. to 6:00 P.M. The cost of construction was \$90,000.

The HSIP application anticipated that rear end crashes would be impacted by this improvement. It was anticipated that there would be a 20% crash reduction for these crashes. The initial benefit/cost ratio was estimated to be 0.42. This project was grouped at the time with other ramp metering project locations having qualifying B/C ratios and was thus approved on the basis of employing a systemic approach for this larger ramp metering effort.

Summary and Findings

The analysis considered only those crashes that occurred in the eastbound direction during the hours that the ramp metering was in effect. The analysis of safety before and after the ramp metering at eastbound C-470 and Kipling showed safety measurably improved in terms of total crashes and rear end crashes. There were 18 total crashes including four (4) injury crashes during the five-year period before the improvement (2003 – 2007). In the five years after construction (2010 – 2014), there were 10 total crashes with three (3) injury crashes. There was a small increase (2.5%) in traffic volume from an average AADT of 57,174 to 59,084. There was a 54% reduction in rear end crashes (from 13 crashes to 6 crashes). There was one (1) same direction sideswipe crash in the before period and three (3) in the after period.

The ramp metering has likely contributed to decreases in the number of rear end crashes and total crashes. We have provided a benefit/cost analysis based on the comparison of crashes in the before period to those in the after period. The cost associated with the improvement was \$90,000. The ratio of benefits and cost for this project shows that benefits outweigh the costs with a B/C ratio of 9.16 to one, showing that the improvement was cost effective in terms of safety benefits. This B/C ratio took into account safety benefits only and is considered conservative since ramp metering is expected to improve operations as well as safety.

Results of Safety Analyses

Using VZS, the review of before and after crash records showed the number of crashes decreased between the two study periods. The total number of crashes was 18 during the five-year period (2003 to 2007) before the ramp metering and 10 during the five-year after period (2010 to 2014) (see **Table 1**). The number of injury crashes was decreased from four (4) crashes in the before period to three (3) crashes in the after period.

- Before (2003 – 2007) – no fatal crashes and 4 injury crashes with 5 injuries
- After (2010 – 2014) – no fatal crashes and 3 injury crashes with 3 injuries

Although there was a 2.5% increase in traffic volumes in the segment, the crash rates at the merge zone still decreased. To estimate crash rates, we multiplied the average AADT for the period by 0.245. This multiplier is based on multiplying the total ADT by 0.50 for the directional component and by 0.49 for the proportion of the ADT component that occurs during ramp metering, which was calculated using hourly volume data at the ramp ($0.50 \times 0.49 = 0.245$).

- Before (2003 – 2007): 0.387 crashes per million entering vehicles (cpmev)
- After (2010 – 2014): 0.200 cpmev

Table 1 - 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 (C-470) | 57,174 | 59,084 |
| Filters: | Eastbound 6:30 AM to 9:30 AM and 3:00 PM to 6:00 PM Mainline Non Intersection | Eastbound 6:30 AM to 9:30 AM and 3:00 PM to 6:00 PM Mainline Non Intersection |
| Total Crashes | 18 | 10 |
| Fatal Crashes (Fatalities) | 0 | 0 |
| Injury Crashes (Injuries) | 4 (5) | 3 (3) |
| Property Damage Only | 14 | 7 |
| Crash Types: # (%) | | |
| Rear-End | 13 (72%) | 6 (60%) |
| Sideswipe Same Direction | 1 (6%) | 3 (30%) |

The magnitude of safety problems on select highway sections and intersections can often be assessed through the use of Safety Performance Function (SPF) methodology. However, it is not as feasible to derive meaningful SPF relationships for cases like this one where we are observing only those crashes that occurred during certain hours of the day in one direction because the predictive functions were developed using the entire traffic volumes and all crashes for the locations under consideration. Therefore we will dispense with SPF analyses for this project location and focus on crash numbers, crash rates and benefit to cost analysis.

A more detailed review of the before and after crash record expands on the results of the crash data for the ramp metering for eastbound C-470 at Kipling. **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: rear-end and same direction sideswipes. The installation of the ramp metering may have significantly reduced the number of rear end crashes (from 13 to 6). The number of same direction sideswipes increased but in a small enough amount that the observed difference could be random. The No Build After crashes were estimated using the change in C-470 traffic volumes between the before and after period, as found in **Table 1** (increase is 1.025 = 59,084/57,174). As the numbers in the table show, the increase in traffic volume was not sufficient to show an increase in the number of crashes in the no-build after period.

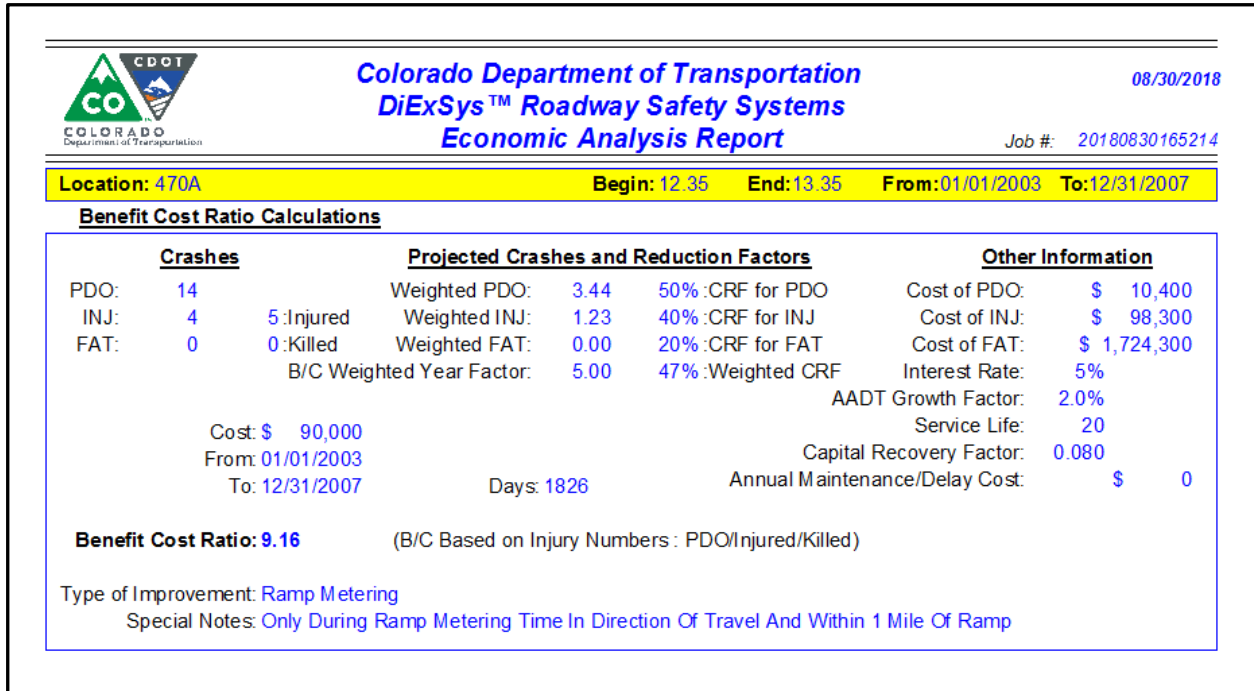
Table 3 – Results of Crash Analyses

| | 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: | | | |
| Total Crashes | 18 | 10 | 18 |
| Fatal (fatalities) | 0 | 0 | 0 |
| Injury (injuries) | 4 (5) | 3 (3) | 4 (5) |
| PDO | 14 | 7 | 14 |
| % Change in Total (Fatalities/Injuries/PDO) | | NA / -25% / -50% | |
| Rear Ends – Total | 13 | 6 | 13 |
| Injury (injuries) | 1 (1) | 2 (2) | 1 (1) |
| PDO | 12 | 4 | 12 |
| % Change in Total (Injuries/PDO) | | +100% / -67% | |
| Same Dir. Sideswipe - Total | 1 | 3 | 1 |
| Fatal (fatalities) | 0 | 0 | 0 |
| Injury (injuries) | 0 | 1 (1) | 0 |
| PDO | 1 | 2 | 1 |
| % Change in Total (Fatalities/Injuries/PDO) | | NA / NA / +200% | |

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. As shown, using the full \$90,000 project cost as the cost basis, the safety related B/C ratio for the improvement is 9.16, showing that the improvement was cost effective from the safety standpoint. This calculation is

conservative since additional benefit was also likely gained for this cost from an operational standpoint.

Figure 3 – Benefit Cost Analysis –Crashes During Metering Hours Only



Figures 4 and 5 show the location of the eastbound crashes in the before and after periods respectively.

Figure 4 – Eastbound Crashes in Before Period (2003-2007) Ramp Metering Hours Only

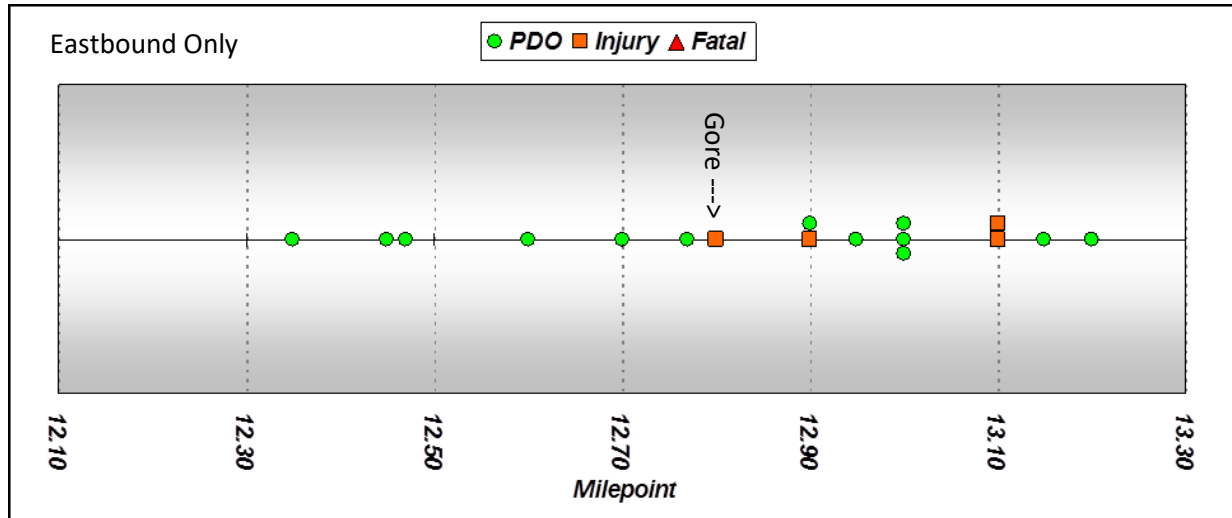
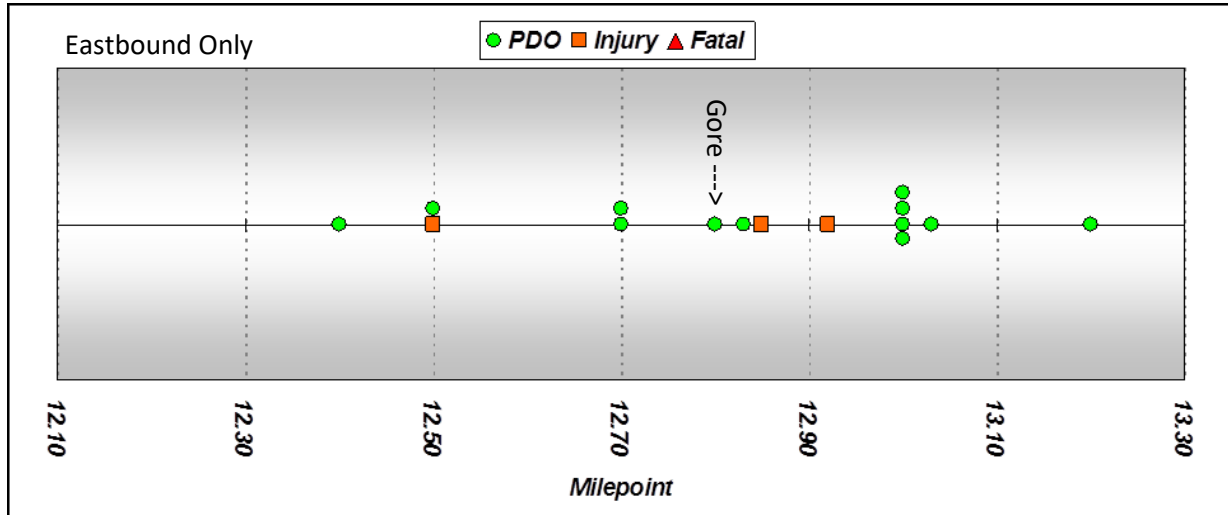


Figure 5 – Eastbound Crashes in After Period (2010-2014) Ramp Metering Hours Only





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

CDOT Project # 16642 06/17/2019

Exhibit 1

Job #: 20190617111905

Location: 470A **Begin: 12.35** **End: 13.35** **From:01/01/2003** **To:12/31/2007**

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 24 | |
| INJ: | 10 | 16 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 34 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 11 |
| Two Vehicles: | 20 |
| Three or More: | 3 |
| Unknown: | 0 |
| Total: | 34 |

Location

| | |
|------------------|-----------|
| On Road: | 23 |
| Off Road Left: | 2 |
| Off Road Right: | 8 |
| Off Road at Tee: | 0 |
| Off in Median: | 1 |
| Unknown: | 0 |
| Total: | 34 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 25 |
| Dawn or Dusk: | 3 |
| Dark - Lighted: | 0 |
| Dark - Unlighted: | 5 |
| Unknown: | 1 |
| Total: | 34 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 25 |
| Rain: | 4 |
| Snow/Sleet/Hail: | 4 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 1 |
| Total: | 34 |

Crash Rates

| | | |
|---------------|--------------|-------------|
| PDO: | 0.23* | * MVMT |
| INJ: | 0.09* | ** 100 MVMT |
| FAT: | 0.00** | |
| Total: | 0.32* | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 4 | 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: | 14 | Delineator Post: | 1 |
| Sideswipe (Same): | 5 | Fence: | 0 |
| Sideswipe (Opposite): | 1 | Tree: | 1 |
| 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: | 6 |
| Wild Animal: | 1 | 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: | 1 |
| Bridge Rail: | 1 | Total Other Objects: | 2 |
| Guard Rail: | 0 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 34 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|----|------------------------------------|
| Mainline: | 34 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | | Left Frontage Rd (L): 0 |
| C: 0 G: 0 K: 0 | | Rt Frontage Rd (R): 0 |
| D: 0 H: 0 T: 0 | | HOV Lanes (V): 0 |
| E: 0 I: 0 | | Unknown: 0 |
| | | Total: 34 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 34 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 34 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 22 |
| Wet: | 7 |
| Muddy: | 0 |
| Snowy: | 1 |
| 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: | 1 |
| Total: | 34 |

ADT: 57,174 **Length: 1.01**



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

CDOT Project #16642 06/17/2019
Exhibit 1

Job #: 20190617111905

Location: 470A Begin: 12.35 End: 13.35 From:01/01/2003 To:12/31/2007

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 22 | 14 | 3 |
| Passenger Car/Van w/Trl: | 1 | 0 | 0 |
| Pickup Truck/Utility Van: | 7 | 4 | 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: | 3 | 1 | 0 |
| School Bus < 15 People: | 0 | 0 | 0 |
| Non School Bus < 15 People: | 0 | 0 | 0 |
| Motorhome: | 0 | 0 | 0 |
| Motorcycle: | 0 | 1 | 0 |
| Bicycle: | 0 | 0 | 0 |
| Motorized Bicycle: | 0 | 0 | 0 |
| Farm Equipment: | 0 | 0 | 0 |
| Hit and Run - Unknown: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 1 | 2 | 0 |
| Total: | 34 | 23 | 3 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 26 | 9 | 0 |
| Slowing: | 2 | 9 | 1 |
| Stopped in Traffic: | 0 | 3 | 2 |
| 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: | 5 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 1 | 0 |
| Total: | 34 | 23 | 3 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 27 | 21 | 3 |
| Asleep at the Wheel: | 1 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 1 | 0 | 0 |
| Driver Fatigue: | 1 | 0 | 0 |
| Driver Preoccupied: | 2 | 0 | 0 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 1 | 2 | 0 |
| Total: | 34 | 23 | 3 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 0 | 0 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 32 | 22 | 3 |
| Southeast: | 0 | 0 | 0 |
| South: | 0 | 0 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 2 | 0 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 1 | 0 |
| Total: | 34 | 23 | 3 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 33 | 23 | 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: | 34 | 23 | 3 |

ADT: 57,174 Length: 1.01



Location: 470A **Begin: 12.35** **End: 13.35** **From:01/01/2010** **To:12/31/2014**

| Severity | |
|---------------|---------------------|
| PDO: | 18 |
| INJ: | 11 14 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 29 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 11 |
| Two Vehicles: | 14 |
| Three or More: | 4 |
| Unknown: | 0 |
| Total: | 29 |

| Location | |
|------------------|-----------|
| On Road: | 19 |
| Off Road Left: | 6 |
| Off Road Right: | 4 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 29 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 15 |
| Dawn or Dusk: | 3 |
| Dark - Lighted: | 3 |
| Dark - Unlighted: | 8 |
| Unknown: | 0 |
| Total: | 29 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 26 |
| Rain: | 0 |
| Snow/Sleet/Hail: | 2 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 1 |
| Unknown: | 0 |
| Total: | 29 |

| Crash Rates | |
|---------------|------------------------|
| PDO: | 0.17* * MVMT |
| INJ: | 0.10* ** 100 MVMT |
| FAT: | 0.00** |
| Total: | 0.27* |

| Crash Type | | | |
|-----------------------|---|-----------------------------|-----------|
| Overtuning: | 2 | Bridge Abutment: | 0 |
| Other Non Collision: | 1 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 0 | Embankment: | 0 |
| Head On: | 0 | Curb: | 0 |
| Rear End: | 9 | Delineator Post: | 1 |
| Sideswipe (Same): | 8 | 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: | 1 | 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: | 1 | Unknown: | 0 |
| Cable Rail: | 4 | Total: | 29 |
| Concrete Barrier: | 0 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | | | |
|-------------------------------|----|-----------------------------|---|---------------|-----------|
| Mainline: | 29 | M: | 0 | N: | 0 |
| Crossroad (A): | 0 | O: | 0 | P: | 0 |
| Ramps | | Left Frontage Rd (L): | 0 | | |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 | | |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 | | |
| D: 0 H: 0 T: 0 | | Unknown: | 0 | Total: | 29 |
| E: 0 I: 0 | | | | | |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 29 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 29 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 24 |
| Wet: | 1 |
| Muddy: | 0 |
| Snowy: | 3 |
| 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: | 29 |

ADT: 59,084 **Length: 0.99**



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

CDOT Project #16642 06/17/2019
 Exhibit 2

Job #: 20190617111816

Location: 470A **Begin: 12.35** **End: 13.35** **From:01/01/2010** **To:12/31/2014**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 12 | 8 | 3 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 5 | 2 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 9 | 7 | 1 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 2 | 0 | 0 |
| School Bus < 15 People: | 0 | 0 | 0 |
| Non School Bus < 15 People: | 0 | 0 | 0 |
| Motorhome: | 0 | 0 | 0 |
| Motorcycle: | 1 | 0 | 0 |
| Bicycle: | 0 | 0 | 0 |
| Motorized Bicycle: | 0 | 0 | 0 |
| Farm Equipment: | 0 | 0 | 0 |
| Hit and Run - Unknown: | 0 | 0 | 0 |
| Other: | 0 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 29 | 18 | 4 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 16 | 7 | 0 |
| Slowing: | 2 | 6 | 1 |
| Stopped in Traffic: | 0 | 1 | 3 |
| Making Right Turn: | 0 | 0 | 0 |
| Making Left Turn: | 0 | 0 | 0 |
| Making U-Turn: | 0 | 0 | 0 |
| Passing: | 2 | 1 | 0 |
| Backing: | 0 | 0 | 0 |
| Enter/Leave Parked Position: | 0 | 0 | 0 |
| Starting in Traffic: | 0 | 0 | 0 |
| Parked: | 0 | 0 | 0 |
| Changing Lanes: | 4 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 2 | 0 |
| Weaving: | 1 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 4 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 29 | 18 | 4 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 11 | 16 | 4 |
| Asleep at the Wheel: | 2 | 0 | 0 |
| Illness: | 2 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 1 | 1 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 4 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 1 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 8 | 1 | 0 |
| Total: | 29 | 18 | 4 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 0 | 0 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 28 | 17 | 3 |
| Southeast: | 1 | 1 | 1 |
| South: | 0 | 0 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 0 | 0 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 29 | 18 | 4 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 26 | 18 | 4 |
| Alcohol Involved: | 2 | 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: | 29 | 18 | 4 |

ADT: 59,084 **Length: 0.99**

Project Information

| | | |
|-----------------------------|---|------------------------------------|
| Project Name: | SH 21A (Powers Boulevard) at Grinnell Street | |
| Project Description: | Install a signal and extend the existing turning lanes. | |
| CDOT Region: 2 | <u>Project Def:</u> 17221 | <u>County:</u> El Paso |
| Location: SH 21A | <u>Mile Points:</u> 136.61 | <u>Length:</u> N/A |
| Schedule: | <u>Work Start Date:</u> 5/4/2010 | <u>Completion Date:</u> 12/12/2012 |

Problem Description: As described in the Federal Hazard Elimination Program (FHEP) application for this project, the four-year crash history (2002 – 2005) showed that there was a total of 20 injury crashes, 26 PDO crashes, and one fatal crash. Of the 47 crashes, 26 were broadsides and four were approach turn type crashes.

Improvement Description: Between May 4, 2010 and December 12, 2012, this three-leg intersection was signalized. Previously, the intersection had stop control on one leg. Additionally, the turn lanes were extended. The cost of construction was \$400,000.

The FHEP application anticipated that an 80% reduction in broadside crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 8.56.

Summary and Findings

The analysis of safety before and after the improvements at this intersection shows a reduction in the number and severity of broadside type crashes. There were 14 total crashes during the three-year period before the improvements were made (2007 – 2009). In the three years after construction (2013 – 2015), the number of crashes decreased to 13, a reduction of 7%. The ADT slightly increased from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a 100% decrease in fatal crashes with 1 crash in the before period and no crashes in the after period. There was no decrease in injury crashes, but the number of injuries decrease from 20 injuries in the three years before construction to 15 injuries in the three years after construction. The number of PDO remained unchanged. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 10 years for this project is **17.07** to one. The result is an improvement that certainly was justified from the safety improvement as well as cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 136.56 to 136.66 shows a slight decrease in the number of crashes from 14 during the three-year period (2007 to 2009) before the improvements to 13 during the three-year after period (2013 to 2015) (**Table 1**). The number of serious crashes also showed a decrease in the after period:

- Before (2007 – 2009) – One fatal crash and 8 injury crashes with 20 injuries
- After (2013 – 2015) – No fatal crashes and 8 injury crashes with 15 injuries

The crash rate at this intersection also decrease in the after period:

- Before (2007 – 2009) – 0.21 crashes per million entering vehicles (cpmev)
- After (2013 – 2015) – 0.17 cpmev

It is reasonable to conclude that the observed decrease in the frequency and severity of crashes is related to the various safety improvements constructed on this project.

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2013 to 12/31/2015 (3 yr.) |
| AADT (SH 21A/Grinnell St) | 21,100 vpd / approx. 9,750 vpd | 23,250 vpd / 10,700 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 14 | 13 |
| Fatal Crashes (Fatalities) | 1 (1) | 0 (0) |
| Injury Crashes (Injuries) | 8 (20) | 8 (15) |
| Property Damage Only | 5 | 5 |
| Crash Types: # (%) [significance] | | |
| Broadside | 10 (71.4%) [100.0%] | 2 (15.4%) |
| Rear-End | 2 (14.3%) | 4 (30.8%) |
| Sideswipe Same Direction | 1 (7.1%) | 1 (7.7%) |
| Fixed Object | 1 (7.1%) | 0 |
| Approach Turn | 0 | 5 (38.5%) [99.0%] |
| Head-On | 0 | 1 (7.7%) |

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 of safety uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity.

If the level of service 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 (**Figures 1 and 2**) and for fatal and injury crashes (**Figures 3 and 4**) reflect an improvement in the crash record for this project. LOSS improved from very high in the LOSS IV range for total crashes in the before period to LOSS II in the after period. Injury/Fatal crashes also improved from a high LOSS IV to a low LOSS IV in the after period. These figures also show that the number and severity of crashes during the period after construction improved in comparison to what it could have been without this safety improvement project. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes (Unsignalized) – Before/No Action After
SH 21A, MP 136.61
Before: 2007 to 2009 After: 2013 to 2015

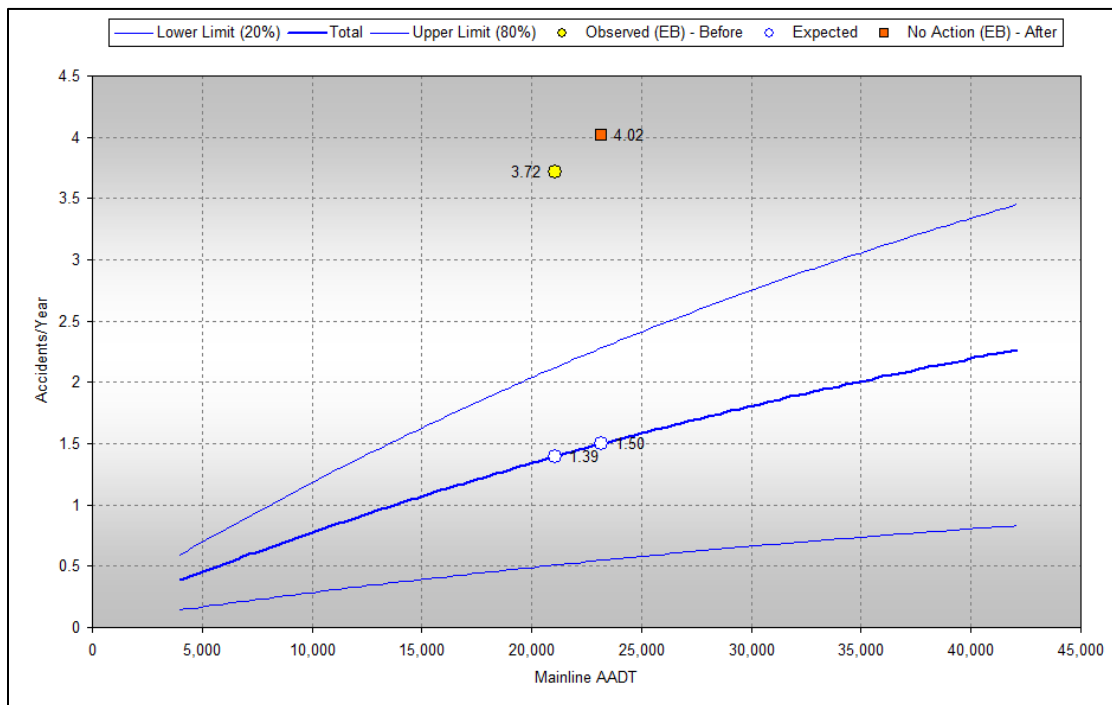


Figure 2 – SPF for Total Crashes (Signalized) – After

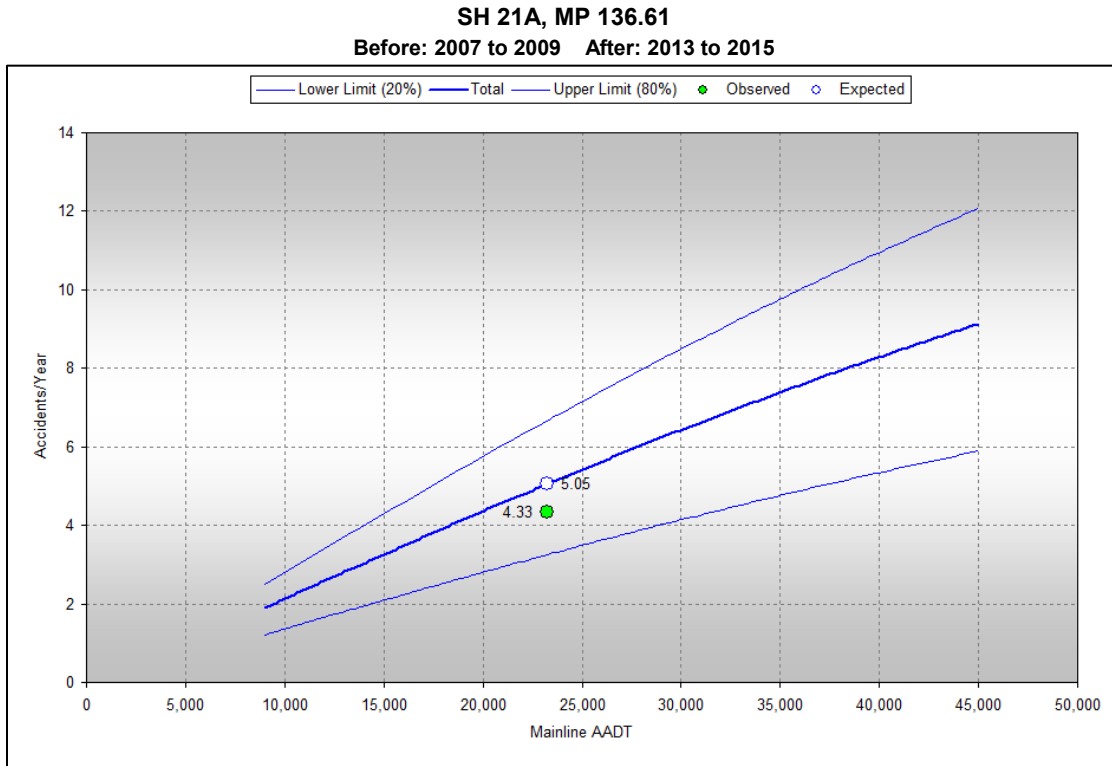


Figure 3 – SPF for Injury and Fatal Crashes (Unsignalized) – Before/No Action After

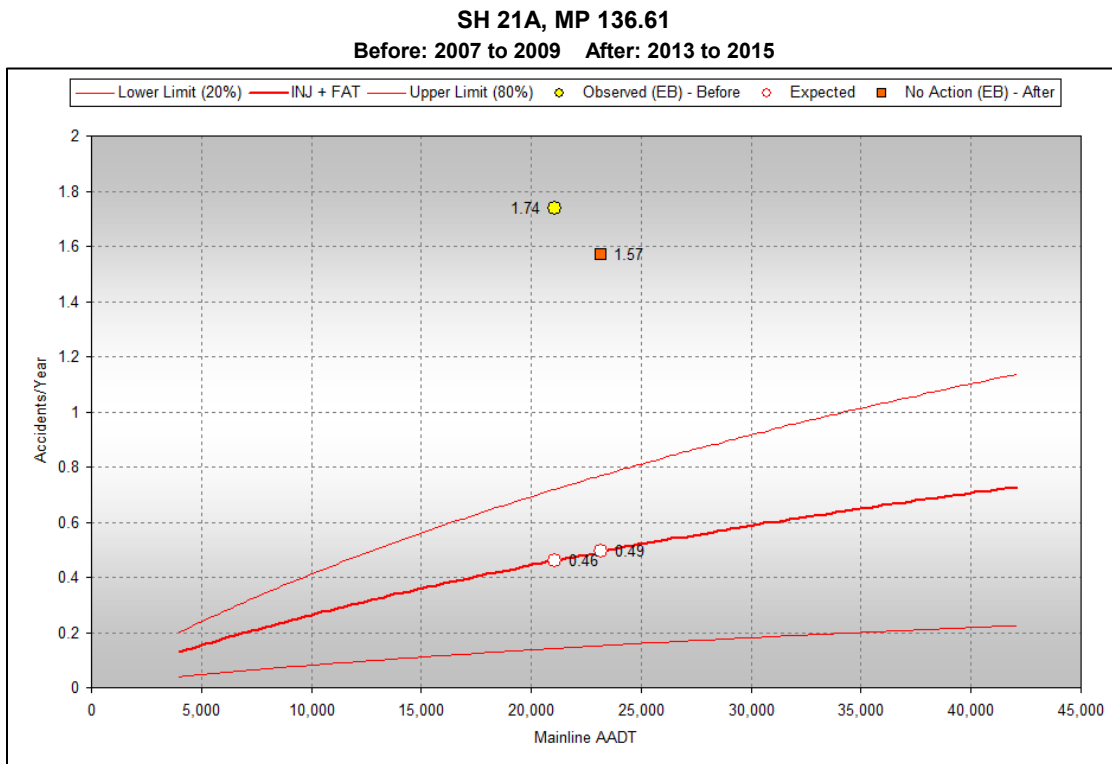


Figure 4 – SPF for Injury and Fatal Crashes (Signalized) – After

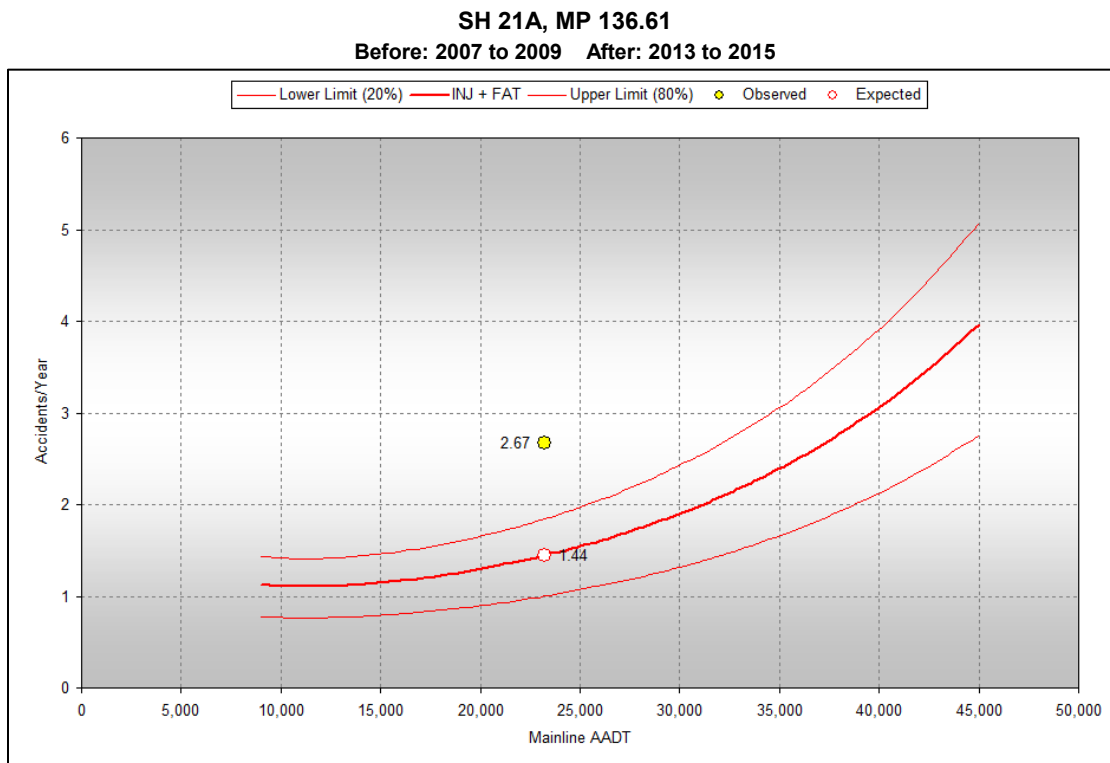


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action 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 IV | LOSS II | LOSS IV |
| CPY | 3.72 | 4.33 | 4.02 |
| Mean CPY | 1.39 | 5.05 | 1.50 |
| Proportion of Mean | 2.68 | 0.86 | 2.68 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS IV | LOSS IV | LOSS IV |
| CPY | 1.47 | 2.67 | 1.57 |
| Mean CPY | 0.46 | 1.44 | 0.49 |
| Proportion of Mean | 3.20 | 1.85 | 3.20 |

A more detailed review of the before and after crash record shows the crash types that were most affected by the signal installation. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: broadside, and rear-end. The installation of the signal reduced the number of broadside crashes, but increased the number of rear-ends. This is an expected outcome when signaling an intersection. The number of crashes does not necessarily decrease, but the crash types become less severe by reducing the broadside crashes. Additionally, there were approach turn crashes in the after

period, when there were none in the before period. The No-Build After crashes were estimated using the change in SH 21A traffic volumes between the before and after period, as found in **Table 1** (AADT increase is 10% = $|1-(23,250/21,100)|$).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|---|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2013 to 12/31/2015 (3 yr.) | 1/1/2013 to 12/31/2015 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 14 | 13 | 15 |
| Fatal (fatalities) | 1 (1) | 0 (0) | 1 (1) |
| Injury (injuries) | 8 (20) | 8 (15) | 9 (22) |
| PDO | 5 | 5 | 5 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | 100% / 32% / 0% | |
| Broadside – Total | 10 | 2 | 11 |
| Fatal (fatalities) | 1 (1) | 0 (0) | 1 (1) |
| Injury (injuries) | 6 (15) | 1 (1) | 7 (17) |
| PDO | 3 | 1 | 3 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | 100% / 94% / 66% | |
| Rear Ends – Total | 2 | 4 | 2 |
| Injury (injuries) | 1 (1) | 1 (1) | 1(1) |
| PDO | 1 | 3 | 1 |
| % Reduction in Total (Injuries/PDO) | | 0% / -200% | |
| Approach Turns – Total | 0 | 4 | 0 |
| Injury (injuries) | 0 (0) | 5 (11) | 0(0) |
| PDO | 0 | 0 | 0 |
| % Reduction in Total (Injuries/PDO) | | NA / 0% | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 17.07 was ultimately realized.** This outcome displays that this safety improvement project was justified from a cost-effectiveness standpoint.



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

CDOT Project # 17221 11/15/2018

Exhibit 1

Job #: 20181115060656

Location: 21A **Begin: 136.56** **End: 136.66** **From: 01/01/2007** **To: 12/31/2009**

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 5 | |
| INJ: | 8 | 20 :Injured |
| FAT: | 1 | 1 :Killed |
| Total: | 14 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 1 |
| Two Vehicles: | 12 |
| Three or More: | 1 |
| 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: | 9 |
| Dawn or Dusk: | 0 |
| Dark - Lighted: | 0 |
| Dark - Unlighted: | 5 |
| Unknown: | 0 |
| Total: | 14 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 14 |
| Rain: | 0 |
| Snow/Sleet/Hail: | 0 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 14 |

Crash Rates

| | | |
|---------------|--------------|-------------|
| PDO: | 2.19* | * MVMT |
| INJ: | 3.50* | ** 100 MVMT |
| FAT: | 43.74** | |
| Total: | 6.12* | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 10 | Embankment: | 0 |
| Head On: | 0 | Curb: | 0 |
| Rear End: | 2 | 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: | 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 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | | Left Frontage Rd (L): 0 |
| C: 0 G: 0 K: 0 | | Rt Frontage Rd (R): 0 |
| D: 0 H: 0 T: 0 | | HOV Lanes (V): 0 |
| E: 0 I: 0 | | Unknown: 0 |
| | | Total: 14 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 13 |
| At Driveway Access: | 0 |
| Intersection Related: | 1 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 14 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 11 |
| Wet: | 1 |
| 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: | 1 |
| Unknown: | 0 |
| Total: | 14 |

ADT: 21,072 **Length: 0.09**



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

CDOT Project # 17221 11/15/2018
 Exhibit 1
 Job #: 20181115060656

Location: 21A **Begin: 136.56** **End: 136.66** **From: 01/01/2007** **To: 12/31/2009**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 8 | 8 | 1 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 3 | 1 | 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 | 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: | 14 | 13 | 1 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 3 | 8 | 1 |
| Slowing: | 0 | 1 | 0 |
| Stopped in Traffic: | 0 | 1 | 0 |
| Making Right Turn: | 1 | 0 | 0 |
| Making Left Turn: | 10 | 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 | 1 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 14 | 13 | 1 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 9 | 13 | 1 |
| Asleep at the Wheel: | 0 | 0 | 0 |
| Illness: | 1 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 1 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 0 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 3 | 0 | 0 |
| Total: | 14 | 13 | 1 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 0 | 2 | 0 |
| Northeast: | 3 | 0 | 0 |
| East: | 6 | 1 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 5 | 10 | 1 |
| Southwest: | 0 | 0 | 0 |
| West: | 0 | 0 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 14 | 13 | 1 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 13 | 13 | 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: | 14 | 13 | 1 |

ADT: 21,072 **Length: 0.09**



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

CDOT Project # 17221 11/15/2018

Exhibit 2

Job #: 20181115060449

Location: 21A **Begin: 136.56** **End: 136.66** **From: 01/01/2013** **To: 12/31/2015**

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 5 | |
| INJ: | 8 | 15 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 13 | |

Number of Vehicles

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

Location

| | |
|------------------|-----------|
| On Road: | 13 |
| Off Road Left: | 0 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 13 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 11 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 1 |
| Dark - Unlighted: | 0 |
| Unknown: | 0 |
| Total: | 13 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 11 |
| Rain: | 1 |
| Snow/Sleet/Hail: | 0 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 1 |
| Unknown: | 0 |
| Total: | 13 |

Crash Rates

| | | |
|---------------|---------------|-------------|
| PDO: | 2.01 * | * MVMT |
| INJ: | 3.21 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 5.21 * | |

Crash Type

| | | | |
|-----------------------|---|-----------------------------|-----------|
| Overtuning: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 2 | Embankment: | 0 |
| Head On: | 1 | Curb: | 0 |
| Rear End: | 4 | Delineator Post: | 0 |
| Sideswipe (Same): | 1 | Fence: | 0 |
| Sideswipe (Opposite): | 0 | Tree: | 0 |
| Approach Turn: | 5 | Large Boulders or Rocks: | 0 |
| Overtaking Turn: | 0 | Barricade: | 0 |
| Parked Motor Vehicle: | 0 | Wall/Building: | 0 |
| Railway Vehicle: | 0 | Crash Cushion: | 0 |
| Bicycle: | 0 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 0 |
| Domestic Animal: | 0 | Total Fixed Objects: | 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: | 13 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----------------------|------------------------------------|
| Mainline: | 13 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | Left Frontage Rd (L): | 0 |
| C: 0 G: 0 K: 0 | Rt Frontage Rd (R): | 0 |
| D: 0 H: 0 T: 0 | HOV Lanes (V): | 0 |
| E: 0 I: 0 | Unknown: | 0 |
| | Total: | 13 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 10 |
| At Driveway Access: | 0 |
| Intersection Related: | 3 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 13 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 11 |
| 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: | 0 |
| Total: | 13 |

ADT: 23,233 **Length: 0.09**



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

CDOT Project # 17221 11/15/2018

Exhibit 2

Job #: 20181115060449

Location: 21A **Begin: 136.56** **End: 136.66** **From: 01/01/2013** **To: 12/31/2015**

| 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: | 4 | 1 | 1 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 4 | 6 | 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: | 13 | 13 | 2 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 6 | 3 | 1 |
| Slowing: | 1 | 1 | 0 |
| Stopped in Traffic: | 0 | 5 | 1 |
| Making Right Turn: | 1 | 1 | 0 |
| Making Left Turn: | 4 | 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 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 13 | 13 | 2 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 3 | 13 | 2 |
| 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: | 5 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 4 | 0 | 0 |
| Total: | 13 | 13 | 2 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 4 | 3 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 1 | 2 | 1 |
| Southeast: | 0 | 1 | 0 |
| South: | 7 | 6 | 1 |
| Southwest: | 0 | 0 | 0 |
| West: | 0 | 1 | 0 |
| Northwest: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 13 | 13 | 2 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 11 | 13 | 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: | 13 | 13 | 2 |

ADT: 23,233 Length: 0.09

Project Information

Project Name: SH 160 Wolf Creek Safety Hair Pin Curve 160.5

Project Description: Upgrades to Truck Ramp, Signing, and Barriers

CDOT Region: 5 Project Def: 17314 County: Mineral

Location: SH 160A Mile Points: 160.00 to 161.00 Length: 1.00

Schedule: Work Start Date: 4/22/2011 Completion Date: 6/21/2012

Problem Description: As described in the Federal Hazard Elimination Program (FHEP) application for this project, the three-year crash history (2007 – 2009) showed that there was a total of 16 truck crashes, with 4 being injury crashes and 12 being PDO crashes.

Improvement Description: Between April 22, 2011 and June 21, 2012, the curve at MP 160.5 had barrier upgrades, signing improvements, and improvements to the truck ramp. The cost of construction was \$575,000.

The FHEP application anticipated that a 60% reduction in fatal and injury crashes and a 25% reduction in property damage only crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 1.62.

Summary and Findings

The analysis of safety before and after the improvements were made on this portion of the corridor shows a reduction in property damage only crashes but an increase in the severity of crashes. In this segment of 2-lane undivided highway, there were 36 total crashes during the three-year period before the improvements were made (2008 – 2010). In the three years after construction (2013 – 2015), the number of crashes decreased to 31, a reduction of 14%. The ADT slightly increased from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a 32% decrease in property damage only crashes, from 25 crashes in the three years before construction to 17 crashes in the three years after construction. The number of injury crashes increased from 11 crashes (12 injuries) in the three years before construction to 13 crashes (14 injuries) in the three years after construction. There were no fatalities in the before period, but there was a single overturning fatality in the after period. However, with an overall decrease in overturning type crashes, this fatality is more likely random than reflective of an actual increase in the probability of overturnings to be injurious or fatal. Since there were no decreases in overall crash numbers, it is not meaningful to attempt to derive a benefit cost ratio for this project as doing so would result in negative values. The result is an improvement that was not justified from the safety improvement or cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 160.00 to 161.00 shows a slight decrease in the number of crashes from 36 during the three-year period (2008 to 2010) before the improvements to 31 during the three-year after period (2013 to 2015) (**Table 1**). However, the number of serious crashes increased in the after period:

- Before (2008 – 2010) – No fatal crashes and 11 injury crashes with 12 injuries
- After (2013 – 2015) – One fatal crash and 13 injury crashes with 14 injuries

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|--------------------------------|--------------------------------|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2013 to 12/31/2015 (3 yr.) |
| AADT | 2,850 vpd | 3,150 vpd |
| Filters: | Non-Intersection | Non-Intersection |
| Total Crashes | 36 (19 Trucks) | 31 (16 Trucks) |
| Fatal Crashes (Fatalities) | 0 (0) | 1 (1) |
| Injury Crashes (Injuries) | 11 (12) | 13 (14) |
| Property Damage Only | 25 | 17 |
| Crash Types: # (%) [significance] | | |
| Overturning | 18 (50.0%) [100.0%] | 13 (41.9%) [100.0%] |
| Fixed Object | 13 (36.1%) | 15 (48.4%) |

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 of safety uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 (**Figure 1**) and for fatal and injury crashes (**Figure 2**) reflect no improvement in the crash record for this project. LOSS was not improved, with a LOSS IV in both the before and after periods for both the frequency and severity of crashes. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes
US 160, MP 160.00 to 161.00
Before: 2008 to 2010 After: 2013 to 2015

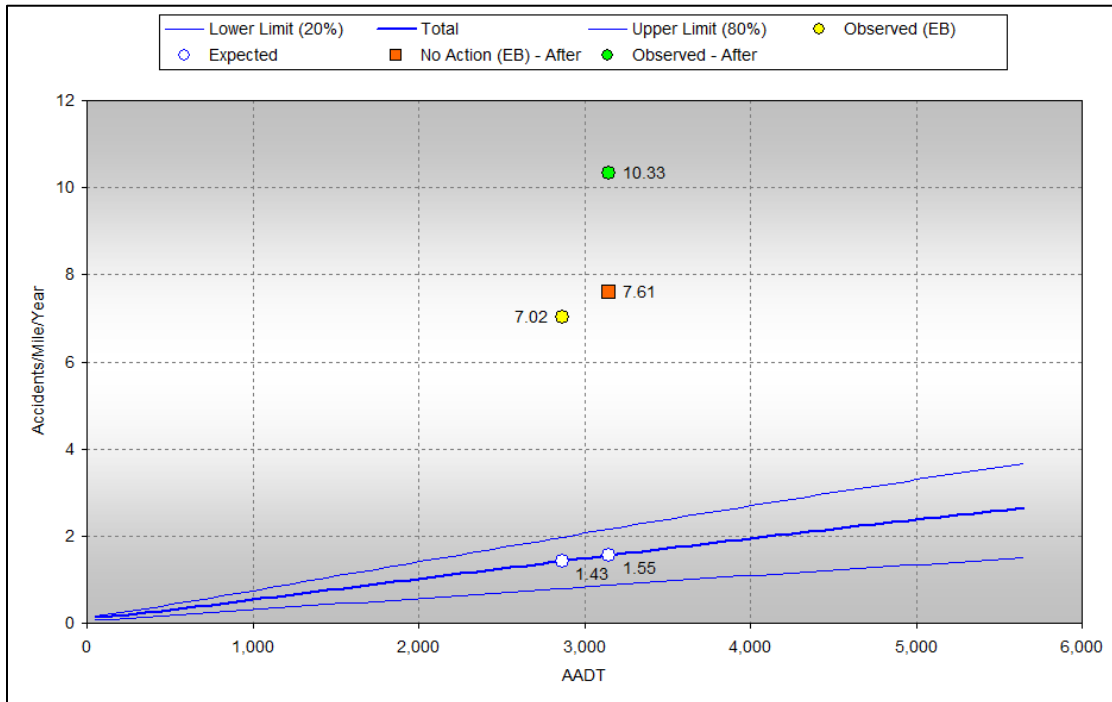


Figure 2 – SPF for Injury and Fatal Crashes

US 160, MP 160.00 to 161.00
 Before: 2008 to 2010 After: 2013 to 2015

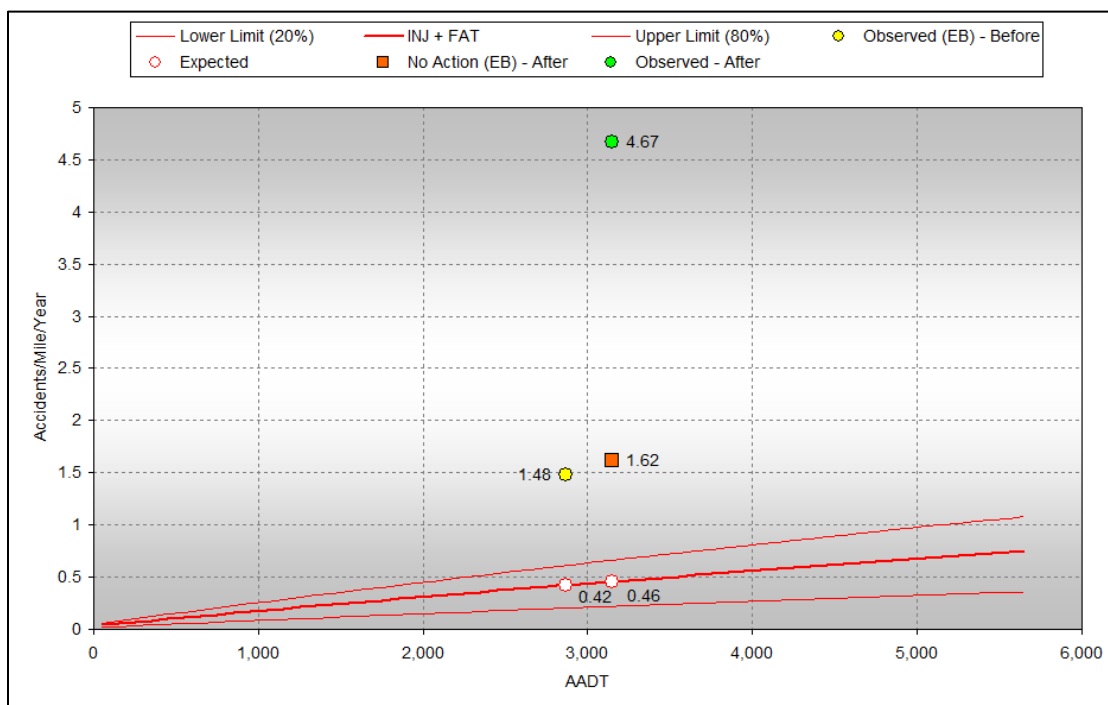


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action After |
|------------------------------------|--|--|--|
| EB Correction: | Yes | No | Yes |
| SPF Graph | Rural Mountainous 2-Lane Undivided Highway | Rural Mountainous 2-Lane Undivided Highway | Rural Mountainous 2-Lane Undivided Highway |
| Total Crashes: | | | |
| LOSS | LOSS IV | LOSS IV | LOSS IV |
| CPY | 7.02 | 10.33 | 7.61 |
| Mean CPY | 1.43 | 1.55 | 1.55 |
| Proportion of Mean | 4.91 | 6.66 | 4.91 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS IV | LOSS IV | LOSS IV |
| CPY | 1.48 | 4.67 | 1.62 |
| Mean CPY | 0.42 | 0.46 | 0.46 |
| Proportion of Mean | 3.52 | 10.15 | 3.52 |

A more detailed review of the before and after crash record shows the crash types that were most affected by the project. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: overturning and fixed object. The improvement appears to have reduced the number of property damage only crashes, but did not reduce severe crashes on the segment. The No-Build After crashes were estimated

using the change in SH 160A traffic volumes between the before and after period, as found in Table 1 (increase is 11% = $|1-(3,150/2,850)|$).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|---|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2013 to 12/31/2015 (3 yr.) | 1/1/2013 to 12/31/2015 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 36 | 31 | 40 |
| Fatal (fatalities) | 0 (0) | 1 (1) | 0 (0) |
| Injury (injuries) | 11 (12) | 13 (14) | 12 (13) |
| PDO | 25 | 17 | 28 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | NA / -8% / 39% | |
| Overtuning – Total | 18 | 13 | 20 |
| Fatal (fatalities) | 0 (0) | 1 (1) | 0 (0) |
| Injury (injuries) | 9 (10) | 9 (10) | 10 (11) |
| PDO | 9 | 3 | 10 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | NA / 0% / 0% | |
| Fixed Object – Total | 13 | 15 | 14 |
| Injury (injuries) | 1 (1) | 4 (4) | 1(1) |
| PDO | 12 | 11 | 13 |
| % Reduction in Total (Injuries/PDO) | | -300% / 15% | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. However, as previously mentioned, it is not meaningful to provide benefit to cost analysis for this case because there was no measurable safety benefit realized from the construction. Therefore, no B/C report is provided for this location.



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

CDOT Project # 17314 11/17/2018
Exhibit 1

Job #: 20181117200810

Location: 160A Begin: 160.00 End: 161.00 From: 01/01/2008 To: 12/31/2010

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 25 | |
| INJ: | 11 | 12 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 36 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 32 |
| Two Vehicles: | 4 |
| Three or More: | 0 |
| Unknown: | 0 |
| Total: | 36 |

Location

| | |
|------------------|-----------|
| On Road: | 17 |
| Off Road Left: | 3 |
| Off Road Right: | 16 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 36 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 22 |
| Dawn or Dusk: | 2 |
| Dark - Lighted: | 0 |
| Dark - Unlighted: | 12 |
| Unknown: | 0 |
| Total: | 36 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 21 |
| Rain: | 1 |
| Snow/Sleet/Hail: | 12 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 2 |
| Unknown: | 0 |
| Total: | 36 |

Crash Rates

| | | |
|---------------|----------------|-------------|
| PDO: | 7.96 * | * MVMT |
| INJ: | 3.50 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 11.47 * | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 18 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 0 | Embankment: | 4 |
| Head On: | 0 | Curb: | 0 |
| Rear End: | 0 | Delineator Post: | 0 |
| Sideswipe (Same): | 0 | Fence: | 0 |
| Sideswipe (Opposite): | 2 | Tree: | 0 |
| Approach Turn: | 0 | Large Boulders or Rocks: | 3 |
| Overtaking Turn: | 0 | Barricade: | 2 |
| 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: | 13 |
| Wild Animal: | 1 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 0 | Vehicle Cargo/Debris: | 0 |
| Traffic Signal Pole: | 0 | Road Maintenance Equipment: | 0 |
| Sign: | 0 | Involving Other Object: | 1 |
| Bridge Rail: | 0 | Total Other Objects: | 1 |
| Guard Rail: | 2 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 36 |
| Concrete Barrier: | 2 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----------------------|------------------------------------|
| Mainline: | 36 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | Left Frontage Rd (L): | 0 |
| C: 0 G: 0 K: 0 | Rt Frontage Rd (R): | 0 |
| D: 0 H: 0 T: 0 | HOV Lanes (V): | 0 |
| E: 0 I: 0 | Unknown: | 0 |
| | Total: | 36 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 36 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 36 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 19 |
| Wet: | 2 |
| Muddy: | 0 |
| Snowy: | 7 |
| Icy: | 6 |
| 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: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 36 |

ADT: 2,867 Length: 0.99



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

CDOT Project # 17314 11/17/2018
Exhibit 1
 Job #: 20181117200810

Location: 160A **Begin: 160.00** **End: 161.00** **From: 01/01/2008** **To: 12/31/2010**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|----------|----------|
| Passenger Car/Van: | 9 | 3 | 0 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 3 | 0 | 0 |
| Pickup Truck/Utility Van w/Trl: | 1 | 0 | 0 |
| SUV: | 4 | 0 | 0 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 19 | 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: | 36 | 4 | 0 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|----------|----------|
| Going Straight: | 22 | 1 | 0 |
| Slowing: | 2 | 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: | 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: | 1 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 10 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 36 | 4 | 0 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|----------|----------|
| No Apparent Contributing Factor: | 20 | 3 | 0 |
| Asleep at the Wheel: | 0 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 8 | 1 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 0 | 0 | 0 |
| Driver Unfamiliar with Area: | 8 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 36 | 4 | 0 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|----------|----------|
| North: | 0 | 0 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 6 | 2 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 0 | 0 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 30 | 2 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 36 | 4 | 0 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|----------|----------|
| No Impairment Suspected: | 35 | 4 | 0 |
| Alcohol Involved: | 0 | 0 | 0 |
| RX, Medication, or Drugs Involved: | 1 | 0 | 0 |
| Illegal Drugs Involved: | 0 | 0 | 0 |
| Alcohol and Drugs Involved: | 0 | 0 | 0 |
| Driver/Pedestrian not Observed: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 36 | 4 | 0 |

ADT: 2,867 **Length: 0.99**



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

CDOT Project # 17314 12/17/2018

Exhibit 2

Job #: 20181217114019

Location: 160A **Begin: 160.00** **End: 161.00** **From: 01/01/2013** **To: 12/31/2015**

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 17 | |
| INJ: | 13 | 14 :Injured |
| FAT: | 1 | 1 :Killed |
| Total: | 31 | |

Crash Type

| | |
|-----------------------|-----------|
| Overtuning: | 13 |
| Other Non Collision: | 0 |
| Pedestrians: | 0 |
| Broadside: | 0 |
| Head On: | 0 |
| Rear End: | 0 |
| Sideswipe Same: | 0 |
| Sideswipe Opposite: | 0 |
| Approach Turn: | 0 |
| Overtaking Turn: | 0 |
| Parked Motor Vehicle: | 1 |
| Railway Vehicle: | 0 |
| Bicycles: | 0 |
| Domestic Animal: | 0 |
| Wild Animal: | 0 |
| Fixed Objects: | 15 |
| Other Objects: | 2 |
| Unknown: | 0 |
| Total: | 31 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 19 |
| Rain: | 0 |
| Snow/Sleet/Hail: | 11 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 1 |
| Unknown: | 0 |
| Total: | 31 |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 29 |
| Two Vehicles: | 2 |
| Three or More: | 0 |
| Unknown: | 0 |
| Total: | 31 |

Road Conditions

| | |
|----------------------|-----------|
| Dry: | 18 |
| Wet: | 1 |
| Muddy: | 0 |
| Snowy: | 8 |
| Icy: | 4 |
| Slushy: | 0 |
| Foreign Material: | 0 |
| With Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 31 |

Location

| | |
|---------------|-----------|
| On Road: | 13 |
| Off Road: | 18 |
| Unknown: | 0 |
| Total: | 31 |

Mainline/Ramps/Frontage Rds

| | |
|----------------------|-----------|
| Mainline: | 31 |
| Ramps: | 0 |
| Frontage/Ramp Intsx: | 0 |
| Frontage Roads: | 0 |
| HOV Lanes: | 0 |
| Unknown: | 0 |
| Total: | 31 |

Vehicle Types

| | Vehicle 1 | Vehicle 2 | Vehicle 3 |
|--------------------------------------|-----------|-----------|-----------|
| Passenger Car/Van: | 7 | 2 | 0 |
| Passenger Car/Van w/Trailer: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 2 | 0 | 0 |
| Pickup Truck/Utility Van w/Trailer: | 1 | 0 | 0 |
| SUV: | 5 | 0 | 0 |
| SUV w/Trailer: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Busses > 15 People: | 16 | 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: | 31 | 2 | 0 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 15 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 0 |
| Dark - Unlighted: | 15 |
| Unknown: | 0 |
| Total: | 31 |

Crash Rates

| | | |
|---------------|--------------|-----------------|
| PDO: | 4.96* | * Per MVMT |
| INJ: | 3.79* | ** Per 100 MVMT |
| FAT: | 29.15** | |
| Total: | 9.04* | |

ADT: 3,133 **Length: 1.00**

Project Information

Project Name: US 40Z Ranney Street Intersection Improvements

Project Description: Signal Upgrade & Geometric Improvements

CDOT Region: 3 Project Def: 17366 County: Moffat

Location: SH 40Z Mile Points: 0.63 Length: N/A

Schedule: Work Start Date: 5/5/2010 Completion Date: 7/2/2010

Problem Description: As described in the Federal Hazard Elimination Program (FHEP) application for this project, the five-year crash history (1998 – 2003) showed that there was a total of 14 crashes, with 2 injury crashes and 12 PDO crashes. Half of these crashes were broadsides, additionally the intersection was noted to have restrictive geometry; its short turning radii had insufficient off-tracking width to accommodate commercial vehicles.

Improvement Description: Between May 5, 2010 and July 2, 2010, the signal was replaced and the geometry was improved. The cost of construction was \$417,807.

The FHEP application anticipated that a 40% reduction in crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 1.07.

Summary and Findings

The analysis of safety before and after the improvements at this intersection shows a reduction in the number of all crash types. There were 11 total crashes during the five-year period before the improvements were made (2005 – 2009). In the five years after construction (2011 – 2015), the number of crashes decreased to two, a reduction of 82%. All crashes in the before and after period were property damage only. The ADT slightly decreased from the before period to the after period.

Although there was a significant crash reduction due to the project, the overall costs of the project outweighed the benefits. This is because all crashes in the before period were property damage only crashes, thus there was limited potential for economic benefit from crash reduction at this location. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 20 years for this project is **0.61** to one. These findings suggest that while a beneficial improvement in safety was observed, it may not have been cost-effective to upgrade the signal.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 0.61 to 0.65 shows a decrease in the number of crashes from 11 during the five-year period (2005 to 2009) before the improvements to two during the five-year after period (2011 to 2015) (**Table 1**). All crashes in the before and after periods were property damage only.

The crash rate at this intersection decreased in the after period:

- Before (2005 – 2009) – 0.47 crashes per million entering vehicles (cpmev)
- After (2011 – 2015) – 0.10 cpmev

It is reasonable to conclude that the observed decrease in the frequency and severity of crashes is related to the various safety improvements constructed on this project.

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2005 to 12/31/2009 (5 yr.) | 1/1/2011 to 12/31/2015 (5 yr.) |
| AADT (SH 40Z/Ranney St) | 9,250 vpd / 3,650 vpd | 8,400 vpd / 2,650 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 11 | 2 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 0 (0) | 0 (0) |
| Property Damage Only | 11 | 2 |
| Crash Types: # (%) [significance] | | |
| Fixed Object | 3 (27.3%) | 0 |
| Rear End | 3 (27.3%) | |
| Broadside | 2 (18.2%) | 1 (50.0%) |
| Sideswipe Same Direction | 1 (9.1%) | 0 |
| Sideswipe Opposite Direction | 1 (9.1%) | 0 |
| Approach Turn | 1 (9.1%) | 1 (50.0%) |

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 intersection, so this analysis could not be completed.

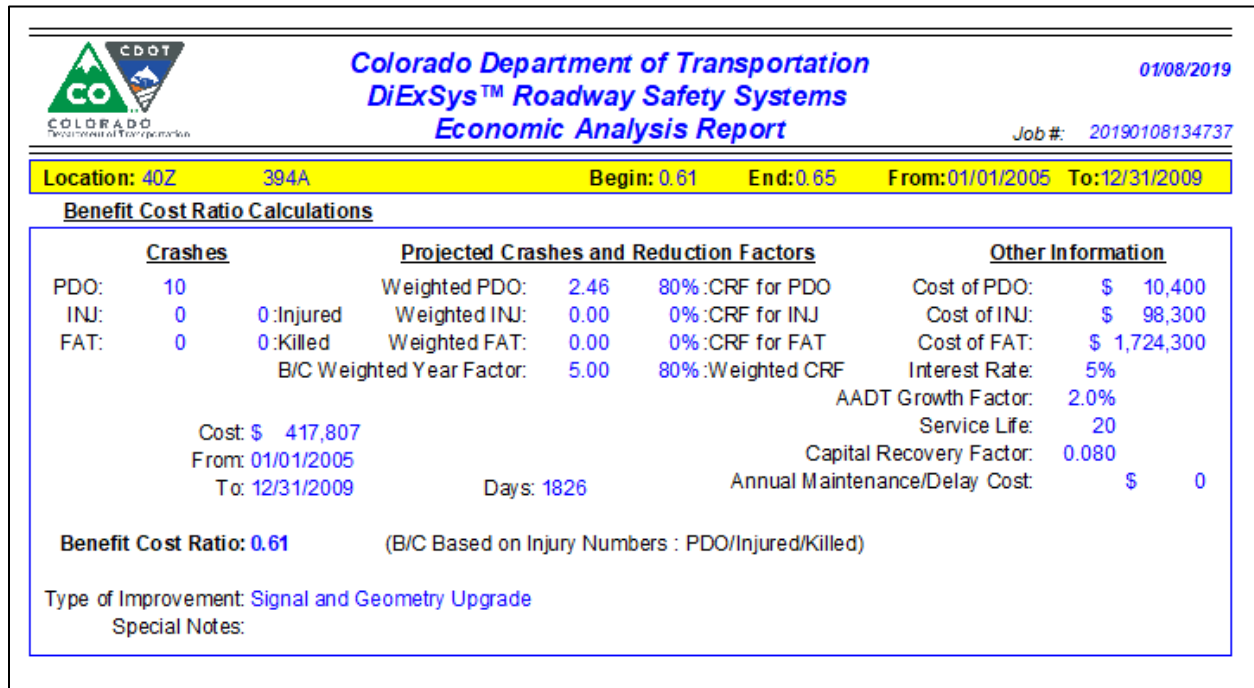
A more detailed review of the before and after crash record shows the crash types that were most affected by the intersection improvements. **Table 2** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: fixed object, broadside, and approach turn. The geometric improvements reduced the number of all crash types other than broadside crashes. The No-Build After crashes were estimated using the change in SH 40Z traffic volumes between the before and after period, as found in **Table 1** (decrease is 9%= |1-(8,400/9,250)|).

Table 2 – Results of Crash Analyses

| | Before | After | No-Build After |
|-------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2005 to 12/31/2009 (5 yr.) | 1/1/2011 to 12/31/2015 (5 yr.) | 1/1/2011 to 12/31/2015 (5 yr.) |
| Crash Types: | | | |
| Total Crashes | 11 | 2 | 10 |
| PDO | 11 | 2 | 10 |
| % Reduction in Total (PDO) | | 80% | |
| Fixed Object – Total | 3 | 0 | 3 |
| PDO | 3 | 0 | 3 |
| % Reduction in Total (PDO) | | 100% | |
| BroadSides – Total | 2 | 1 | 2 |
| PDO | 2 | 1 | 2 |
| % Reduction in Total (PDO) | | 50% | |
| Approach Turns – Total | 1 | 1 | 1 |
| PDO | 1 | 1 | 1 |
| % Reduction in Total (PDO) | | 50% | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 1** for all crashes at the intersection. **A calculated B/C ratio of 0.61 was ultimately realized.** This outcome displays that while there was a notable safety improvement, this safety improvement project was not justified from a cost-effectiveness standpoint.

Figure 1 – Benefit Cost Analysis





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

CDOT Project # 17366 01/08/2019
Exhibit 1
 Job #: 20190108110105

Location: 40Z 394A Begin: 0.61 End: 0.65 From:01/01/2005 To:12/31/2009

Severity

| | | |
|---------------|-----------|------------|
| PDO: | 11 | |
| INJ: | 0 | 0 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 11 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 3 |
| Two Vehicles: | 7 |
| Three or More: | 1 |
| Unknown: | 0 |
| Total: | 11 |

Location

| | |
|------------------|-----------|
| On Road: | 8 |
| Off Road Left: | 1 |
| Off Road Right: | 2 |
| 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: | 9 |
| Rain: | 1 |
| Snow/Sleet/Hail: | 1 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 11 |

Crash Rates

| | | |
|---------------|----------------|-------------|
| PDO: | 13.57 * | * MVMT |
| INJ: | 0.00 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 13.57 * | |

Crash Type

| | | | |
|-----------------------|---|-----------------------------|-----------|
| Overturing: | 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): | 1 | Tree: | 0 |
| Approach Turn: | 1 | Large Boulders or Rocks: | 0 |
| Overtaking Turn: | 0 | Barricade: | 0 |
| Parked Motor Vehicle: | 0 | Wall/Building: | 0 |
| Railway Vehicle: | 0 | Crash Cushion: | 0 |
| Bicycle: | 0 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 1 |
| Domestic Animal: | 0 | Total Fixed Objects: | 3 |
| Wild Animal: | 0 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 2 | 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 | Frontage/Ramp Intersections | | | | |
| Crossroad (A): | 0 | M: | 0 N: | 0 O: | 0 P: | 0 |
| Ramps | | Left Frontage Rd (L): | 0 | | | |
| B: | 0 F: | 0 J: | 0 | Rt Frontage Rd (R): | 0 | |
| C: | 0 G: | 0 K: | 0 | HOV Lanes (V): | 0 | |
| D: | 0 H: | 0 T: | 0 | Unknown: | 0 | |
| E: | 0 I: | 0 | | Total: | 11 | |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 8 |
| At Driveway Access: | 0 |
| Intersection Related: | 3 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 11 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 7 |
| Wet: | 1 |
| 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: | 11 |

ADT: 9,250 Length: 0.04



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

CDOT Project # 17366 01/08/2019

Exhibit 1

Job #: 20190108110105

Location: 40Z 394A Begin: 0.61 End: 0.65 From:01/01/2005 To:12/31/2009

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|----------|----------|
| Passenger Car/Van: | 2 | 0 | 0 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 5 | 6 | 0 |
| Pickup Truck/Utility Van w/Trl: | 1 | 0 | 1 |
| SUV: | 0 | 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: | 1 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 11 | 8 | 1 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|----------|----------|
| Going Straight: | 4 | 4 | 0 |
| Slowing: | 0 | 0 | 0 |
| Stopped in Traffic: | 0 | 4 | 1 |
| Making Right Turn: | 3 | 0 | 0 |
| Making Left Turn: | 3 | 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 | 0 | 0 |
| Changing Lanes: | 0 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 11 | 8 | 1 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|----------|----------|
| No Apparent Contributing Factor: | 4 | 7 | 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: | 1 | 0 | 0 |
| Driver Preoccupied: | 1 | 0 | 0 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 2 | 1 | 0 |
| Total: | 11 | 8 | 1 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|----------|----------|
| North: | 3 | 3 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 1 | 1 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 3 | 2 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 3 | 2 | 1 |
| Northwest: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 11 | 8 | 1 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|----------|----------|
| No Impairment Suspected: | 11 | 8 | 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 | 8 | 1 |

ADT: 9,250 Length: 0.04



Location: 40Z 394A Begin: 0.61 End: 0.65 From:01/01/2011 To:12/31/2015

| Severity | |
|---------------|------------|
| PDO: | 2 |
| INJ: | 0 :Injured |
| FAT: | 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: | 2.90 * * MVMT |
| INJ: | 0.00 * ** 100 MVMT |
| FAT: | 0.00 ** |
| Total: | 2.90 * |

| Crash Type | | | |
|-----------------------|---|-----------------------------|----------|
| Overturing: | 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: | 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: | 2 |
| Concrete Barrier: | 0 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | |
|-------------------------------|---|------------------------------|------------------|
| Mainline: | 2 | M: | 0 N: 0 O: 0 P: 0 |
| Crossroad (A): | 0 | | |
| Ramps | | Left Frontage Rd (L): | 0 |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 |
| D: 0 H: 0 T: 0 | | Unknown: | 0 |
| E: 0 I: 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: | 1 |
| 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: | 2 |

ADT: 8,400 Length: 0.04



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

CDOT Project # 17366 01/08/2019
 Exhibit 2

Job #: 20190108110546

Location: 40Z 394A Begin: 0.61 End: 0.65 From:01/01/2011 To:12/31/2015

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|----------|----------|----------|
| Passenger Car/Van: | 2 | 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 | 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 | 1 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 2 | 2 | 0 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|----------|----------|----------|
| Going Straight: | 1 | 1 | 0 |
| Slowing: | 0 | 0 | 0 |
| Stopped in Traffic: | 0 | 0 | 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 |
| Wrong Way: | 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: | 1 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 0 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 2 | 2 | 0 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|----------|----------|----------|
| North: | 1 | 0 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 0 | 0 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 1 | 1 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 0 | 1 | 0 |
| Northwest: | 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 |

ADT: 8,400 Length: 0.04

Project Information

| | | |
|-----------------------------|---|-----------------------------------|
| Project Name: | SH 45A Goodnight Avenue Intersection Improvements | |
| Project Description: | Upgrade signal, add right turning lane, improve pedestrian crossing | |
| CDOT Region: 2 | <u>Project Def:</u> 17409 | <u>County:</u> Pueblo |
| Location: SH 45A | <u>Mile Points:</u> 5.07 | <u>Length:</u> N/A |
| Schedule: | <u>Work Start Date:</u> 7/19/2010 | <u>Completion Date:</u> 9/29/2010 |

Problem Description: As described in the Federal Hazard Elimination Program (FHEP) application for this project, the five-year crash history (2000 – 2004) showed that there was a total of 13 injury crashes, 17 PDO crashes, and one fatal crash. Of the 31 crashes, 11 were approach turn type crashes and 6 were broadside type crashes.

Improvement Description: Between July 19, 2010 and September 29, 2010, the signal was replaced and a northbound right turn lane was constructed. Additionally, the pedestrian ramps and signal heads were upgraded. The cost of construction was \$633,897.

The FHEP application anticipated that an 24% reduction in crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 1.28.

Summary and Findings

The analysis of safety before and after the improvements at this intersection shows an increase in the number of crashes, with a decrease in the number of injuries. There were 24 total crashes during the three-year period before the improvements were made (2007 – 2009). In the three years after construction (2011 – 2013), the number of crashes increased to 36. The ADT slightly increased from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was no decrease in the total number of crashes for any related crash type due to the completion of the project. There was no decrease in injury crashes, but the number of injuries decrease from 22 injuries in the three years before construction to 16 injuries in the three years after construction. The number of PDO increased from 13 to 23. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 10 years for this project is **1.54** to one. The result is an improvement that was justified from the safety improvement as well as cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 5.02 to 5.12 shows an increase in the number of crashes from 24 during the three-year period (2007 to 2009) before the improvements to 36 during the three-year after period (2011 to 2013) (**Table 1**). The number of serious crashes also showed a slight increase in the after period, although there was a decrease in the number of injuries:

- Before (2007 – 2009) – No fatal crashes and 11 injury crashes with 22 injuries
- After (2011 – 2013) – No fatal crashes and 13 injury crashes with 16 injuries

The crash rate at this intersection also increased in the after period:

- Before (2007 – 2009) – 0.76 crashes per million entering vehicles (cpmev)
- After (2011 – 2013) – 1.09 cpmev

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2011 to 12/31/2013 (3 yr.) |
| AADT (SH 45A/Goodnight Ave) | 25,250 vpd / approx. 3,650 vpd | 26,250 vpd / approx. 3,800 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 24 | 36 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 11 (22) | 13 (16) |
| Property Damage Only | 13 | 23 |
| Crash Types: # (%) [significance] | | |
| Rear-End | 14 (58.3%) | 20 (55.6%) |
| Broadside | 3 (12.5%) | 5 (13.9%) |
| Approach Turn | 3 (12.5%) | 7 (19.4%) |
| Fixed Object | 0 | 4 (11.1%) |

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 (**Figures 1 and 2**) and for fatal and injury crashes (**Figures 3 and 4**) reflect no improvement in the crash record for this project. LOSS went from LOSS III in the before period to LOSS IV in the after period for total crashes. For severe crashes the intersection is LOSS IV in both the before and after periods. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes – Before
SH 45A, MP 5.07
Before: 2007 to 2009 After: 2011 to 2013

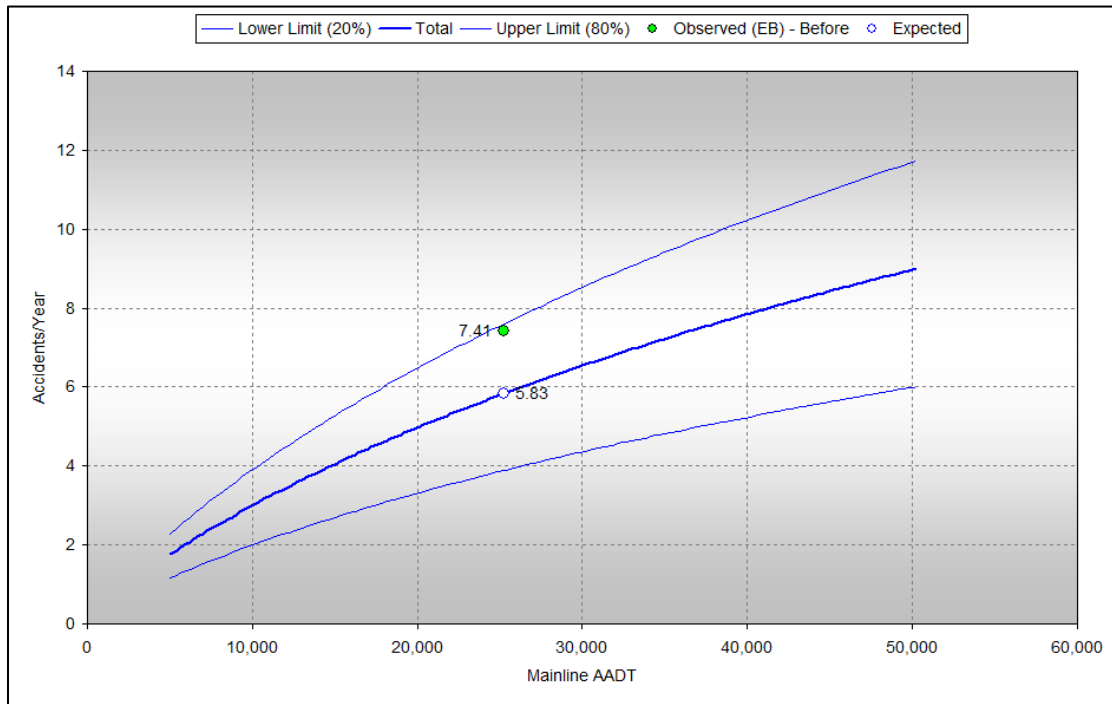


Figure 2 – SPF for Total Crashes – After/No Action After

SH 45A, MP 5.07

Before: 2007 to 2009 After: 2011 to 2013

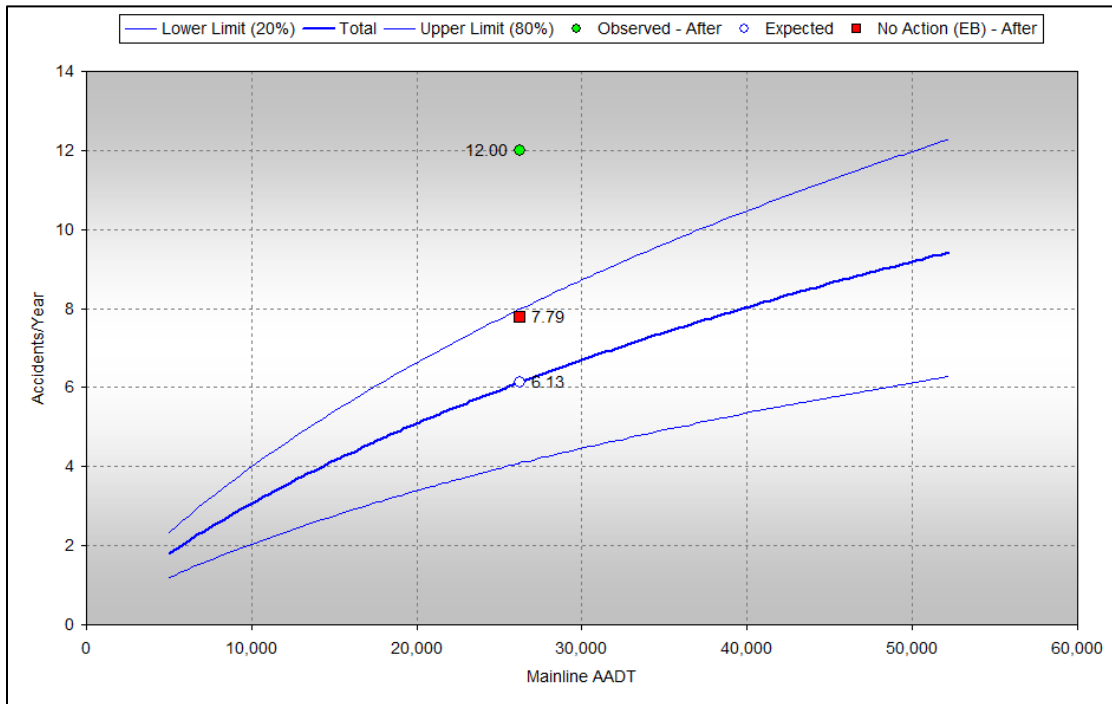


Figure 3 – SPF for Injury and Fatal Crashes – Before

SH 45A, MP 5.07

Before: 2007 to 2009 After: 2011 to 2013

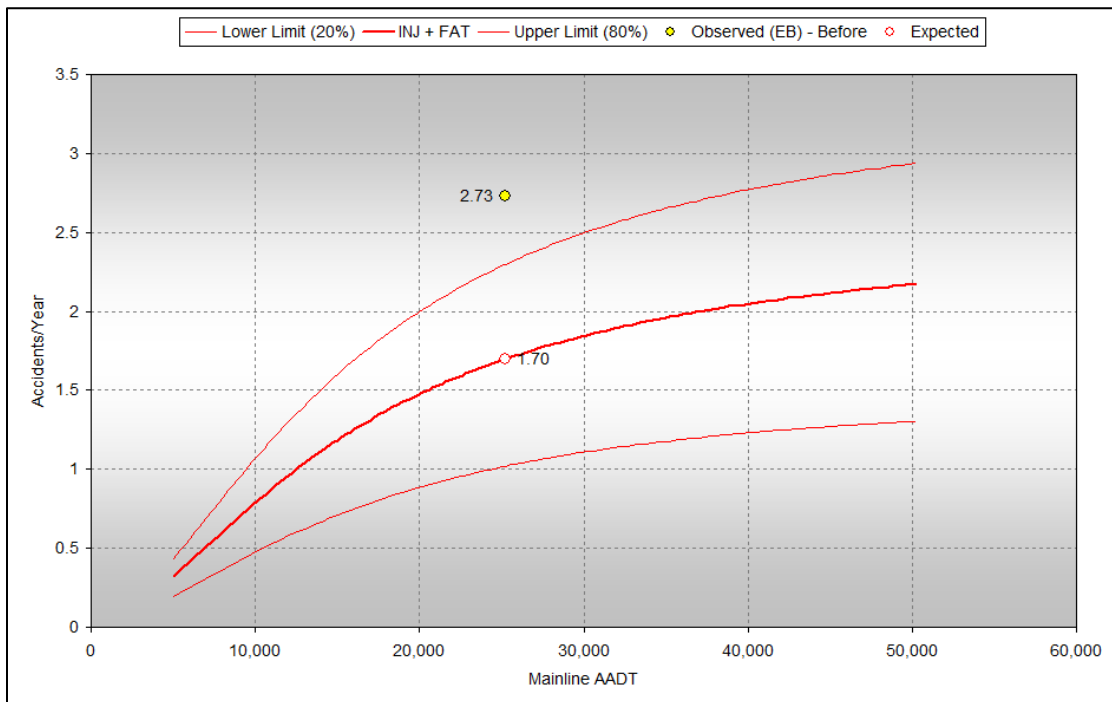


Figure 3 – SPF for Injury and Fatal Crashes – After/No Action After

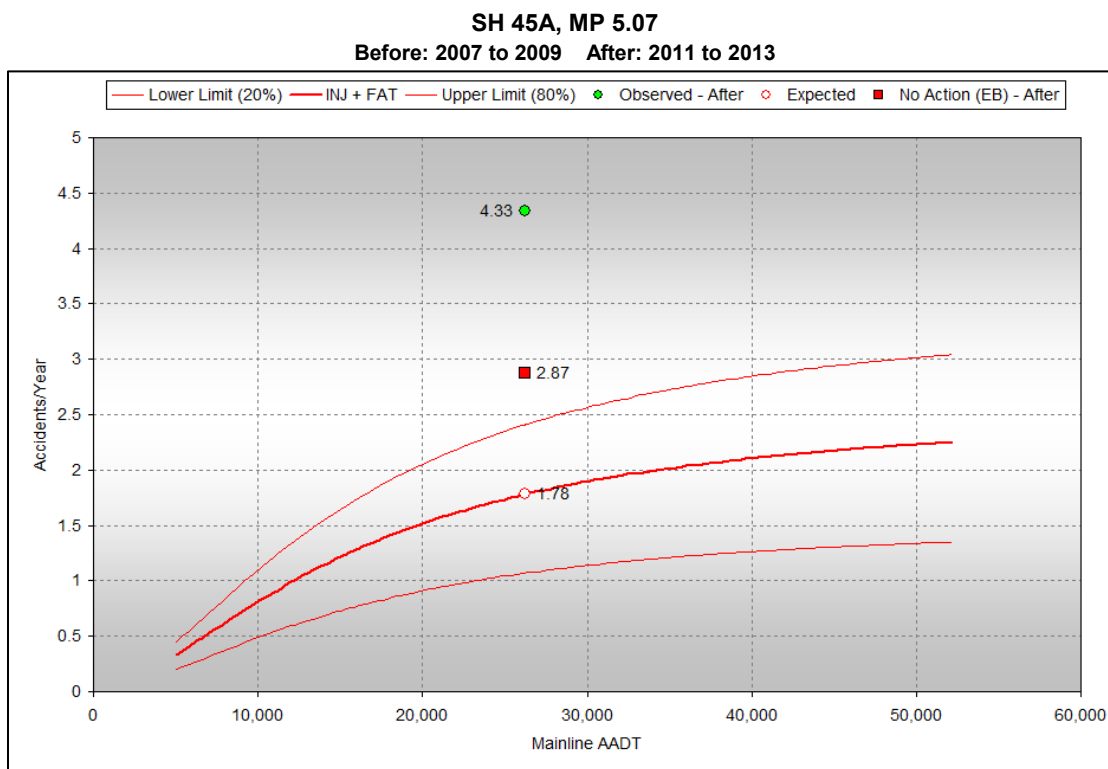


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action 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 | 7.41 | 12.00 | 7.79 |
| Mean CPY | 5.83 | 6.13 | 6.13 |
| Proportion of Mean | 1.27 | 1.96 | 1.27 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS IV | LOSS IV | LOSS IV |
| CPY | 2.73 | 4.33 | 2.87 |
| Mean CPY | 1.70 | 1.78 | 1.78 |
| Proportion of Mean | 1.61 | 2.43 | 1.61 |

A more detailed review of the before and after crash record shows the crash types that were most affected by the signal upgrade. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: rear-end, broadside, and approach turn. After the signal upgrade, all of these crash types had an increase in the number of crashes. However, there was a decrease in the number of injuries resulting from rear-end and approach turn type crashes. Over the design life of 20 years for the improvements,

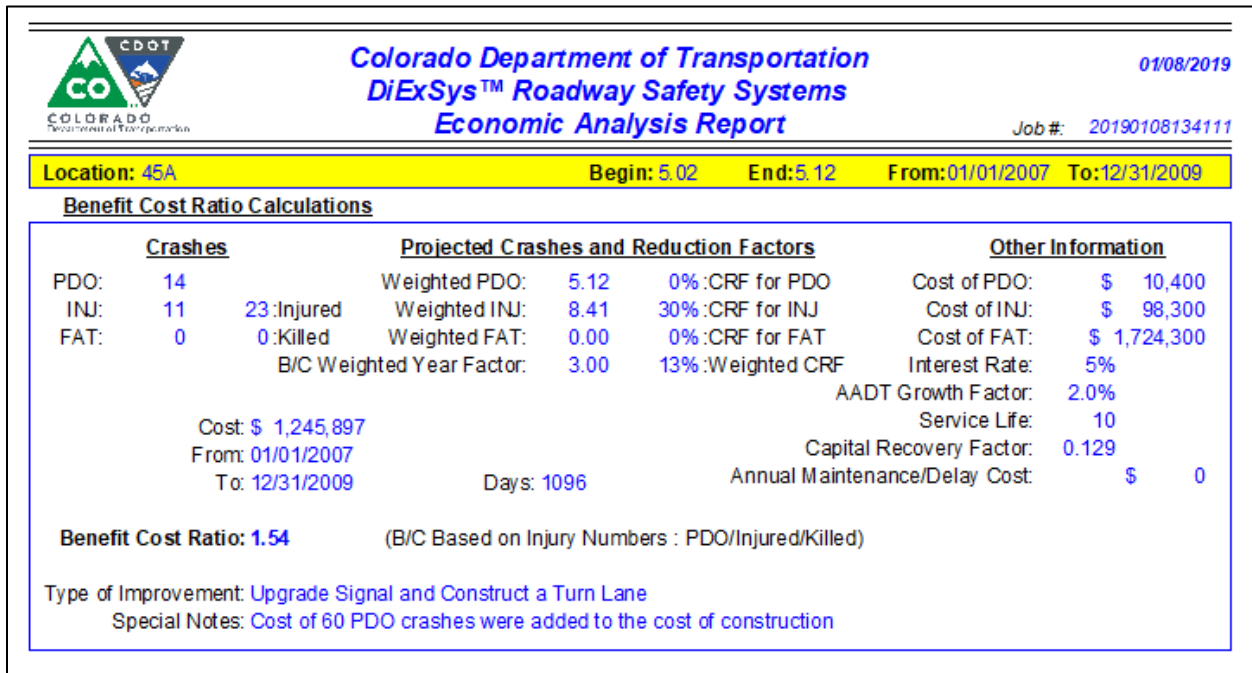
the increased cost of crashes would be \$612,000 (60 PDO = \$612,000). The No-Build After crashes were estimated using the change in SH 45A traffic volumes between the before and after period, as found in **Table 1** (increase is 4% = $|1-(26,250/25,250)|$).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|--|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2011 to 12/31/2013 (3 yr.) | 1/1/2011 to 12/31/2013 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 24 | 36 | 25 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 11 (22) | 13 (16) | 11 (23) |
| PDO | 13 | 23 | 14 |
| % Reduction in Total (Injuries/PDO) | | 30% / -64% | |
| Rear-End – Total | 14 | 20 | 15 |
| Injury (injuries) | 6 (9) | 4 (5) | 6 (9) |
| PDO | 8 | 16 | 9 |
| % Reduction in Total (Injuries/PDO) | | 44% / -78% | |
| Broadside – Total | 3 | 5 | 3 |
| Injury (injuries) | 1 (2) | 4 (4) | 1 (2) |
| PDO | 2 | 1 | 2 |
| % Reduction in Total (Injuries/PDO) | | -100% / -100% | |
| Approach Turn – Total | 3 | 7 | 3 |
| Injury (injuries) | 3 (10) | 3 (6) | 3 (10) |
| PDO | 0 | 3 | 0 |
| % Reduction in Total (Injuries/PDO) | | 40% / NA | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 1.54 was ultimately realized.** This outcome displays that while crashes overall increased, this safety improvement project was justified from a cost-effectiveness standpoint due to the notable decrease in persons injured.

Figure 5 – Benefit Cost Analysis



Examining safety performance at this intersection over a 10-year period (2007-2016), there is an observed significant improvement in safety performance beginning in 2014 (Figures 6, 7 and 8). It is recommended that Region 2 be contacted to learn what operational changes may have been made that can explain the improvement; this information would likely be extremely useful.

Figure 6 – Cumulative Crashes Over 10 Years

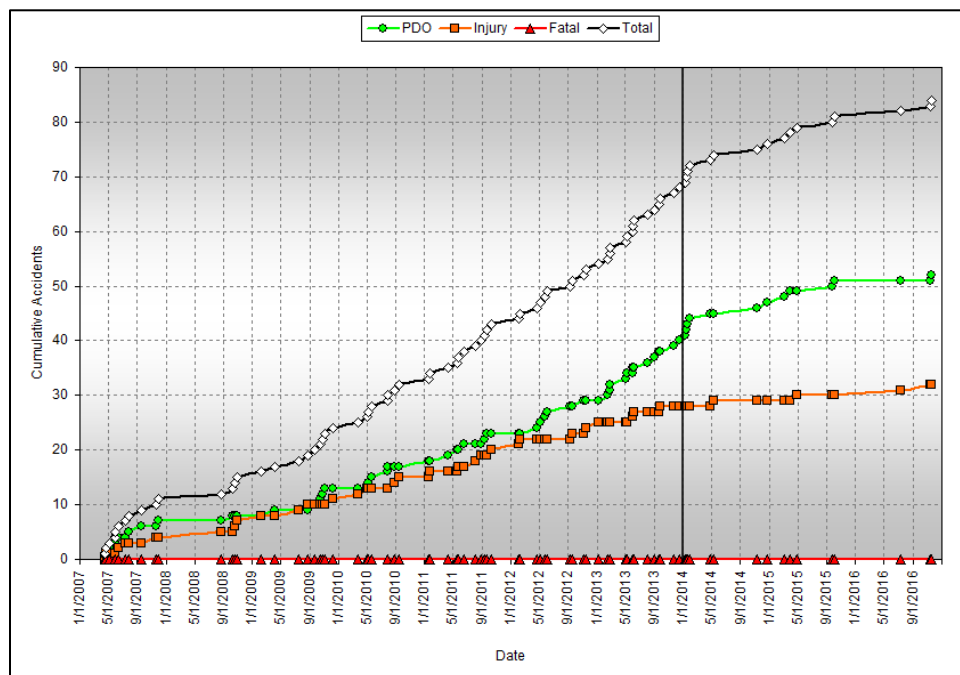


Figure 7 – SPF for Total Crashes - SH 45A, MP 5.07

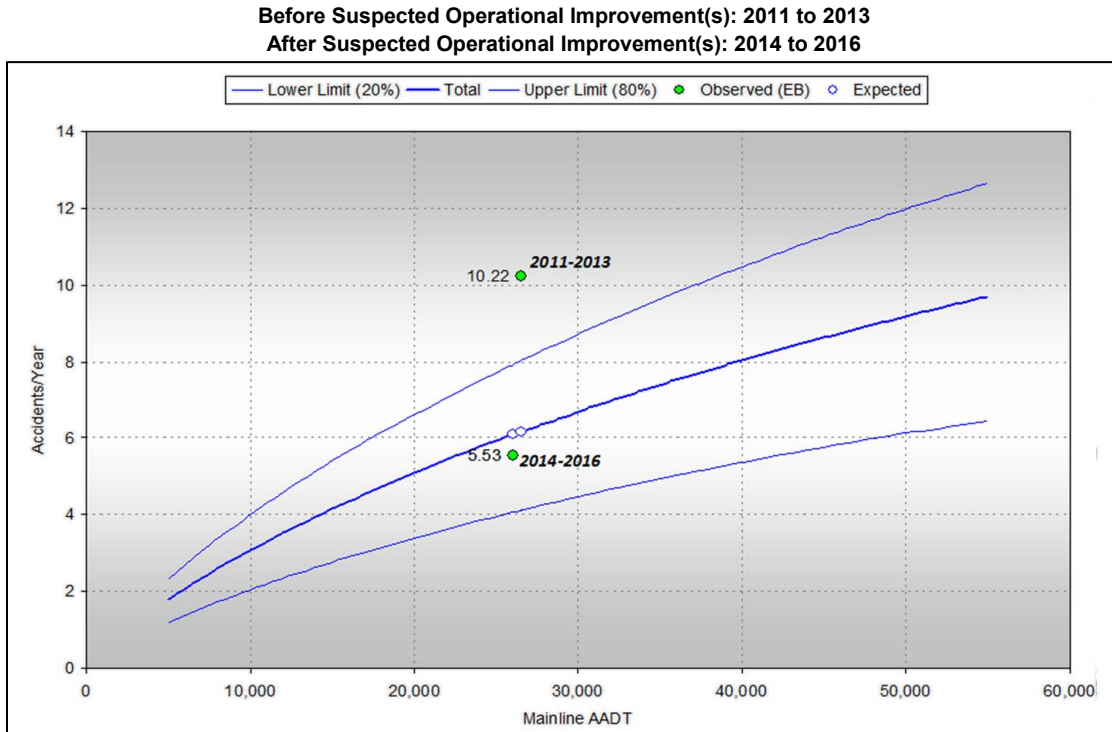
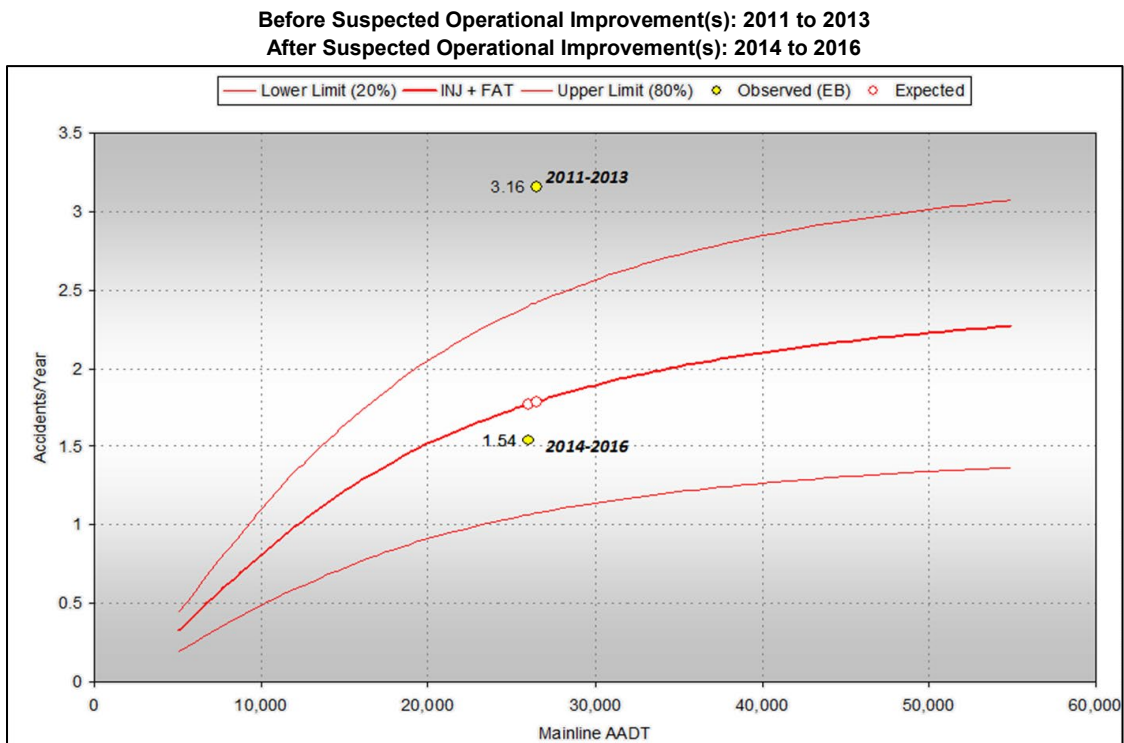


Figure 8 – SPF for Injury and Fatal Crashes - SH 45A, MP 5.07





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

CDOT Project # 17409 12/18/2018
Exhibit 1

Job #: 20181218102044

Location: 45A Begin: 5.02 End: 5.12 From:01/01/2007 To:12/31/2009

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 13 | |
| INJ: | 11 | 22 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 24 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 2 |
| Two Vehicles: | 18 |
| Three or More: | 4 |
| Unknown: | 0 |
| Total: | 24 |

Location

| | |
|------------------|-----------|
| On Road: | 24 |
| Off Road Left: | 0 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 24 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 16 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 6 |
| Dark - Unlighted: | 0 |
| Unknown: | 1 |
| Total: | 24 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 19 |
| Rain: | 4 |
| Snow/Sleet/Hail: | 1 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 24 |

Crash Rates

| | | |
|---------------|--------------|-------------|
| PDO: | 3.59* | * MVMT |
| INJ: | 3.03* | ** 100 MVMT |
| FAT: | 0.00** | |
| Total: | 6.62* | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 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: | 14 | Delineator Post: | 0 |
| Sideswipe (Same): | 1 | Fence: | 0 |
| Sideswipe (Opposite): | 0 | Tree: | 0 |
| Approach Turn: | 3 | Large Boulders or Rocks: | 0 |
| Overtaking Turn: | 1 | Barricade: | 0 |
| Parked Motor Vehicle: | 0 | Wall/Building: | 0 |
| Railway Vehicle: | 0 | Crash Cushion: | 0 |
| Bicycle: | 0 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 0 |
| Domestic Animal: | 0 | Total Fixed Objects: | 0 |
| Wild Animal: | 1 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 0 | Vehicle Cargo/Debris: | 0 |
| Traffic Signal Pole: | 0 | Road Maintenance Equipment: | 0 |
| Sign: | 0 | Involving Other Object: | 0 |
| Bridge Rail: | 0 | Total Other Objects: | 0 |
| Guard Rail: | 0 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 24 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|----|------------------------------------|
| Mainline: | 24 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | | Left Frontage Rd (L): 0 |
| C: 0 G: 0 K: 0 | | Rt Frontage Rd (R): 0 |
| D: 0 H: 0 T: 0 | | HOV Lanes (V): 0 |
| E: 0 I: 0 | | Unknown: 0 |
| | | Total: 24 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 16 |
| At Driveway Access: | 0 |
| Intersection Related: | 8 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 24 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 18 |
| 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: | 0 |
| Total: | 24 |

ADT: 25,248 Length: 0.13



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

CDOT Project # 17409 12/18/2018
 Exhibit 1

Job #: 20181218102044

Location: 45A **Begin: 5.02** **End: 5.12** **From:01/01/2007** **To:12/31/2009**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 19 | 11 | 1 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 2 | 3 | 1 |
| Pickup Truck/Utility Van w/Trl: | 0 | 1 | 0 |
| SUV: | 1 | 7 | 2 |
| 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: | 24 | 22 | 4 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 14 | 11 | 0 |
| Slowing: | 1 | 3 | 1 |
| Stopped in Traffic: | 0 | 7 | 3 |
| Making Right Turn: | 2 | 0 | 0 |
| Making Left Turn: | 5 | 1 | 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: | 1 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 24 | 22 | 4 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 17 | 22 | 4 |
| Asleep at the Wheel: | 0 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 3 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 1 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 3 | 0 | 0 |
| Total: | 24 | 22 | 4 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 6 | 10 | 1 |
| Northeast: | 0 | 0 | 0 |
| East: | 1 | 0 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 15 | 12 | 3 |
| Southwest: | 0 | 0 | 0 |
| West: | 2 | 0 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 24 | 22 | 4 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 20 | 22 | 4 |
| 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: | 24 | 22 | 4 |

ADT: 25,248 Length: 0.13



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

CDOT Project # 17409 12/18/2018

Exhibit 2

Job #: 20181218102728

Location: 45A **Begin: 5.02** **End: 5.12** **From:01/01/2011** **To:12/31/2013**

| Severity | |
|---------------|---------------------|
| PDO: | 23 |
| INJ: | 13 16 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 36 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 4 |
| Two Vehicles: | 31 |
| Three or More: | 1 |
| Unknown: | 0 |
| Total: | 36 |

| Location | |
|------------------|-----------|
| On Road: | 32 |
| Off Road Left: | 1 |
| Off Road Right: | 3 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 36 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 31 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 3 |
| Dark - Unlighted: | 1 |
| Unknown: | 0 |
| Total: | 36 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 32 |
| Rain: | 1 |
| Snow/Sleet/Hail: | 2 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 1 |
| Unknown: | 0 |
| Total: | 36 |

| Crash Rates | |
|---------------|-------------------------|
| PDO: | 6.10 * * MVMT |
| INJ: | 3.45 * ** 100 MVMT |
| FAT: | 0.00 ** |
| Total: | 9.55 * |

| Crash Type | |
|-----------------------------|-----------|
| Overtuning: | 0 |
| Other Non Collision: | 0 |
| Pedestrians: | 0 |
| Broadside: | 5 |
| Head On: | 0 |
| Rear End: | 20 |
| Sideswipe (Same): | 0 |
| Sideswipe (Opposite): | 0 |
| Approach Turn: | 7 |
| Overtaking Turn: | 0 |
| Parked Motor Vehicle: | 0 |
| Railway Vehicle: | 0 |
| Bicycle: | 0 |
| Motorized Bicycle: | 0 |
| Domestic Animal: | 0 |
| Wild Animal: | 0 |
| Light/Utility Pole: | 0 |
| Traffic Signal Pole: | 1 |
| Sign: | 0 |
| Bridge Rail: | 0 |
| Guard Rail: | 0 |
| Cable Rail: | 0 |
| Concrete Barrier: | 0 |
| Bridge Abutment: | 0 |
| Column/Pier: | 0 |
| Culvert/Headwall: | 0 |
| Embankment: | 0 |
| Curb: | 2 |
| Delineator Post: | 0 |
| Fence: | 0 |
| Tree: | 1 |
| Large Boulders or Rocks: | 0 |
| Barricade: | 0 |
| Wall/Building: | 0 |
| Crash Cushion: | 0 |
| Mailbox: | 0 |
| Other Fixed Object: | 0 |
| Total Fixed Objects: | 4 |
| Rocks in Roadway: | 0 |
| Vehicle Cargo/Debris: | 0 |
| Road Maintenance Equipment: | 0 |
| Involving Other Object: | 0 |
| Total Other Objects: | 0 |
| Unknown: | 0 |
| Total: | 36 |

| Mainline/Ramps/Frontage Roads | |
|------------------------------------|-----------|
| Mainline: | 36 |
| Crossroad (A): | 0 |
| Ramps | |
| B: 0 F: 0 J: 0 | |
| C: 0 G: 0 K: 0 | |
| D: 0 H: 0 T: 0 | |
| E: 0 I: 0 | |
| Frontage/Ramp Intersections | |
| M: 0 N: 0 O: 0 P: 0 | |
| Left Frontage Rd (L): | 0 |
| Rt Frontage Rd (R): | 0 |
| HOV Lanes (V): | 0 |
| Unknown: | 0 |
| Total: | 36 |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 27 |
| At Driveway Access: | 0 |
| Intersection Related: | 9 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 36 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 33 |
| Wet: | 2 |
| Muddy: | 0 |
| Snowy: | 0 |
| Icy: | 1 |
| Slushy: | 0 |
| Foreign Material: | 0 |
| With Road Treatment: | 0 |
| Dry w/Icy Road Treatment: | 0 |
| Wet w/Icy Road Treatment: | 0 |
| Snowy w/Icy Road Treatment: | 0 |
| Icy w/Icy Road Treatment: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 36 |

ADT: 26,252 Length: 0.13



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

CDOT Project # 17409 12/18/2018
 Exhibit 2

Job #: 20181218102728

Location: 45A **Begin: 5.02** **End: 5.12** **From:01/01/2011** **To:12/31/2013**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 21 | 21 | 0 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 7 | 4 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 1 | 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: | 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: | 5 | 0 | 1 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 36 | 32 | 1 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 20 | 11 | 0 |
| Slowing: | 3 | 3 | 0 |
| Stopped in Traffic: | 0 | 13 | 1 |
| Making Right Turn: | 4 | 1 | 0 |
| Making Left Turn: | 7 | 2 | 0 |
| Making U-Turn: | 0 | 0 | 0 |
| Passing: | 0 | 1 | 0 |
| Backing: | 2 | 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 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 1 | 0 |
| Total: | 36 | 32 | 1 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 28 | 32 | 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: | 1 | 0 | 0 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 1 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 5 | 0 | 0 |
| Total: | 36 | 32 | 1 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 5 | 8 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 2 | 1 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 19 | 18 | 1 |
| Southwest: | 0 | 0 | 0 |
| West: | 10 | 4 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 1 | 0 |
| Total: | 36 | 32 | 1 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 33 | 32 | 1 |
| 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: | 36 | 32 | 1 |

ADT: 26,252 Length: 0.13

Project Information

Project Name: SH 50B @ Bonforte Boulevard Intersection Improvements

Project Description: Extend westbound acceleration lane and install guardrail

CDOT Region: 2 Project Def: 17410 County: Pueblo

Location: SH 50B Mile Points: 316.55 Length: N/A

Schedule: Work Start Date: 8/18/2010 Completion Date: 10/26/2010

Problem Description: As described in the Federal Hazard Elimination Program (FHEP) application for this project, the five-year crash history (2001 – 2005) showed that there was a total of 134 crashes. There were 16 PDO and 10 injury crashes that were westbound rear-end or sideswipe same direction type crashes.

Improvement Description: Between August 18, 2010 and October 26, 2010, the westbound acceleration lane was extended and guardrail was installed. The cost of construction was \$578,577.

The FHEP application anticipated that an 35% reduction in crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 1.36.

Summary and Findings

The analysis of safety before and after the improvements at this intersection shows a decrease in the number of crashes. There were 65 total crashes during the three-year period before the improvements were made (2007 – 2009). In the three years after construction (2011 – 2013), the number of crashes decreased to 54. The ADT slightly decreased from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a slight decrease in the total number of crashes for any related crash type after the completion of the project. There was also a slight decrease in injury crashes, with injuries decreasing from 23 in the before period to 21 in the after period. The number of PDO decreased from 48 to 40. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 20 years for this project is 0.35 to one. The result is an improvement that was not justified from the cost effectiveness standpoint.

This intersection is not congested and has fairly good geometrics, yet it is not performing well from the safety standpoint even after construction. We recommend that Region staff examines its traffic signal phasing, timing and yellow plus all red intervals to find a possible explanation for its performance well above the mean predicted by the frequency and severity SPFs.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 316.30 to 316.70 shows a decrease in the number of crashes from 65 during the three-year period (2007 to 2009) before the improvements to 54 during the three-year after period (2011 to 2013) (**Table 1**). The number of serious crashes also showed a slight decrease in the after period:

- Before (2007 – 2009) – No fatal crashes and 17 injury crashes with 23 injuries
- After (2011 – 2013) – No fatal crashes and 14 injury crashes with 21 injuries

The crash rate at this intersection also decreased slightly in the after period:

- Before (2007 – 2009) – 1.43 crashes per million entering vehicles (cpmev)
- After (2011 – 2013) – 1.41 cpmev

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2011 to 12/31/2013 (3 yr.) |
| AADT (SH 50B/Bonforte Blvd.) | 25,540 vpd / approx. 16,000 vpd | 22,880 vpd / approx. 12,200 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 65 | 54 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 17 (23) | 14 (21) |
| Property Damage Only | 48 | 40 |
| Crash Types: # (%) [significance] | | |
| Rear-End | 35 (53.8%) | 34 (63.0%)[98.07%] |
| Sideswipe Same Direction | 9 (13.8%) | 3 (5.6%) |
| Approach Turn | 9 (13.8%) | 5 (9.3%) |
| Broadside | 7 (10.8%) | 3 (5.6%) |

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 are shown for both total crashes (**Figures 1 and 2**) and for fatal and injury crashes (**Figures 3 and 4**). Total crash LOSS remained LOSS IV in the before and after periods. For severe crashes, the intersection went from LOSS III in the before period to LOSS IV in the after period. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes – Before
SH 50B, MP 316.55
Before: 2007 to 2009 After: 2011 to 2013

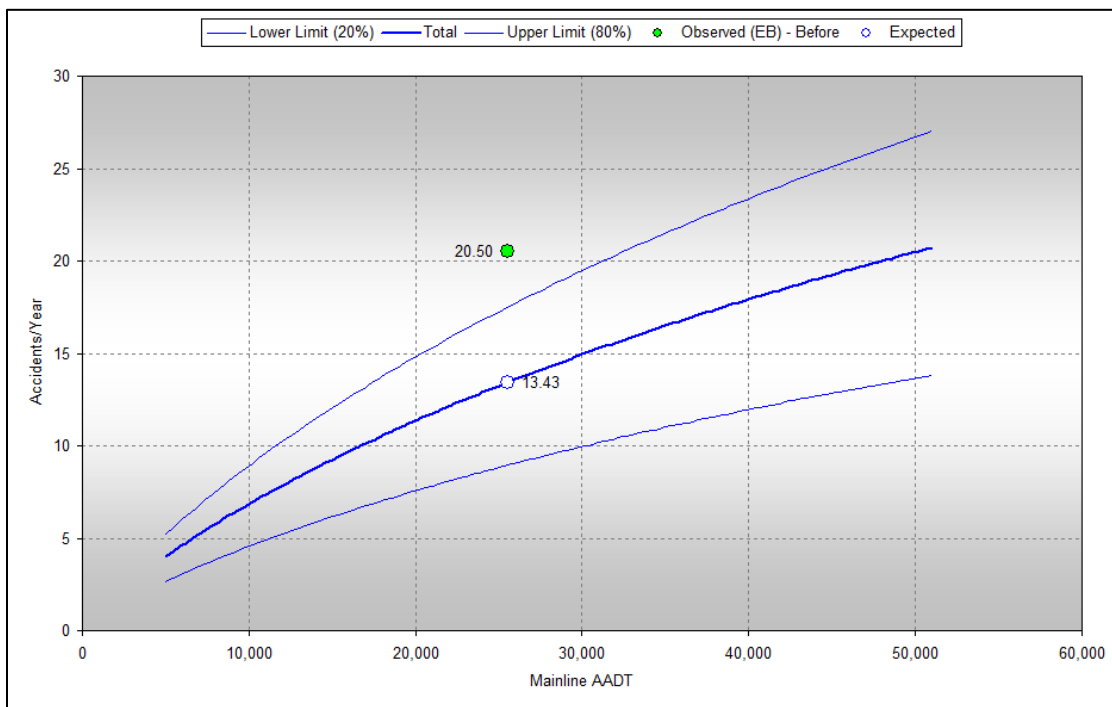


Figure 2 – SPF for Total Crashes – After/No Action After

SH 50B, MP 316.55

Before: 2007 to 2009 After: 2011 to 2013

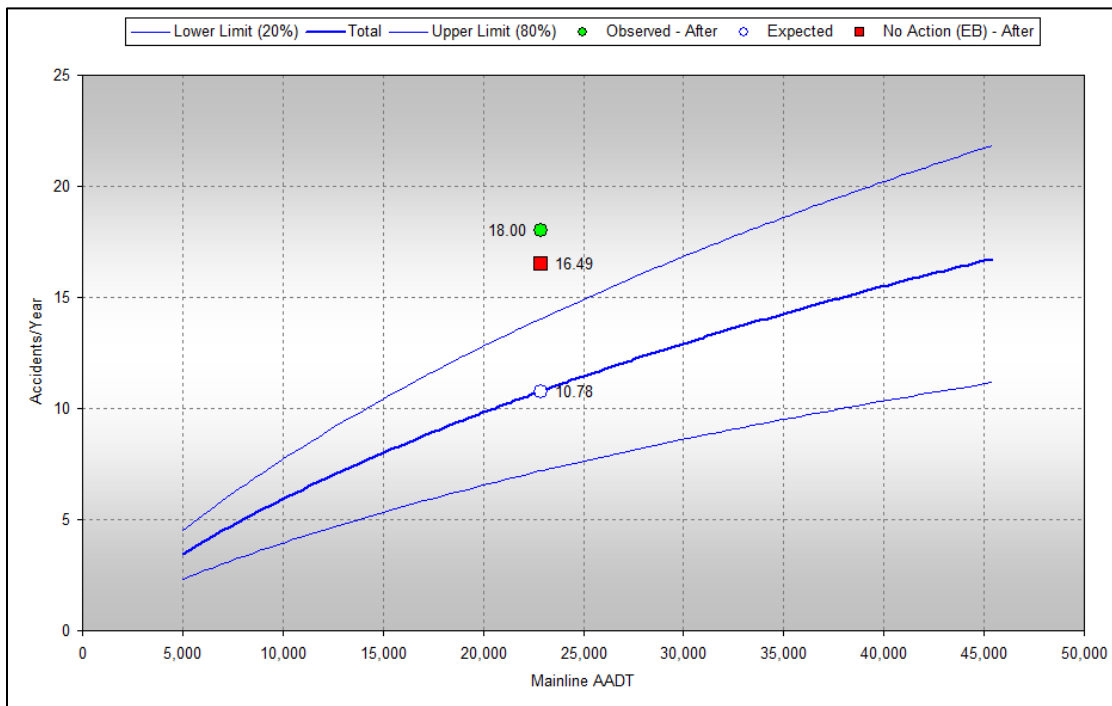


Figure 3 – SPF for Injury and Fatal Crashes – Before

SH 50B, MP 316.55

Before: 2007 to 2009 After: 2011 to 2013

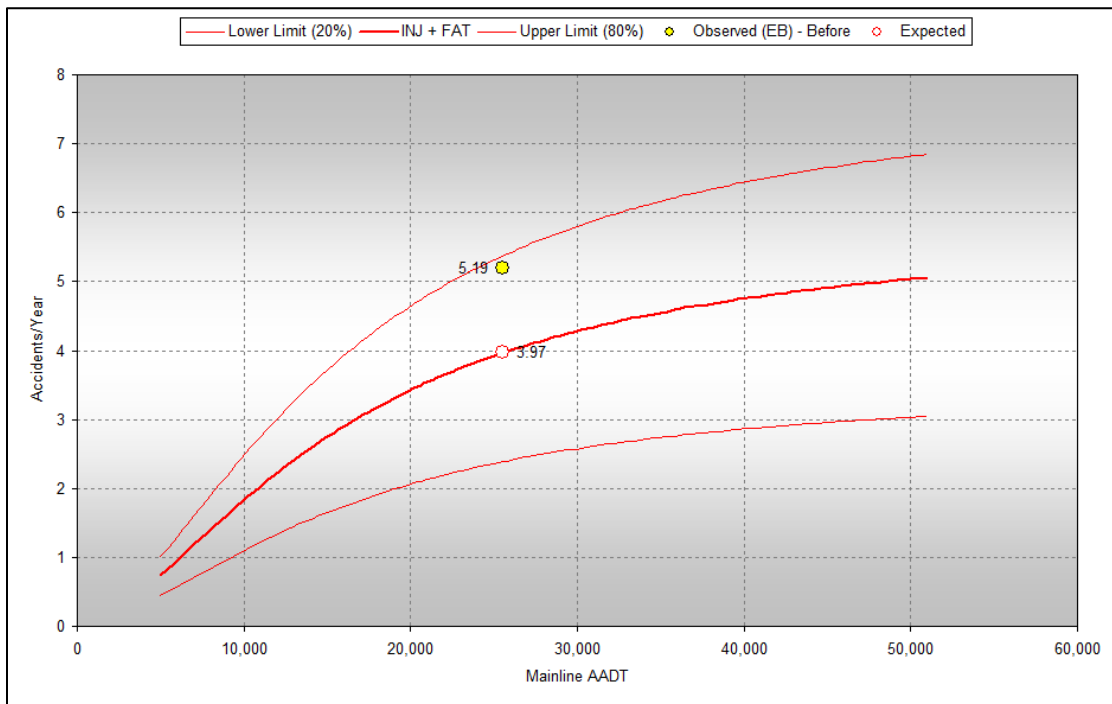


Figure 3 – SPF for Injury and Fatal Crashes – After/No Action After

SH 50B, MP 316.55

Before: 2007 to 2009 After: 2011 to 2013

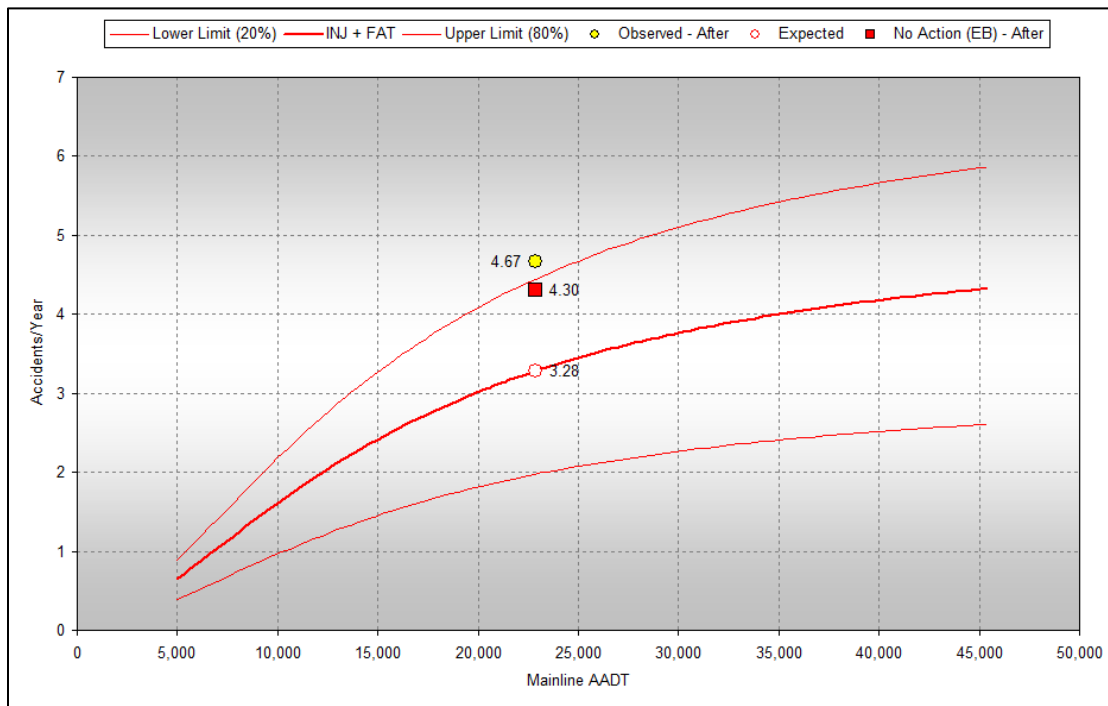


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action 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 | 20.50 | 18.00 | 16.49 |
| Mean CPY | 13.43 | 10.78 | 10.78 |
| Proportion of Mean | 1.53 | 1.67 | 1.53 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS III | LOSS IV | LOSS III |
| CPY | 5.19 | 4.67 | 4.30 |
| Mean CPY | 3.97 | 3.28 | 3.28 |
| Proportion of Mean | 1.31 | 1.42 | 1.31 |

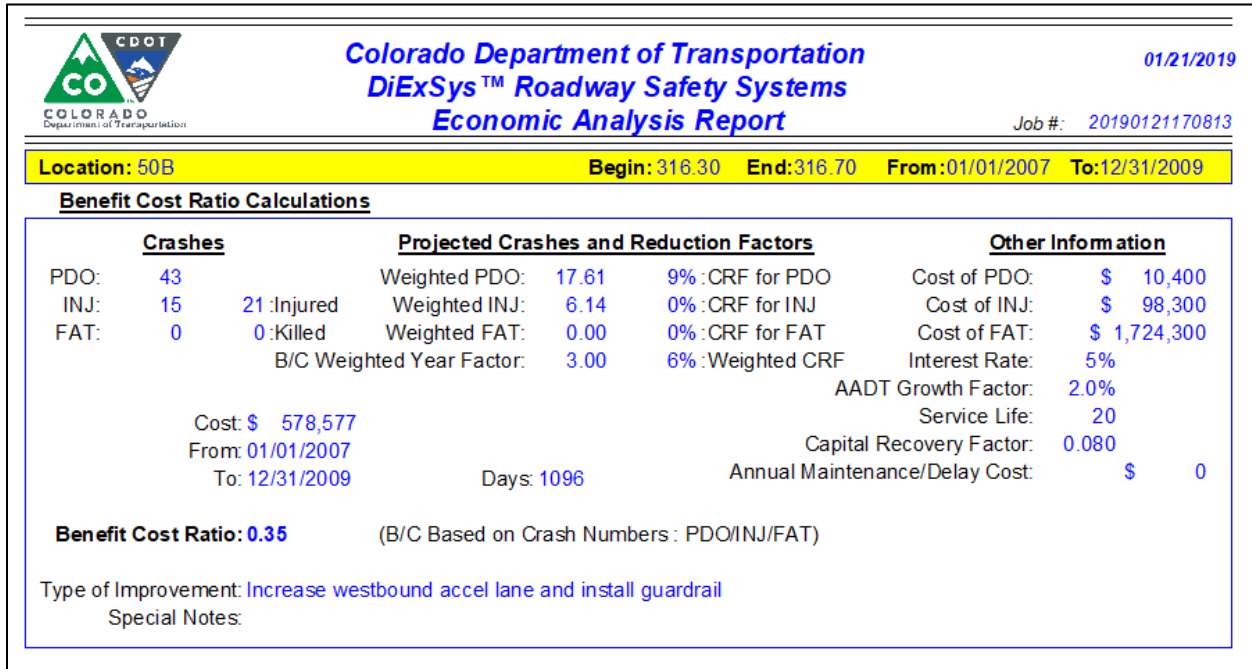
A more detailed review of the before and after crash record shows the crash types that were most affected by the improvements. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: rear-end and sideswipe same direction. After construction, these crash types had a decrease in the number of crashes. The No-Build After crashes were estimated using the change in SH 50B traffic volumes between the before and after period, as found in **Table 1** (decrease is 10% = $|1-(22,880/25,540)|$).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|--|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2011 to 12/31/2013 (3 yr.) | 1/1/2011 to 12/31/2013 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 65 | 54 | 58 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 17 (23) | 14 (21) | 15 (21) |
| PDO | 48 | 40 | 43 |
| % Reduction in Total (Injuries/PDO) | | 0% / 9% | |
| Rear-End – Total | 35 | 34 | 31 |
| Injury (injuries) | 8(10) | 6(7) | 7 (9) |
| PDO | 27 | 28 | 24 |
| % Reduction in Total (Injuries/PDO) | | 22% / -17% | |
| Sideswipe Same Direction– Total | 8 | 3 | 7 |
| Injury (injuries) | 1 (2) | 0(0) | 1 (2) |
| PDO | 9 | 3 | 8 |
| % Reduction in Total (Injuries/PDO) | | 100% / 63% | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 0.35 was ultimately realized.** This outcome displays that while crashes overall decreased, this safety improvement project was not justified from a cost-effectiveness standpoint.

Figure 5 – Benefit Cost Analysis





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

CDOT Project # 17410 01/21/2019

Exhibit 1

Job #: 20190121151926

Location: 50B **Begin: 316.30** **End: 316.70** **From: 01/01/2007** **To: 12/31/2009**

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 48 | |
| INJ: | 17 | 23 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 65 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 2 |
| Two Vehicles: | 59 |
| Three or More: | 4 |
| Unknown: | 0 |
| Total: | 65 |

Location

| | |
|------------------|-----------|
| On Road: | 63 |
| Off Road Left: | 1 |
| Off Road Right: | 1 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 65 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 47 |
| Dawn or Dusk: | 4 |
| Dark - Lighted: | 14 |
| Dark - Unlighted: | 0 |
| Unknown: | 0 |
| Total: | 65 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 59 |
| Rain: | 4 |
| Snow/Sleet/Hail: | 2 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 65 |

Crash Rates

| | | |
|---------------|---------------|-------------|
| PDO: | 4.00 * | * MVMT |
| INJ: | 1.42 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 5.41 * | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overturing: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 2 | Culvert/Headwall: | 0 |
| Broadside: | 7 | Embankment: | 0 |
| Head On: | 0 | Curb: | 0 |
| Rear End: | 35 | Delineator Post: | 0 |
| Sideswipe (Same): | 9 | Fence: | 0 |
| Sideswipe (Opposite): | 1 | Tree: | 0 |
| Approach Turn: | 9 | Large Boulders or Rocks: | 0 |
| Overtaking Turn: | 0 | Barricade: | 0 |
| Parked Motor Vehicle: | 0 | Wall/Building: | 0 |
| Railway Vehicle: | 0 | Crash Cushion: | 0 |
| Bicycle: | 0 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 0 |
| Domestic Animal: | 0 | Total Fixed Objects: | 2 |
| Wild Animal: | 0 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 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: | 65 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----------------------|------------------------------------|
| Mainline: | 65 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | Left Frontage Rd (L): | 0 |
| C: 0 G: 0 K: 0 | Rt Frontage Rd (R): | 0 |
| D: 0 H: 0 T: 0 | HOV Lanes (V): | 0 |
| E: 0 I: 0 | Unknown: | 0 |
| | Total: | 65 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 43 |
| At Driveway Access: | 0 |
| Intersection Related: | 22 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 65 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 54 |
| Wet: | 6 |
| Muddy: | 0 |
| Snowy: | 1 |
| Icy: | 2 |
| 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: | 1 |
| Total: | 65 |

ADT: 25,543 **Length: 0.42**



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

CDOT Project # 17410 01/21/2019

Exhibit 1

Job #: 20190121151926

Location: 50B **Begin: 316.30** **End: 316.70** **From: 01/01/2007** **To: 12/31/2009**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 27 | 41 | 1 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 10 | 10 | 2 |
| Pickup Truck/Utility Van w/Trl: | 0 | 1 | 0 |
| SUV: | 12 | 7 | 1 |
| 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 | 1 | 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: | 12 | 0 | 0 |
| Other: | 2 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 65 | 63 | 4 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 42 | 17 | 1 |
| Slowing: | 2 | 7 | 1 |
| Stopped in Traffic: | 0 | 26 | 2 |
| Making Right Turn: | 4 | 3 | 0 |
| Making Left Turn: | 10 | 10 | 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 |
| Wrong Way: | 1 | 0 | 0 |
| Other: | 3 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 65 | 63 | 4 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 45 | 63 | 4 |
| Asleep at the Wheel: | 0 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 2 | 0 | 0 |
| Driver Inexperience: | 2 | 0 | 0 |
| Driver Fatigue: | 1 | 0 | 0 |
| Driver Preoccupied: | 3 | 0 | 0 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 1 | 0 | 0 |
| Unknown: | 10 | 0 | 0 |
| Total: | 65 | 63 | 4 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 11 | 8 | 2 |
| Northeast: | 0 | 0 | 0 |
| East: | 25 | 25 | 1 |
| Southeast: | 0 | 0 | 0 |
| South: | 9 | 12 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 20 | 18 | 1 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 65 | 63 | 4 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 61 | 63 | 4 |
| Alcohol Involved: | 4 | 0 | 0 |
| RX, Medication, or Drugs Involved: | 0 | 0 | 0 |
| Illegal Drugs Involved: | 0 | 0 | 0 |
| Alcohol and Drugs Involved: | 0 | 0 | 0 |
| Driver/Pedestrian not Observed: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 65 | 63 | 4 |

ADT: 25,543 **Length: 0.42**



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

CDOT Project # 17410 01/21/2019

Exhibit 2

Job #: 20190121152121

Location: 50B **Begin: 316.30** **End: 316.70** **From: 01/01/2011** **To: 12/31/2013**

| Severity | |
|---------------|---------------------|
| PDO: | 40 |
| INJ: | 14 21 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 54 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 8 |
| Two Vehicles: | 43 |
| Three or More: | 3 |
| Unknown: | 0 |
| Total: | 54 |

| Location | |
|------------------|-----------|
| On Road: | 48 |
| Off Road Left: | 1 |
| Off Road Right: | 5 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 54 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 36 |
| Dawn or Dusk: | 2 |
| Dark - Lighted: | 16 |
| Dark - Unlighted: | 0 |
| Unknown: | 0 |
| Total: | 54 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 49 |
| Rain: | 2 |
| Snow/Sleet/Hail: | 3 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 54 |

| Crash Rates | |
|---------------|-------------------------|
| PDO: | 3.72 * * MVMT |
| INJ: | 1.30 * ** 100 MVMT |
| FAT: | 0.00 ** |
| Total: | 5.02 * |

| Crash Type | | | |
|-----------------------|----|-----------------------------------|-----------|
| Overtuning: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 1 | Column/Pier: | 0 |
| Pedestrians: | 1 | Culvert/Headwall: | 0 |
| Broadside: | 3 | Embankment: | 0 |
| Head On: | 0 | Curb: | 1 |
| Rear End: | 34 | Delineator Post: | 0 |
| Sideswipe (Same): | 3 | 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: | 6 |
| Wild Animal: | 0 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 2 | Vehicle Cargo/Debris: | 0 |
| Traffic Signal Pole: | 1 | Green Road Maintenance Equipment: | 1 |
| Sign: | 2 | Involving Other Object: | 0 |
| Bridge Rail: | 0 | Total Other Objects: | 1 |
| Guard Rail: | 0 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 54 |
| Concrete Barrier: | 0 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | |
|-------------------------------|----|------------------------------|------------------|
| Mainline: | 54 | M: | 0 N: 0 O: 0 P: 0 |
| Crossroad (A): | 0 | | |
| Ramps | | Left Frontage Rd (L): | 0 |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 |
| D: 0 H: 0 T: 0 | | Unknown: | 0 |
| E: 0 I: 0 | | Total: | 54 |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 41 |
| At Driveway Access: | 0 |
| Intersection Related: | 13 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 54 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 48 |
| Wet: | 2 |
| Muddy: | 0 |
| Snowy: | 2 |
| Icy: | 1 |
| Slushy: | 0 |
| Foreign Material: | 0 |
| With Road Treatment: | 0 |
| Dry w/Icy Road Treatment: | 0 |
| Wet w/Icy Road Treatment: | 1 |
| Snowy w/Icy Road Treatment: | 0 |
| Icy w/Icy Road Treatment: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 54 |

ADT: 22,879 **Length: 0.42**



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

CDOT Project # 17410 01/21/2019
Exhibit 2

Job #: 20190121152121

Location: 50B Begin: 316.30 End: 316.70 From: 01/01/2011 To: 12/31/2013

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 24 | 24 | 1 |
| Passenger Car/Van w/Trl: | 1 | 0 | 0 |
| Pickup Truck/Utility Van: | 4 | 10 | 1 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 8 | 10 | 1 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 5 | 0 | 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: | 10 | 1 | 0 |
| Other: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 54 | 46 | 3 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 32 | 8 | 0 |
| Slowing: | 3 | 5 | 0 |
| Stopped in Traffic: | 0 | 24 | 2 |
| Making Right Turn: | 3 | 3 | 0 |
| Making Left Turn: | 7 | 5 | 1 |
| Making U-Turn: | 0 | 0 | 0 |
| Passing: | 0 | 0 | 0 |
| Backing: | 1 | 0 | 0 |
| Enter/Leave Parked Position: | 0 | 0 | 0 |
| Starting in Traffic: | 0 | 0 | 0 |
| Parked: | 0 | 0 | 0 |
| Changing Lanes: | 2 | 0 | 0 |
| Avoiding Object/Veh in Road: | 1 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 5 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 54 | 46 | 3 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 30 | 46 | 3 |
| 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: | 6 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 14 | 0 | 0 |
| Total: | 54 | 46 | 3 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 6 | 6 | 1 |
| Northeast: | 0 | 0 | 0 |
| East: | 17 | 16 | 2 |
| Southeast: | 0 | 0 | 0 |
| South: | 10 | 6 | 0 |
| Southwest: | 1 | 1 | 0 |
| West: | 20 | 17 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 54 | 46 | 3 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 46 | 46 | 3 |
| Alcohol Involved: | 5 | 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: | 54 | 46 | 3 |

ADT: 22,879 Length: 0.42

Project Information

| | | |
|-----------------------------|---|---------------------------------|
| Project Name: | SH 7D (160 th Ave) @ York Street Signal Installation | |
| Project Description: | Install a signal and an eastbound right turn lane. | |
| CDOT Region: 6 | <u>Project Def:</u> 17523 | <u>County:</u> Adams |
| Location: SH 7D | <u>Mile Points:</u> 69.86 | <u>Length:</u> N/A |
| Schedule: | <u>Work Start Date:</u> 8/30/10 | <u>Completion Date:</u> 1/13/11 |

Problem Description: As described in the Federal Hazard Elimination Program (FHEP) application for this project, the five-year crash history (2003 – 2007) showed that there was a total of nine injury crashes, seven PDO crashes, and one fatal crash. Of the 17 crashes, 10 were broadsides including the fatal crash.

Improvement Description: Between August 30, 2010 and January 13, 2011, the intersection was signalized. Previously, the intersection had two-way stop control. Additionally, an eastbound right turn lane was constructed. The cost of construction was \$747,230.

The FHEP application anticipated that an 50% reduction for all crash types might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 2.19.

Summary and Findings

The analysis of safety before and after the improvements at this intersection shows a reduction in the number and severity of broadside type crashes. There were 11 total crashes during the three-year period before the improvements were made (2007 – 2009). In the three years after construction (2012 – 2014), the number of crashes decreased to 9, a reduction of 18%. It should be noted that there were no fatalities in either the before or after study periods. The ADT slightly decreased from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a 50% decrease in injury crashes with 6 crashes in the before period and 3 crashes in the after period. There was no decrease in injury crashes, but the number of injuries decrease from 20 injuries in the three years before construction to 15 injuries in the three years after construction. The number of PDO increased from 5 in the before period to 6 in the after period. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 10 years for this project is **1.17** to one. The result is an improvement that was justified from the safety improvement as well as cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 69.81 to 69.91 shows a slight decrease in the number of crashes from 11 during the three-year period (2007 to 2009) before the improvements to 9 during the three-year after period (2012 to 2014) (**Table 1**). The number of serious crashes also showed a decrease in the after period:

- Before (2007 – 2009) – No fatal crashes and 6 injury crashes with 9 injuries
- After (2012 – 2014) – No fatal crashes and 3 injury crashes with 4 injuries

The crash rate at this intersection also decrease in the after period:

- Before (2007 – 2009) – 0.53 crashes per million entering vehicles (cpmev)
- After (2013 – 2015) – 0.38 cpmev

It is reasonable to conclude that the observed decrease in the frequency and severity of crashes is related to the various safety improvements constructed on this project.

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) |
| AADT (SH 7D/York St) | 16,650 vpd / 2,250 vpd | 19,000 vpd / 2,650 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 11 | 9 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 6 (9) | 3 (4) |
| Property Damage Only | 5 | 6 |
| Crash Types: # (%) [significance] | | |
| Broadside | 8 (72.7%) [96.7%] | 0 |
| Fixed Object | 2 (18.2%) | 0 |
| Rear End | 1 (9.1%) | 4 (44.4%) |
| Approach Turn | 0 | 2 (22.2%) |
| Sideswipe Same Direction | 0 | 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 of safety uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 (**Figure 1**) and for fatal and injury crashes (**Figure 2**) reflect an improvement in the crash record for this project. LOSS continued to be LOSS III in the after period for total crashes. Injury/Fatal crashes improved from a LOSS IV to a LOSS III in the after period. These figures also show that the number and severity of crashes during the period after construction improved in comparison to what it could have been without this safety improvement project. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes
SH 7D, MP 69.86
Before: 2007 to 2009 After: 2012 to 2014

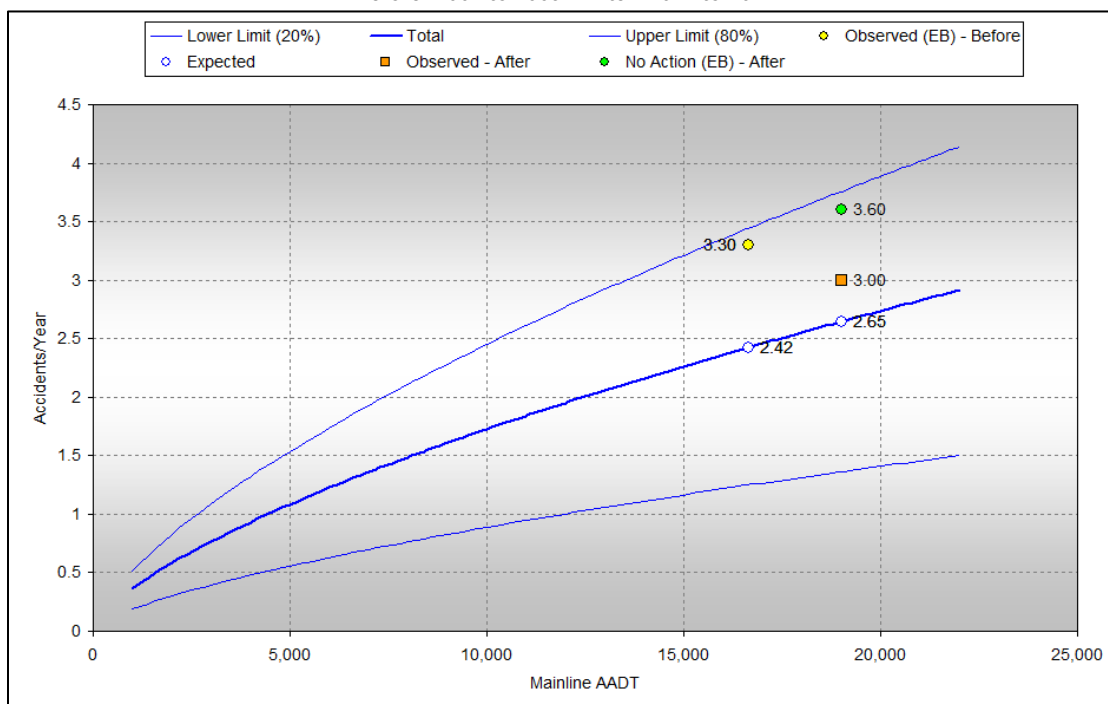


Figure 2 – SPF for Injury and Fatal Crashes

SH 7D, MP 69.86

Before: 2007 to 2009 After: 2012 to 2014

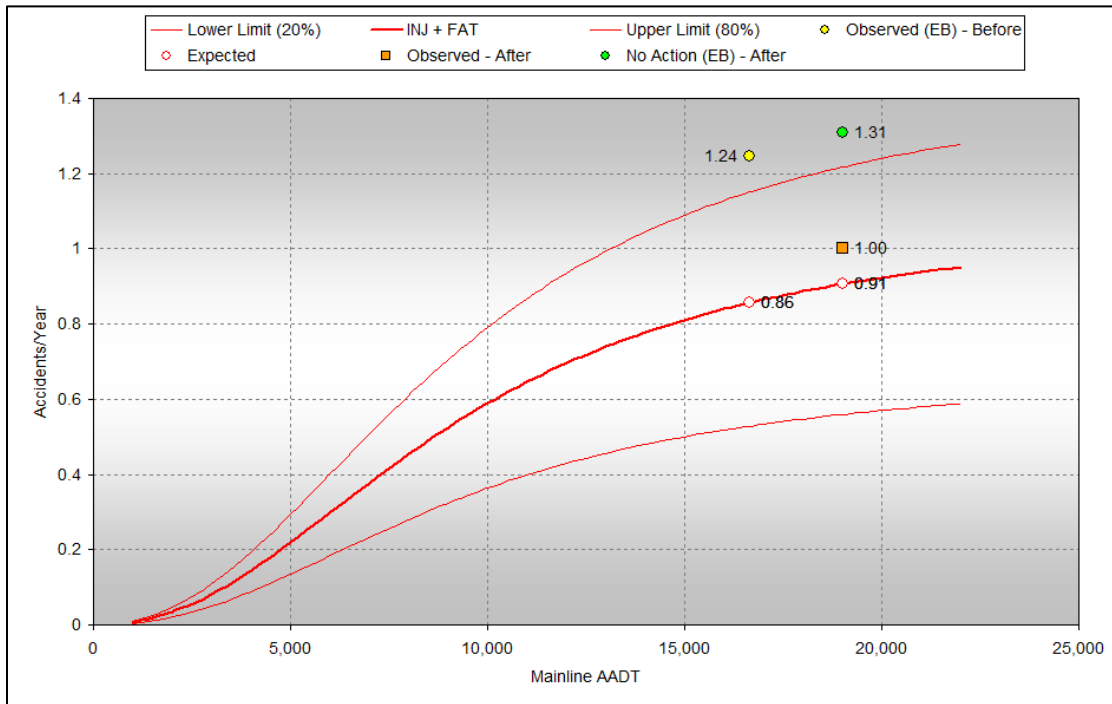


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action After |
|------------------------------------|--|--|--|
| EB Correction: | Yes | No | Yes |
| SPF Graph | Urban 2-Lane Divided Unsignalized 4-Leg Intersection | Urban 2-Lane Divided Unsignalized 4-Leg Intersection | Urban 2-Lane Divided Unsignalized 4-Leg Intersection |
| Total Crashes: | | | |
| LOSS | LOSS III | LOSS III | LOSS III |
| CPY | 3.30 | 3.00 | 3.60 |
| Mean CPY | 2.42 | 2.65 | 2.65 |
| Proportion of Mean | 1.36 | 1.13 | 1.36 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS IV | LOSS III | LOSS IV |
| CPY | 1.24 | 1.00 | 1.31 |
| Mean CPY | 0.86 | 0.91 | 0.91 |
| Proportion of Mean | 1.44 | 1.10 | 1.44 |

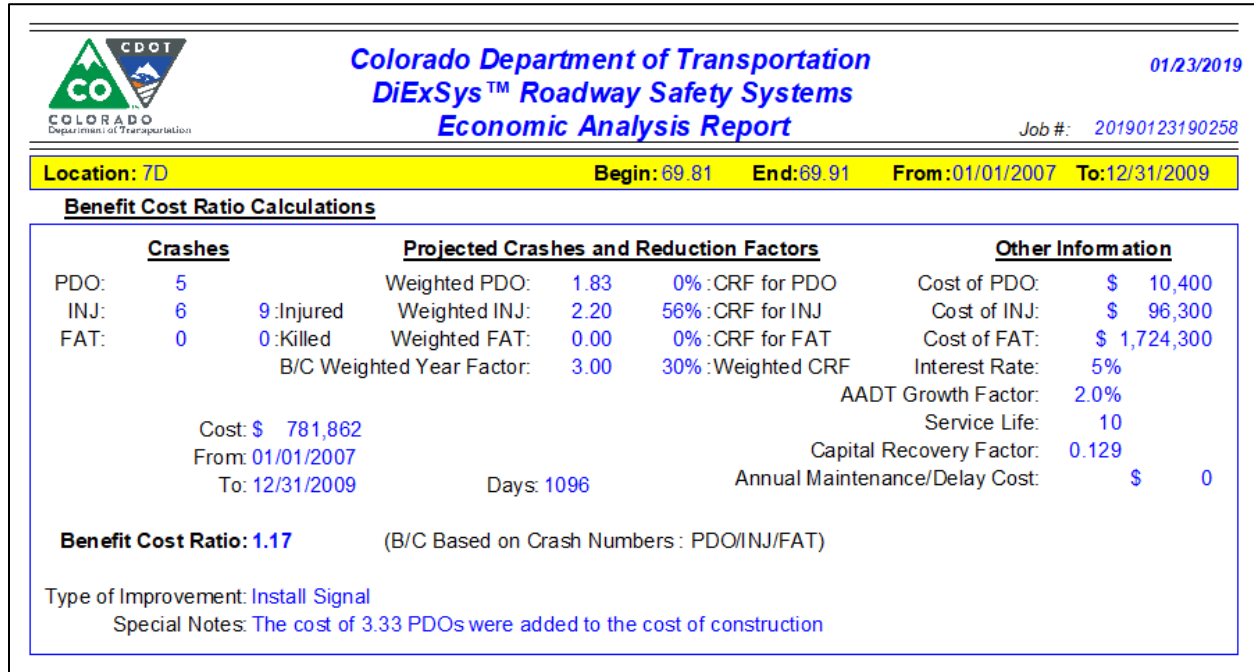
A more detailed review of the before and after crash record shows the crash types that were most affected by the signal installation. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: broadside, approach turn, and rear-end. The installation of the signal reduced the number of broadside crashes, but increased the number of rear-end crashes. This is an expected outcome when signaling an intersection. The number of crashes does not necessarily decrease, but the crash types become less severe by reducing the broadside crashes. Additionally, there were approach turn crashes in the after period, when there were none in the before period. Over the design life of 10 years for the improvements, the increased cost of crashes would be \$34,632 (3.33 PDO = \$34,632). The No-Build After crashes were estimated using the change in SH 7D traffic volumes between the before and after period, as found in **Table 1** (AADT decrease is 7% = |1-(17,100/18,450)|).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|--|--------------------------------|--------------------------------|--------------------------------|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 11 | 9 | 11 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 6 (9) | 3 (4) | 6 (9) |
| PDO | 5 | 6 | 5 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | 0% / 56% / -20% | |
| Broadside – Total | 8 | 0 | 8 |
| Injury (injuries) | 5 (8) | 0 (0) | 5 (8) |
| PDO | 3 | 0 | 3 |
| % Reduction in Total (Injuries/PDO) | | 100% / 100% | |
| Fixed Object – Total | 2 | 0 | 2 |
| Injury (injuries) | 1 (1) | 0 (0) | 1 (1) |
| PDO | 1 | 0 | 1 |
| % Reduction in Total (Injuries/PDO) | | 100% / 100% | |
| Rear Ends – Total | 1 | 4 | 1 |
| Injury (injuries) | 0 (0) | 1 (2) | 0 (0) |
| PDO | 1 | 3 | 1 |
| % Reduction in Total (Injuries/PDO) | | 100% / -200% | |
| Approach Turns – Total | 0 | 2 | 0 |
| Injury (injuries) | 0 (0) | 2 (2) | 0 (0) |
| PDO | 0 | 0 | 0 |
| % Reduction in Total (Injuries/PDO) | | NA / NA | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes at the intersection. **A calculated B/C ratio of 1.17 was ultimately realized.** This outcome displays that this safety improvement project was justified from a cost-effectiveness standpoint.

Figure 3 – Benefit Cost Analysis





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

CDOT Project # 17523
 Exhibit 1

01/22/2019

Job #: 20190122104032

Location: 7D **Begin: 69.81** **End: 69.91** **From:01/01/2007** **To:12/31/2009**

Severity

| | | |
|---------------|-----------|------------|
| PDO: | 5 | |
| INJ: | 6 | 9 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 11 | |

Number of Vehicles

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

Location

| | |
|------------------|-----------|
| On Road: | 9 |
| Off Road Left: | 1 |
| Off Road Right: | 1 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 11 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 7 |
| Dawn or Dusk: | 0 |
| Dark - Lighted: | 0 |
| Dark - Unlighted: | 4 |
| Unknown: | 0 |
| Total: | 11 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 10 |
| Rain: | 1 |
| Snow/Sleet/Hail: | 0 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 11 |

Crash Rates

| | | |
|---------------|---------------|-------------|
| PDO: | 3.02 * | * MVMT |
| INJ: | 3.62 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 6.64 * | |

Crash Type

| | | | |
|-----------------------|---|-----------------------------|-----------|
| Overtuning: | 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: | 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: | 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: | 2 | 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 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | Left Frontage Rd (L): | 0 |
| C: 0 G: 0 K: 0 | Rt Frontage Rd (R): | 0 |
| D: 0 H: 0 T: 0 | HOV Lanes (V): | 0 |
| E: 0 I: 0 | Unknown: | 0 |
| | Total: | 11 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 10 |
| At Driveway Access: | 0 |
| Intersection Related: | 1 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 11 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 9 |
| 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: | 0 |
| Snowy w/Icy Road Treatment: | 0 |
| Icy w/Icy Road Treatment: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 11 |

ADT: 18,437 **Length: 0.08**



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

CDOT Project # 17523 01/22/2019
 Exhibit 1
 Job #: 20190122104032

Location: 7D **Begin: 69.81** **End: 69.91** **From:01/01/2007** **To:12/31/2009**

| 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: | 2 | 2 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 3 | 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 | 1 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 11 | 9 | 0 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|----------|----------|
| Going Straight: | 5 | 7 | 0 |
| Slowing: | 0 | 0 | 0 |
| Stopped in Traffic: | 0 | 1 | 0 |
| Making Right Turn: | 1 | 1 | 0 |
| Making Left Turn: | 4 | 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 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 11 | 9 | 0 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|----------|----------|
| No Apparent Contributing Factor: | 4 | 9 | 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: | 1 | 0 | 0 |
| Driver Preoccupied: | 2 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 2 | 0 | 0 |
| Total: | 11 | 9 | 0 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|----------|----------|
| North: | 8 | 0 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 2 | 6 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 0 | 0 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 1 | 3 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 11 | 9 | 0 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|----------|----------|
| No Impairment Suspected: | 11 | 9 | 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: | 11 | 9 | 0 |

ADT: 18,437 **Length: 0.08**



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

CDOT Project # 17523 01/22/2019

Exhibit 2

Job #: 20190122192032

Location: 7D **Begin: 69.81** **End: 69.91** **From:01/01/2012** **To:12/31/2014**

| Severity | |
|---------------|--------------|
| PDO: | 6 |
| INJ: | 3 4 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 9 |

| Number of Vehicles | |
|--------------------|----------|
| One Vehicle: | 0 |
| Two Vehicles: | 9 |
| Three or More: | 0 |
| 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: | 8 |
| Dawn or Dusk: | 0 |
| Dark - Lighted: | 1 |
| 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: | 3.95 * * MVMT |
| INJ: | 1.98 * ** 100 MVMT |
| FAT: | 0.00 ** |
| Total: | 5.93 * |

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

| Mainline/Ramps/Frontage Roads | |
|------------------------------------|----------|
| Mainline: | 9 |
| Crossroad (A): | 0 |
| Ramps | |
| B: 0 F: 0 J: 0 | |
| C: 0 G: 0 K: 0 | |
| D: 0 H: 0 T: 0 | |
| E: 0 I: 0 | |
| Frontage/Ramp Intersections | |
| M: 0 N: 0 O: 0 P: 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: | 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: 17,091 **Length: 0.08**



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

CDOT Project # 17523 01/22/2019
Exhibit 2

Job #: 20190122192032

Location: 7D Begin: 69.81 End: 69.91 From:01/01/2012 To:12/31/2014

| 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: | 2 | 2 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 1 | 3 | 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: | 1 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 9 | 9 | 0 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|----------|----------|----------|
| Going Straight: | 5 | 2 | 0 |
| Slowing: | 0 | 0 | 0 |
| Stopped in Traffic: | 0 | 5 | 0 |
| Making Right Turn: | 1 | 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: | 1 | 1 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 9 | 9 | 0 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|----------|----------|----------|
| No Apparent Contributing Factor: | 4 | 9 | 0 |
| 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 Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 9 | 9 | 0 |

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

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|----------|----------|----------|
| No Impairment Suspected: | 9 | 9 | 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 | 9 | 0 |

ADT: 17,091 Length: 0.08

Project Information

Project Name: SH 470 Median Cable Rail

Project Description: Install a Median Cable Rail between Green Acres Drive and I-25

CDOT Region: 6 Project Def: 17524 County: Douglas

Location: SH 470A Mile Points: 24.54 to 26.20 Length: 1.66

Schedule: Work Start Date: 9/15/2010 Completion Date: 1/26/2012

Problem Description: As described in the Federal Hazard Elimination Program (FHEP) application for this project, the five-year crash history (2000 – 2004) showed that there was a total of 178 crashes, with 45 being injury crashes and 3 being fatal crashes. Of the 178 crashes, 8 of the crashes involved the vehicle going into the median, resulting in an overturning, head on, or sideswipe opposite direction type crash. Two of the median crashes resulted in fatalities.

Improvement Description: Between September 15, 2010 and January 26, 2012, a cable rail was installed in the median. The cost of construction was \$457,220.

The FHEP application anticipated that a 60% reduction in fatal crashes, 40% reduction in injury crashes, and a 20% reduction in property damage only crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 10.43.

Summary and Findings

The analysis of safety before and after the improvements were made on this portion of the corridor shows a reduction in injury crashes but an increase in the total number of crashes. In this segment of the divided freeway, there were 126 total crashes during the three-year period before the improvements were made (2007 – 2009). In the three years after construction (2013 – 2015), the number of crashes increased to 176. The ADT also increased from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was an 8% decrease in injury crashes, from 26 crashes (36 injuries) in the three years before construction to 24 crashes (27 injuries) in the three years after construction. The number of property damage only crashes increased from 100 crashes in the three years before construction to 152 crashes in the three years after construction. There were no fatalities in the before period or after period. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 20 years for this project is **1.58** to one. The result is an improvement that was justified from the safety improvement standpoint as well as cost-effectiveness standpoint.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 24.54 to 26.20 shows a slight decrease in the number of injury crashes from 26 during the three-year period (2007 to 2009) before the improvements to 24 during the three-year after period (2013 to 2015) (**Table 1**). However, the number of property damage only crashes increased in the after period:

- Before (2007 – 2009) – No fatal crashes and 26 injury crashes with 36 injuries
- After (2013 – 2015) – No fatal crashes and 24 injury crashes with 27 injuries

It should be noted that the increase in rear end and sideswipe same direction crashes between the before and after periods appear to be due to the increase in traffic volume on the corridor. These crashes are unrelated to the project and are a result of increased congestion, especially during the peak hours.

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|--------------------------------|--------------------------------|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2013 to 12/31/2015 (3 yr.) |
| AADT | 98,700 vpd | 106,200 vpd |
| Filters: | Non-Intersection | Non-Intersection |
| Total Crashes | 126 | 176 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 26 (36) | 24 (27) |
| Property Damage Only | 100 | 152 |
| Crash Types: # (%) [significance] | | |
| Rear End | 42 (33.3%) | 77 (43.8%) |
| Fixed Object | 36 (28.6%) [100.0%] | 41 (23.3%) [97.0%] |
| Sideswipe Same Direction | 21 (16.7%) | 40 (22.7%) [100.0%] |
| Other Object | 13 (10.3%) [100.0%] | 4 (2.3%) |
| Overturning | 13 (10.3%) [99.9%] | 11 (6.3%) [99.6%] |

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 of safety uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 SPF plot for total crashes (**Figure 1**) shows no improvement in the crash record for this project with LOSS II in the before period and LOSS III in the after period. However, there was improvement for fatal and injury crashes (**Figure 2**) with LOSS II in the before period and LOSS I in the after period. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes
SH 470A, MP 24.54 to 26.20
Before: 2007 to 2009 After: 2013 to 2015

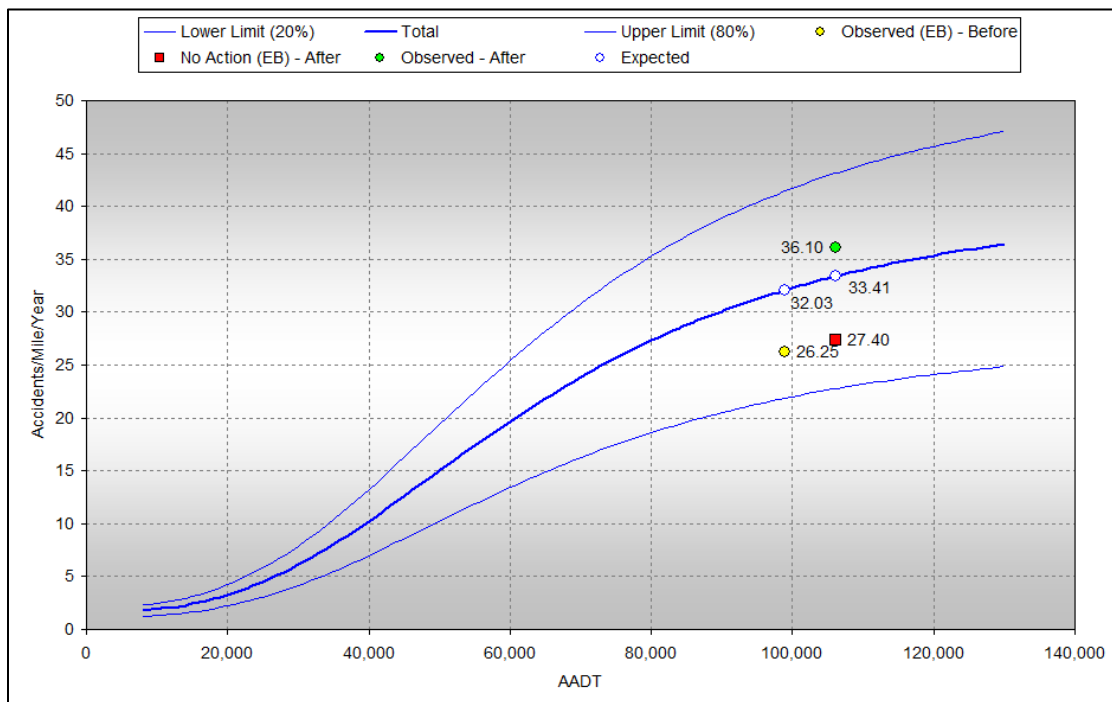


Figure 2 – SPF for Injury and Fatal Crashes

SH 470A, MP 24.54 to 26.20
 Before: 2007 to 2009 After: 2013 to 2015

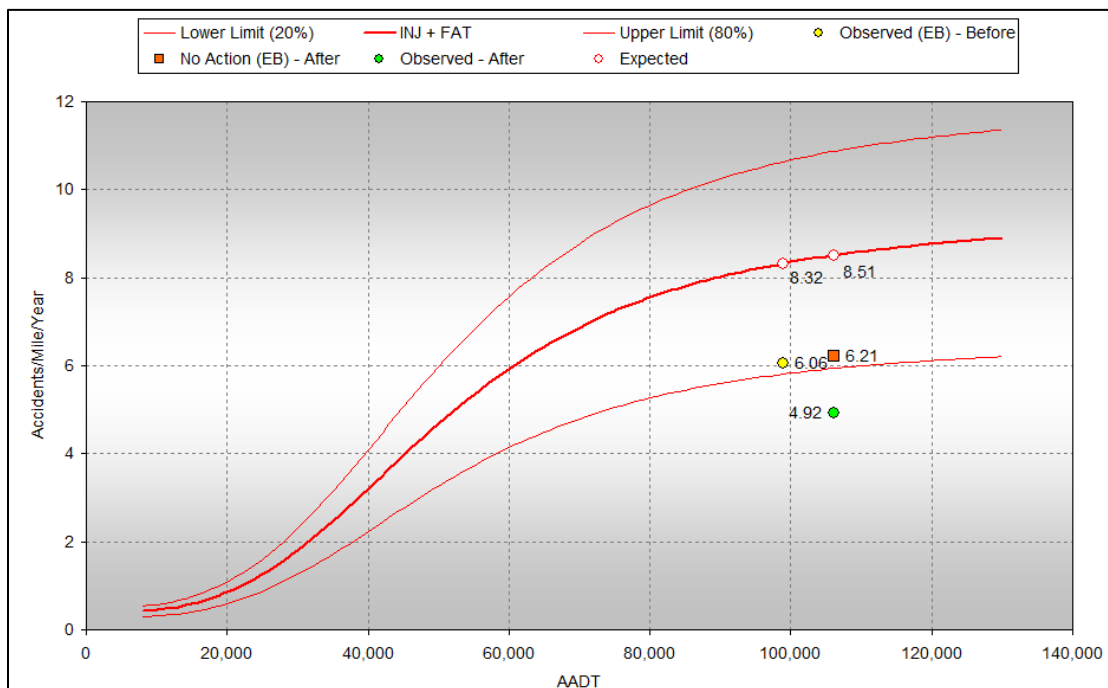


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action After |
|------------------------------------|------------------------------|------------------------------|------------------------------|
| EB Correction: | Yes | No | Yes |
| SPF Graph | Urban 4-Lane Divided Freeway | Urban 4-Lane Divided Freeway | Urban 4-Lane Divided Freeway |
| Total Crashes: | | | |
| LOSS | LOSS II | LOSS III | LOSS II |
| CPY | 26.25 | 36.10 | 27.40 |
| Mean CPY | 32.03 | 33.41 | 33.41 |
| Proportion of Mean | 0.82 | 1.08 | 0.82 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS II | LOSS I | LOSS II |
| CPY | 6.06 | 4.92 | 6.21 |
| Mean CPY | 8.32 | 8.51 | 8.51 |
| Proportion of Mean | 0.73 | 0.58 | 0.73 |

A more detailed review of the before and after crash record shows the crash types that were most affected by the project. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: overturning and fixed object. The improvement appears to have reduced the number of overturning crashes but did not reduce fixed object crashes on the segment. Over the design life of 20 years for the improvements, the increased cost of crashes would be \$3,050,667 (293.33 PDO = \$3,050,667). The No-Build After crashes were estimated using the change in SH 470A traffic volumes


between the before and after period, as found in **Table 1** (increase is 8% = |1-(106,200/98,700)|).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|---|----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2007 to 12/31/209 (3 yr.) | 1/1/2013 to 12/31/2015 (3 yr.) | 1/1/2013 to 12/31/2015 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 126 | 176 | 136 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 26 (36) | 24 (27) | 28 (39) |
| PDO | 100 | 152 | 108 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | NA / 29% / -44% | |
| Overturning – Total | 13 | 11 | 14 |
| Injury (injuries) | 9 (9) | 5(5) | 10 (10) |
| PDO | 4 | 6 | 4 |
| % Reduction in Total (Injuries/PDO) | | 50% / -50% | |
| Fixed Object – Total | 36 | 41 | 39 |
| Injury (injuries) | 6 (9) | 3 (3) | 6(10) |
| PDO | 30 | 38 | 33 |
| % Reduction in Total (Injuries/PDO) | | 70% / -13% | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes at the intersection. **A calculated B/C ratio of 1.58 was ultimately realized.** This outcome displays that this safety improvement project was justified from a cost-effectiveness standpoint.

Figure 3 – Benefit Cost Analysis

| | | | |
|---|---|--|------------------------------------|
|  | Colorado Department of Transportation DiExSys™ Roadway Safety Systems Economic Analysis Report | | 02/24/2019 |
| | | | Job #: 20190224133307 |
| Location: 470A | | Begin: 24.54 End: 26.20 | From: 01/01/2007 To: 12/31/2009 |
| Benefit Cost Ratio Calculations | | | |
| | <u>Crashes</u> | <u>Projected Crashes and Reduction Factors</u> | <u>Other Information</u> |
| PDO: | 136 | Weighted PDO: 55.69 0% :CRF for PDO | Cost of PDO: \$ 10,400 |
| INJ: | 28 39 :Injured | Weighted INJ: 15.97 29% :CRF for INJ | Cost of INJ: \$ 96,300 |
| FAT: | 0 0 :Killed | Weighted FAT: 0.00 0% :CRF for FAT | Cost of FAT: \$ 1,724,300 |
| | B/C Weighted Year Factor: 3.00 | 4% :Weighted CRF | Interest Rate: 5% |
| | Cost: \$ 3,507,887 | | AADT Growth Factor: 2.0% |
| | From: 01/01/2007 | | Service Life: 20 |
| | To: 12/31/2009 | Days: 1096 | Capital Recovery Factor: 0.080 |
| | | Annual Maintenance/Delay Cost: \$ 0 | |
| Benefit Cost Ratio: 1.58 | | (B/C Based on Injury Numbers : PDO/Injured/Killed) | |
| Type of Improvement: Install Cable Rail in Median | | | |
| Special Notes: The cost of 293 PDOs were added to the cost of construction | | | |



Location: 470A Begin: 24.54 End: 26.20 From:01/01/2007 To:12/31/2009

| Severity | |
|---------------|----------------|
| PDO: | 100 |
| INJ: | 26 36 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 126 |

| Number of Vehicles | |
|--------------------|------------|
| One Vehicle: | 52 |
| Two Vehicles: | 55 |
| Three or More: | 19 |
| Unknown: | 0 |
| Total: | 126 |

| Location | |
|------------------|------------|
| On Road: | 78 |
| Off Road Left: | 22 |
| Off Road Right: | 26 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 126 |

| Lighting Conditions | |
|---------------------|------------|
| Daylight: | 81 |
| Dawn or Dusk: | 6 |
| Dark - Lighted: | 27 |
| Dark - Unlighted: | 11 |
| Unknown: | 1 |
| Total: | 126 |

| Weather Conditions | |
|--------------------|------------|
| None: | 98 |
| Rain: | 6 |
| Snow/Sleet/Hail: | 21 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 1 |
| Total: | 126 |

| Crash Rates | |
|---------------|--------------------|
| PDO: | 0.57 * * MVMT |
| INJ: | 0.15 * ** 100 MVMT |
| FAT: | 0.00 ** |
| Total: | 0.72 * |

| Crash Type | | | |
|-----------------------|----|------------------------------|------------|
| Overtuning: | 13 | 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: | 42 | Delineator Post: | 2 |
| Sideswipe (Same): | 21 | Fence: | 4 |
| Sideswipe (Opposite): | 0 | Tree: | 0 |
| Approach Turn: | 0 | Large Boulders or Rocks: | 1 |
| Overtaking Turn: | 0 | Barricade: | 0 |
| Parked Motor Vehicle: | 0 | Wall/Building: | 0 |
| Railway Vehicle: | 0 | Crash Cushion: | 0 |
| Bicycle: | 0 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 0 |
| Domestic Animal: | 0 | Total Fixed Objects: | 36 |
| Wild Animal: | 1 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 0 | Vehicle Cargo/Debris: | 10 |
| Traffic Signal Pole: | 1 | Green Maintenance Equipment: | 1 |
| Sign: | 0 | Involving Other Object: | 2 |
| Bridge Rail: | 2 | Total Other Objects: | 13 |
| Guard Rail: | 19 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 126 |
| Concrete Barrier: | 6 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | |
|-------------------------------|-----|------------------------------|------------------|
| Mainline: | 126 | M: | 0 N: 0 O: 0 P: 0 |
| Crossroad (A): | 0 | | |
| Ramps | | Left Frontage Rd (L): | 0 |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 |
| D: 0 H: 0 T: 0 | | Unknown: | 0 |
| E: 0 I: 0 | | Total: | 126 |

| Road Description | |
|-----------------------|------------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 126 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 126 |

| Road Conditions | |
|------------------------------|------------|
| Dry: | 92 |
| Wet: | 8 |
| Muddy: | 0 |
| Snowy: | 8 |
| 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: | 0 |
| Icy w/Icy Road Treatment: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 3 |
| Total: | 126 |

ADT: 98,702 Length: 1.62



Location: 470A **Begin: 24.54** **End: 26.20** **From:01/01/2007** **To:12/31/2009**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|------------|-----------|-----------|
| Passenger Car/Van: | 68 | 40 | 10 |
| Passenger Car/Van w/Trl: | 1 | 2 | 0 |
| Pickup Truck/Utility Van: | 18 | 11 | 1 |
| Pickup Truck/Utility Van w/Trl: | 3 | 1 | 3 |
| SUV: | 26 | 19 | 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: | 1 | 0 | 0 |
| Bicycle: | 0 | 0 | 0 |
| Motorized Bicycle: | 0 | 0 | 0 |
| Farm Equipment: | 0 | 0 | 0 |
| Hit and Run - Unknown: | 4 | 0 | 0 |
| Other: | 2 | 0 | 0 |
| Unknown: | 0 | 0 | 1 |
| Total: | 126 | 74 | 19 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|------------|-----------|-----------|
| Going Straight: | 52 | 36 | 4 |
| Slowing: | 12 | 16 | 3 |
| Stopped in Traffic: | 1 | 17 | 11 |
| Making Right Turn: | 0 | 0 | 0 |
| Making Left Turn: | 1 | 0 | 0 |
| Making U-Turn: | 2 | 0 | 0 |
| Passing: | 0 | 1 | 0 |
| Backing: | 3 | 0 | 0 |
| Enter/Leave Parked Position: | 0 | 0 | 0 |
| Starting in Traffic: | 0 | 0 | 0 |
| Parked: | 0 | 0 | 0 |
| Changing Lanes: | 26 | 3 | 0 |
| Avoiding Object/Veh in Road: | 3 | 0 | 0 |
| Weaving: | 3 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 23 | 1 | 0 |
| Unknown: | 0 | 0 | 1 |
| Total: | 126 | 74 | 19 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|------------|-----------|-----------|
| No Apparent Contributing Factor: | 61 | 68 | 19 |
| Asleep at the Wheel: | 0 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 2 | 0 | 0 |
| Driver Inexperience: | 15 | 2 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 16 | 1 | 0 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 31 | 3 | 0 |
| Total: | 126 | 74 | 19 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|------------|-----------|-----------|
| North: | 1 | 1 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 61 | 35 | 11 |
| Southeast: | 0 | 0 | 0 |
| South: | 3 | 0 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 61 | 38 | 7 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 1 |
| Total: | 126 | 74 | 19 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|------------|-----------|-----------|
| No Impairment Suspected: | 117 | 74 | 19 |
| Alcohol Involved: | 9 | 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: | 126 | 74 | 19 |

ADT: 98,702 **Length: 1.62**



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

CDOT Project # 17524 02/07/2019
Exhibit 2

Job #: 20190207160540

Location: 470A Begin: 24.54 End: 26.20 From:01/01/2013 To:12/31/2015

| Severity | |
|---------------|---------------------|
| PDO: | 152 |
| INJ: | 24 27 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 176 |

| Number of Vehicles | |
|--------------------|------------|
| One Vehicle: | 49 |
| Two Vehicles: | 110 |
| Three or More: | 17 |
| Unknown: | 0 |
| Total: | 176 |

| Location | |
|------------------|------------|
| On Road: | 126 |
| Off Road Left: | 33 |
| Off Road Right: | 17 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 176 |

| Lighting Conditions | |
|---------------------|------------|
| Daylight: | 131 |
| Dawn or Dusk: | 12 |
| Dark - Lighted: | 23 |
| Dark - Unlighted: | 10 |
| Unknown: | 0 |
| Total: | 176 |

| Weather Conditions | |
|--------------------|------------|
| None: | 127 |
| Rain: | 11 |
| Snow/Sleet/Hail: | 38 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 176 |

| Crash Rates | |
|---------------|-------------------------|
| PDO: | 0.80 * * MVMT |
| INJ: | 0.13 * ** 100 MVMT |
| FAT: | 0.00 ** |
| Total: | 0.93 * |

| Crash Type | |
|-----------------------------|------------|
| Overtuning: | 11 |
| Other Non Collision: | 0 |
| Pedestrians: | 0 |
| Broadside: | 0 |
| Head On: | 0 |
| Rear End: | 77 |
| Sideswipe (Same): | 40 |
| Sideswipe (Opposite): | 0 |
| Approach Turn: | 0 |
| Overtaking Turn: | 0 |
| Parked Motor Vehicle: | 2 |
| Railway Vehicle: | 0 |
| Bicycle: | 0 |
| Motorized Bicycle: | 0 |
| Domestic Animal: | 0 |
| Wild Animal: | 1 |
| Light/Utility Pole: | 2 |
| Traffic Signal Pole: | 0 |
| Sign: | 1 |
| Bridge Rail: | 0 |
| Guard Rail: | 14 |
| Cable Rail: | 18 |
| Concrete Barrier: | 3 |
| Bridge Abutment: | 0 |
| Column/Pier: | 0 |
| Culvert/Headwall: | 0 |
| Embankment: | 0 |
| Curb: | 0 |
| Delineator Post: | 0 |
| Fence: | 2 |
| Tree: | 0 |
| Large Boulders or Rocks: | 0 |
| Barricade: | 0 |
| Wall/Building: | 1 |
| Crash Cushion: | 0 |
| Mailbox: | 0 |
| Other Fixed Object: | 0 |
| Total Fixed Objects: | 41 |
| Rocks in Roadway: | 0 |
| Vehicle Cargo/Debris: | 1 |
| Road Maintenance Equipment: | 0 |
| Involving Other Object: | 3 |
| Total Other Objects: | 4 |
| Unknown: | 0 |
| Total: | 176 |

| Mainline/Ramps/Frontage Roads | |
|------------------------------------|------------|
| Mainline: | 176 |
| Crossroad (A): | 0 |
| Ramps | |
| B: 0 F: 0 J: 0 | |
| C: 0 G: 0 K: 0 | |
| D: 0 H: 0 T: 0 | |
| E: 0 I: 0 | |
| Frontage/Ramp Intersections | |
| M: 0 N: 0 O: 0 P: 0 | |
| Left Frontage Rd (L): | 0 |
| Rt Frontage Rd (R): | 0 |
| HOV Lanes (V): | 0 |
| Unknown: | 0 |
| Total: | 176 |

| Road Description | |
|-----------------------|------------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 176 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 176 |

| Road Conditions | |
|------------------------------|------------|
| Dry: | 111 |
| Wet: | 21 |
| Muddy: | 1 |
| Snowy: | 20 |
| Icy: | 14 |
| Slushy: | 4 |
| 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: | 3 |
| Total: | 176 |

ADT: 106,192 Length: 1.62



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

CDOT Project # 17524 02/07/2019
Exhibit 2

Job #: 20190207160540

Location: 470A Begin: 24.54 End: 26.20 From:01/01/2013 To:12/31/2015

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|------------|------------|-----------|
| Passenger Car/Van: | 85 | 57 | 8 |
| Passenger Car/Van w/Trl: | 1 | 0 | 0 |
| Pickup Truck/Utility Van: | 29 | 16 | 3 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 48 | 50 | 4 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 3 | 3 | 1 |
| School Bus < 15 People: | 1 | 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: | 9 | 0 | 1 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 176 | 127 | 17 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|------------|------------|-----------|
| Going Straight: | 77 | 52 | 5 |
| Slowing: | 18 | 33 | 4 |
| Stopped in Traffic: | 3 | 33 | 6 |
| Making Right Turn: | 0 | 1 | 0 |
| Making Left Turn: | 0 | 0 | 0 |
| Making U-Turn: | 0 | 0 | 0 |
| Passing: | 1 | 0 | 0 |
| Backing: | 2 | 0 | 0 |
| Enter/Leave Parked Position: | 0 | 0 | 0 |
| Starting in Traffic: | 0 | 0 | 0 |
| Parked: | 0 | 2 | 0 |
| Changing Lanes: | 34 | 3 | 1 |
| Avoiding Object/Veh in Road: | 4 | 1 | 0 |
| Weaving: | 1 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 36 | 2 | 1 |
| Unknown: | 0 | 0 | 0 |
| Total: | 176 | 127 | 17 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|------------|------------|-----------|
| No Apparent Contributing Factor: | 62 | 123 | 16 |
| Asleep at the Wheel: | 1 | 0 | 0 |
| Illness: | 5 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 27 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 15 | 0 | 0 |
| Driver Unfamiliar with Area: | 7 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 59 | 4 | 1 |
| Total: | 176 | 127 | 17 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|------------|------------|-----------|
| North: | 1 | 1 | 0 |
| Northeast: | 1 | 0 | 0 |
| East: | 77 | 58 | 11 |
| Southeast: | 0 | 0 | 0 |
| South: | 1 | 1 | 0 |
| Southwest: | 1 | 1 | 0 |
| West: | 95 | 66 | 6 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 176 | 127 | 17 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|------------|------------|-----------|
| No Impairment Suspected: | 169 | 126 | 17 |
| Alcohol Involved: | 3 | 0 | 0 |
| RX, Medication, or Drugs Involved: | 2 | 1 | 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: | 176 | 127 | 17 |

ADT: 106,192 Length: 1.62

Project Information

Project Name: SH 121A @ 9th Avenue Intersection Improvements

Project Description: Install Raised Median to Create $\frac{3}{4}$ Movement Intersection

CDOT Region: 1 Project Def: 17526 County: Jefferson

Location: SH 121A Mile Points: 12.84 Length: N/A

Schedule: Work Start Date: 11/18/2011 Completion Date: 5/9/2012

Problem Description: As described in the Federal Hazard Elimination Program (FHEP) application for this project, the five-year crash history (2001 – 2005) showed that there was a total of 8 injury crashes, 30 PDO crashes, and no fatal crashes. Of the 38 crashes, 9 were approach turn type crashes and 5 were broadside type crashes.

Improvement Description: Between November 18, 2011 and May 9, 2012, a raised median was constructed to create a $\frac{3}{4}$ movement intersection. The cost of construction was \$107,709.

The FHEP application anticipated that an 90% reduction in broadside and approach turn crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 5.69.

Summary and Findings

The analysis of safety before and after the improvements at this location shows an overall decrease in the number of crashes. The number of injury crashes increased, while the number of injuries decreased. There were 28 total crashes during the three-year period before the improvements were made (2008 – 2010). In the three years after construction (2013 – 2015), the number of crashes decreased to 22. The ADT slightly increased from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a decrease in the approach turn crashes since completion of the project. There was no decrease in injury crashes, which increased from 7 crashes (11 injuries) in the before period to 8 crashes (10 injuries) in the after period. The number of PDO decreased from 21 to 14. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 20 years for this project is **13.73** to one. The result is an improvement that was justified from the safety improvement and cost effectiveness standpoints.

Results of Safety Analyses

Although this was an intersection project, the median constructed extended beyond just the intersection and may have impacted non-intersection crashes as well. So all crashes within the impacted mileposts were analyzed and then the crashes at the intersection were reviewed separately.

Using Vision Zero Suite, the review of before and after crash records for all crashes from MP 12.81 to 12.91 shows a decrease in the total number of crashes from 28 during the three-year period (2008 to 2010) before the improvements to 22 during the three-year after period (2013 to 2015) (**Table 1**). The number of serious crashes showed a slight increase in the after period:

- Before (2008 – 2010) – No fatal crashes and 7 injury crashes with 11 injuries
- After (2011 – 2013) – No fatal crashes and 8 injury crashes with 10 injuries

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|----------------------------|--------------------------------|--------------------------------|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2013 to 12/31/2015 (3 yr.) |
| AADT (SH 121A) | 48,750 vpd | 53,650 vpd |
| Filters: | NA | NA |
| Total Crashes | 28 | 22 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 7 (11) | 8 (10) |
| Property Damage Only | 21 | 14 |
| Crash Types: # (%) | | |
| Rear-End | 20 (71.4%) | 13 (59.1%) |
| Approach Turn | 4 (14.3%) | 0 |
| Sideswipe Same Direction | 1 (7.1%) | 4 (18.2%) |
| Broadside | 1 (3.6%) | 2 (9.1%) |

Additionally, the intersection and intersection related crashes at 9th Avenue were reviewed (**Table 2**). The total crashes at the intersection decreased from 15 crashes (4 injury crashes, 5 injured) in the before period to 13 crashes (6 injury crashes, 8 injuries) in the after period. The crash rate at this intersection also decreased in the after period:

- Before (2008 – 2010) – 0.27 crashes per million entering vehicles (cpmev)
- After (2013 – 2015) – 0.22 cpmev

Table 2 –Results of Intersection Crash Analyses (9th Avenue)

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2013 to 12/31/2015 (3 yr.) |
| AADT (SH 121A / 9 th Ave) | 48,750 vpd / approx. 1,500 vpd | 53,650 vpd / approx. 1,500 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 15 | 13 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 4 (5) | 6 (8) |
| Property Damage Only | 11 | 7 |
| Crash Types: # (%) [significance] | | |
| Rear-End | 10 (66.7%) [99.9%] | 6 (46.2%) |
| Approach Turn | 4 (26.7%) | 0 |
| Sideswipe Same Direction | 1 (6.7%) | 2 (15.4%) |
| Broadside | 0 | 2 (15.4%) |

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 SPF plot for total crashes at the intersection of SH 121A and 9th Avenue (**Figure 1**) reflects slight improvement in the crash record for this project, although the LOSS remained LOSS III in both the before and after periods. For fatal and injury crashes (**Figure 2**) the SPF reflects no improvement in the crash record as the LOSS changes from LOSS III to LOSS IV. **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.

Figure 1 – SPF for Total Crashes
SH 121A, MP 12.84
Before: 2008 to 2010 After: 2013 to 2015

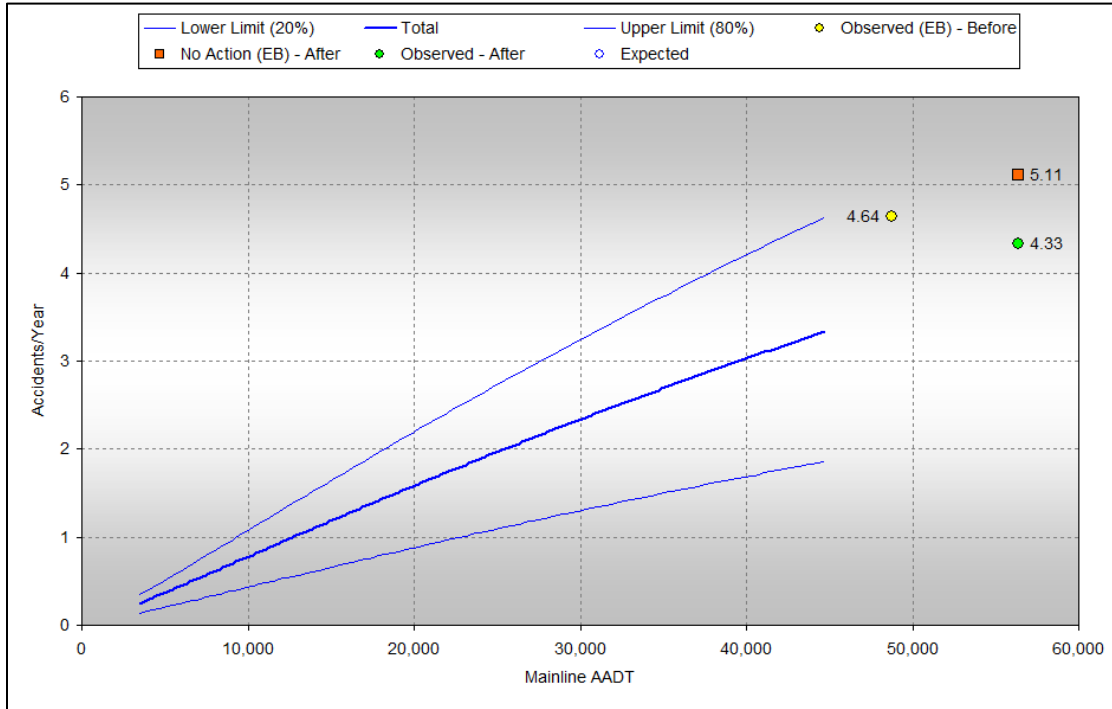


Figure 2 – SPF for Injury and Fatal Crashes

SH 121A, MP 12.84

Before: 2008 to 2010 After: 2013 to 2015

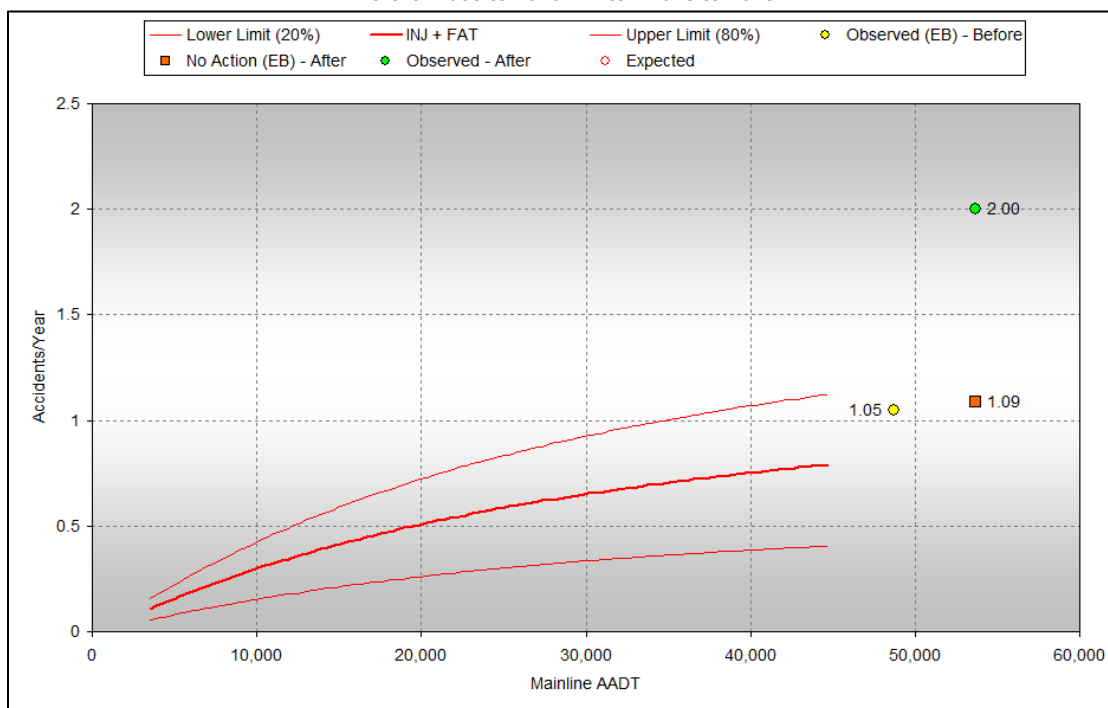


Table 3 –Safety Performance Function (SPF)

| | Before | After | No Action 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 III | LOSS III | LOSS III |
| CPY | 4.64 | 4.33 | 5.11 |
| Mean CPY | 3.55 | 3.90 | 3.90 |
| Proportion of Mean | 1.31 | 1.11 | 1.31 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS III | LOSS IV | LOSS III |
| CPY | 1.05 | 2.00 | 1.09 |
| Mean CPY | 0.81 | 0.84 | 0.84 |
| Proportion of Mean | 1.30 | 2.38 | 1.30 |

A more detailed review of the before and after crash record shows the crash types that were most affected by the project. **Table 4** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: rear-end, broadside, and approach turn. After the project was construction, the number of rear-end and approach turn crashes decreased. However, there was an increase in the number of broadside crashes. Based on the crash reports, it appears both broadsides occurred between a vehicle

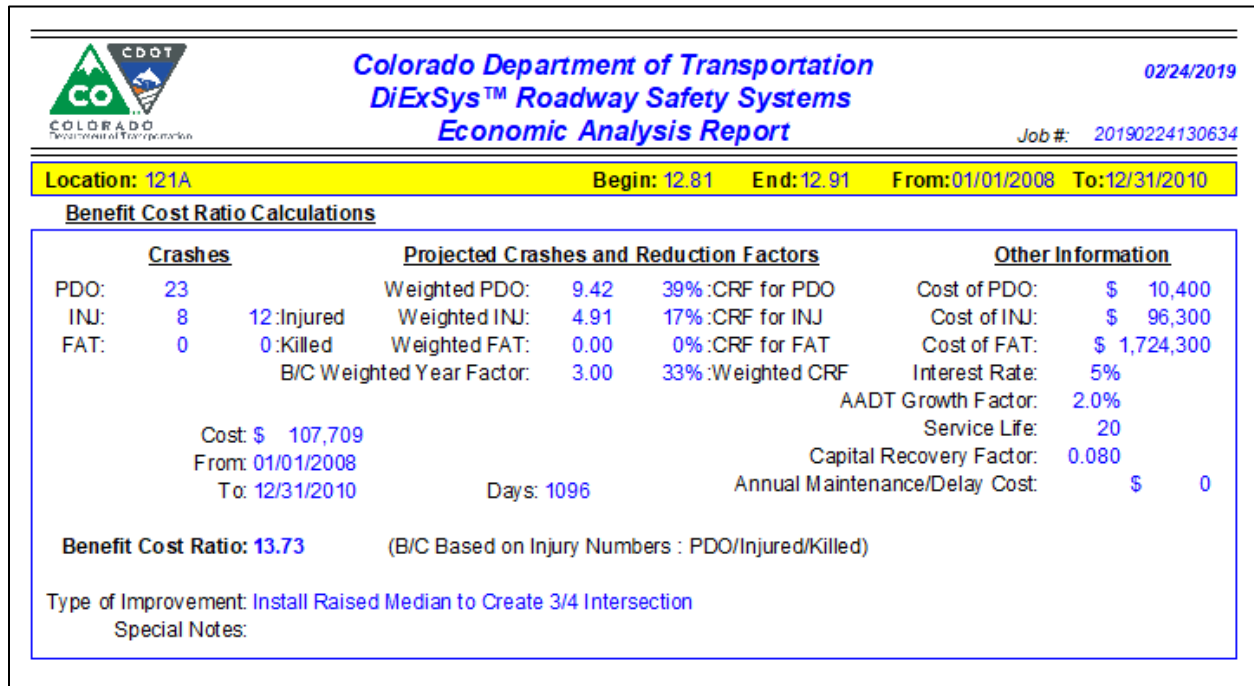
attempting to make an illegal westbound left-turn and a northbound through vehicle. The No-Build After crashes were estimated using the change in SH 121A traffic volumes between the before and after period, as found in **Table 1** (increase is 10% = $|1-(53,650/48,750)|$).

Table 4 – Results of Crash Analyses

| | Before | After | No-Build After |
|---|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2013 to 12/31/2015 (3 yr.) | 1/1/2013 to 12/31/2015 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 28 | 22 | 31 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 7 (11) | 8 (10) | 8 (12) |
| PDO | 21 | 14 | 23 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | NA / 17% / 39% | |
| Rear-End – Total | 20 | 13 | 22 |
| Injury (injuries) | 4 (7) | 4 (4) | 4 (8) |
| PDO | 16 | 9 | 18 |
| % Reduction in Total (Injuries/PDO) | | 50% / 50% | |
| Approach Turn – Total | 4 | 0 | 4 |
| Injury (injuries) | 3 (4) | 0 (0) | 3 (4) |
| PDO | 1 | 0 | 1 |
| % Reduction in Total (Injuries/PDO) | | 100% / 100% | |
| Broadside – Total | 1 | 2 | 1 |
| Injury (injuries) | 0 (0) | 1 (2) | 0 (0) |
| PDO | 1 | 1 | 1 |
| % Reduction in Total (Injuries/PDO) | | 100% / 0% | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes at the intersection. **A calculated B/C ratio of 13.73 was ultimately realized.** This outcome displays that this safety improvement project was likely justified from both safety and cost-effectiveness standpoints.

Figure 3 – Benefit Cost Analysis





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

CDOT Project # 17526 02/20/2019
Exhibit 1

Job #: 20190220142312

Location: 121A Begin: 12.81 End: 12.91 From:01/01/2008 To:12/31/2010

| Severity | |
|---------------|--------------------|
| PDO: | 21 |
| INJ: | 7 11 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 28 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 1 |
| Two Vehicles: | 19 |
| Three or More: | 8 |
| Unknown: | 0 |
| Total: | 28 |

| Location | |
|------------------|-----------|
| On Road: | 23 |
| Off Road Left: | 1 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 4 |
| Total: | 28 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 24 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 3 |
| Dark - Unlighted: | 0 |
| Unknown: | 0 |
| Total: | 28 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 26 |
| Rain: | 1 |
| Snow/Sleet/Hail: | 1 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 28 |

| Crash Rates | |
|---------------|-------------------------|
| PDO: | 7.71 * * MVMT |
| INJ: | 2.57 * ** 100 MVMT |
| FAT: | 0.00 ** |
| Total: | 10.28 * |

| Crash Type | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 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: | 20 | Delineator Post: | 0 |
| Sideswipe (Same): | 2 | 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: | 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: | 28 |
| Concrete Barrier: | 1 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | | | |
|-------------------------------|----|-----------------------------|---|---------------|-----------|
| Mainline: | 28 | M: | 0 | N: | 0 |
| Crossroad (A): | 0 | O: | 0 | P: | 0 |
| Ramps | | Left Frontage Rd (L): | 0 | | |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 | | |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 | | |
| D: 0 H: 0 T: 0 | | Unknown: | 0 | Total: | 28 |
| E: 0 I: 0 | | | | | |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 11 |
| At Driveway Access: | 2 |
| Intersection Related: | 5 |
| Non Intersection: | 10 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 28 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 25 |
| Wet: | 1 |
| 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: | 28 |

ADT: 48,733 Length: 0.05



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

CDOT Project # 17526 02/20/2019
 Exhibit 1

Job #: 20190220142312

Location: 121A **Begin: 12.81** **End: 12.91** **From:01/01/2008** **To:12/31/2010**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 18 | 17 | 2 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 2 | 1 | 1 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 7 | 8 | 4 |
| 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 | 1 | 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 | 1 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 28 | 27 | 8 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 12 | 8 | 1 |
| Slowing: | 6 | 6 | 2 |
| Stopped in Traffic: | 1 | 12 | 5 |
| Making Right Turn: | 2 | 0 | 0 |
| Making Left Turn: | 4 | 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 | 1 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 28 | 27 | 8 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 11 | 25 | 8 |
| Asleep at the Wheel: | 0 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 1 | 0 | 0 |
| Driver Inexperience: | 4 | 0 | 0 |
| Driver Fatigue: | 1 | 0 | 0 |
| Driver Preoccupied: | 3 | 2 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 8 | 0 | 0 |
| Total: | 28 | 27 | 8 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 19 | 21 | 6 |
| Northeast: | 0 | 0 | 0 |
| East: | 1 | 0 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 7 | 6 | 2 |
| Southwest: | 0 | 0 | 0 |
| West: | 1 | 0 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 28 | 27 | 8 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 27 | 27 | 8 |
| 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: | 28 | 27 | 8 |

ADT: 48,733 Length: 0.05



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

CDOT Project # 17526 02/20/2019
Exhibit 2

Job #: 20190220142609

Location: 121A Begin: 12.81 End: 12.91 From:01/01/2013 To:12/31/2015

| Severity | |
|---------------|--------------------|
| PDO: | 14 |
| INJ: | 8 10 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 22 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 2 |
| Two Vehicles: | 13 |
| Three or More: | 7 |
| Unknown: | 0 |
| Total: | 22 |

| Location | |
|------------------|-----------|
| On Road: | 21 |
| Off Road Left: | 1 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 22 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 19 |
| Dawn or Dusk: | 0 |
| Dark - Lighted: | 2 |
| Dark - Unlighted: | 1 |
| Unknown: | 0 |
| Total: | 22 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 18 |
| Rain: | 2 |
| Snow/Sleet/Hail: | 1 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 1 |
| Total: | 22 |

| Crash Rates | |
|---------------|-------------------------|
| PDO: | 4.67 * * MVMT |
| INJ: | 2.67 * ** 100 MVMT |
| FAT: | 0.00 ** |
| Total: | 7.34 * |

| Crash Type | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 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: | 13 | Delineator Post: | 0 |
| Sideswipe (Same): | 4 | 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: | 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: | 22 |
| Concrete Barrier: | 0 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | | | |
|-------------------------------|----|-----------------------------|---|---------------|-----------|
| Mainline: | 22 | M: | 0 | N: | 0 |
| Crossroad (A): | 0 | O: | 0 | P: | 0 |
| Ramps | | Left Frontage Rd (L): | 0 | | |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 | | |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 | | |
| D: 0 H: 0 T: 0 | | Unknown: | 0 | Total: | 22 |
| E: 0 I: 0 | | | | | |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 8 |
| At Driveway Access: | 0 |
| Intersection Related: | 5 |
| Non Intersection: | 9 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 22 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 17 |
| Wet: | 4 |
| Muddy: | 0 |
| Snowy: | 0 |
| Icy: | 1 |
| Slushy: | 0 |
| Foreign Material: | 0 |
| With Road Treatment: | 0 |
| Dry w/Icy Road Treatment: | 0 |
| Wet w/Icy Road Treatment: | 0 |
| Snowy w/Icy Road Treatment: | 0 |
| Icy w/Icy Road Treatment: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 22 |

ADT: 53,667 Length: 0.05



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

CDOT Project # 17526 02/20/2019
 Exhibit 2

Job #: 20190220142609

Location: 121A **Begin: 12.81** **End: 12.91** **From:01/01/2013** **To:12/31/2015**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 10 | 7 | 3 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 4 | 4 | 2 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 6 | 7 | 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 | 1 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 22 | 20 | 7 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 11 | 8 | 1 |
| Slowing: | 1 | 2 | 1 |
| Stopped in Traffic: | 0 | 9 | 4 |
| Making Right Turn: | 3 | 0 | 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: | 1 | 0 | 0 |
| Starting in Traffic: | 0 | 0 | 0 |
| Parked: | 0 | 0 | 0 |
| Changing Lanes: | 3 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 1 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 22 | 20 | 7 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 4 | 19 | 7 |
| 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: | 4 | 0 | 0 |
| Driver Unfamiliar with Area: | 2 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 8 | 1 | 0 |
| Total: | 22 | 20 | 7 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 16 | 17 | 6 |
| Northeast: | 0 | 0 | 0 |
| East: | 0 | 0 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 4 | 3 | 1 |
| Southwest: | 0 | 0 | 0 |
| West: | 2 | 0 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 22 | 20 | 7 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 20 | 20 | 7 |
| 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: | 22 | 20 | 7 |

ADT: 53,667 Length: 0.05

Project Information

Project Name: 64th Avenue / Simms Street Left Turn Lanes

Project Description: Realign eastbound/westbound left turn lanes

CDOT Region: 6 **Project Def:** 17528 **County:** Jefferson

Location: 64th Ave/Simms St **Length:** N/A

Schedule: **Work Start Date:** Approx. 6/10 **Completion Date:** Approx. 5/11

Problem Description: The five-year crash history (2004 – 2008) showed that there was a total of 6 injury crashes and 31 PDO crashes at this intersection. Of the 37 crashes, 16 were approach turn type crashes.

Improvement Description: Between June 2010 and May 2011, the eastbound and westbound left turn lanes were realigned. The median was removed and the lanes were shifted to allow more sight distance. The cost of construction was \$104,341.

The FHEP application anticipated that an 35% reduction in approach turn crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 4.73.

Summary and Findings

The analysis of safety before and after the improvements at this intersection shows an increase in the number of crashes and an increase in the number of injuries. There were 29 total crashes during the three-year period before the improvements were made (2006 – 2008). In the three years after construction (2012 – 2014), the number of crashes increased to 41. The ADT increased from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was an increase in the number of rear-end and approach turn crashes while there was a decrease in the number of broadside crashes after the completion of the project.

There was an increase in injury crashes, the number of injuries increased from 8 injuries in the three years before construction to 11 injuries in the three years after construction. The number of PDO increased from 22 in the before period to 32 in the after period. Since there were no decreases in overall crash numbers, it is not meaningful to attempt to derive a benefit cost ratio for this project as doing so would result in negative values. The result is an improvement that was not justified from the safety improvement or cost effectiveness standpoints. Prior to construction this intersection performed as expected from the frequency standpoint, and better than expected from the severity standpoint, it exhibited no crash patterns readily susceptible to correction. It is not unexpected that no improvement was observed in the post construction period.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records at the intersection of 64th Avenue and Simms Street in Arvada shows an increase in the number of crashes from 29 during the three-year period (2006 to 2008) before the improvements to 41 during the three-year after period (2012 to 2014) (**Table 1**). The number of serious crashes also showed an increase in the after period:

- Before (2006 – 2008) – No fatal crashes and 7 injury crashes with 8 injuries
- After (2012 – 2014) – No fatal crashes and 9 injury crashes with 11 injuries

The crash rate at this intersection increased in the after period:

- Before (2006 – 2008) – 0.84 crashes per million entering vehicles (cpmev)
- After (2012 – 2014) – 1.13 cpmev

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2006 to 12/31/2008 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) |
| AADT (64 th Ave/Simms St) | approx. 22,100 vpd / approx. 9,250 vpd | approx. 23,900 vpd / approx. 9,250 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 29 | 41 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 7 (8) | 9 (11) |
| Property Damage Only | 22 | 32 |
| Crash Types: # (%) [significance] | | |
| Rear- End | 14 (48.3%) | 18 (43.9%) |
| Approach Turn | 5 (17.2%) | 13 (31.7%) [99.7%] |
| Broadside | 5 (17.2%) | 3 (7.3%) |

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 (**Figures 1**) and for fatal and injury crashes (**Figures 2**) reflect a no improvement in the crash record for this project. LOSS was not improved, with LOSS III in the before period and LOSS IV in the after period for the frequency of crashes. For the severity of crashes, the intersection went from LOSS II in the before period to LOSS III in the after period. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes
64th Avenue / Simms Street
Before: 2006 to 2008 After: 2012 to 2014

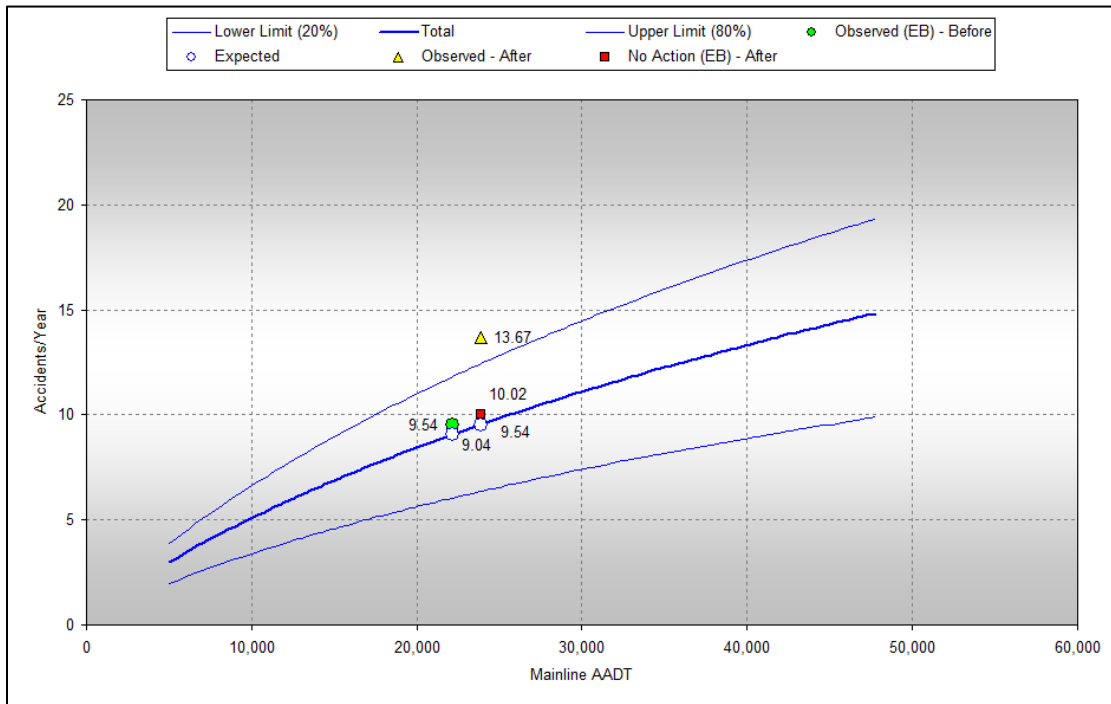


Figure 2 – SPF for Injury and Fatal Crashes

64th Avenue / Simms Street
 Before: 2006 to 2008 After: 2012 to 2014

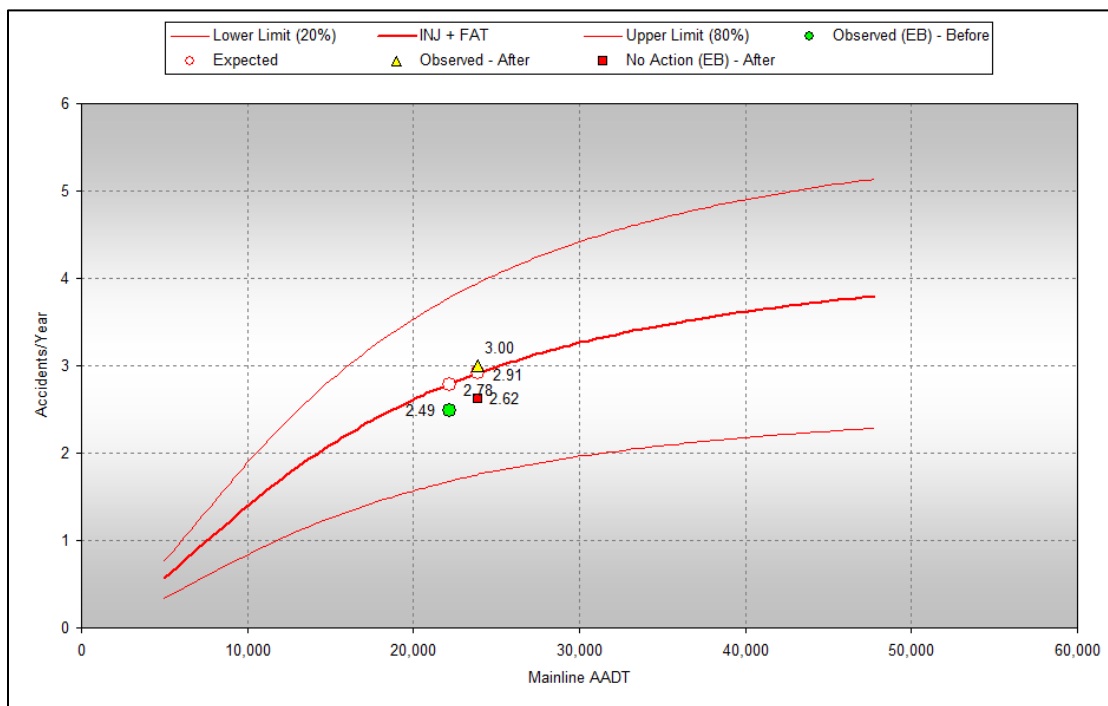


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action After |
|------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| EB Correction: | Yes | No | Yes |
| SPF Graph | Signalized 4-Lane 4-Leg Intersection | Signalized 4-Lane 4-Leg Intersection | Signalized 4-Lane 4-Leg Intersection |
| Total Crashes: | | | |
| LOSS | LOSS III | LOSS IV | LOSS III |
| CPY | 9.54 | 13.67 | 10.02 |
| Mean CPY | 9.04 | 9.54 | 9.54 |
| Proportion of Mean | 1.05 | 1.43 | 1.05 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS II | LOSS III | LOSS II |
| CPY | 2.49 | 3.00 | 2.62 |
| Mean CPY | 2.78 | 2.91 | 2.91 |
| Proportion of Mean | 0.90 | 1.03 | 0.90 |

A more detailed review of the before and after crash record shows the crash types that were most affected by the intersection changes. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the changes: rear-end, approach turn, and broadside. After the intersection changes, there was an increase in rear-end crashes (and related injuries). The number of approach turn crashes remained the same, but the number of injuries increased. There was a decrease in broadside crash types with no injuries in either period. The No-Build After crashes were estimated using the change in 64th

Avenue traffic volumes between the before and after period, as found in **Table 1** (increase is 8% = |1-(23,900/22,100)|).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|--|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2006 to 12/31/2008 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 29 | 41 | 31 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 7 (8) | 9 (11) | 7 (9) |
| PDO | 22 | 32 | 24 |
| % Reduction in Total (Injuries/PDO) | | NA / NA | |
| Rear-End – Total | 14 | 18 | 15 |
| Injury (injuries) | 1 (1) | 3 (3) | 1 (1) |
| PDO | 13 | 15 | 14 |
| % Reduction in Total (Injuries/PDO) | | NA / NA | |
| Approach Turn – Total | 5 | 13 | 5 |
| Injury (injuries) | 4 (4) | 4 (6) | 4 (4) |
| PDO | 1 | 9 | 1 |
| % Reduction in Total (Injuries/PDO) | | NA / NA | |
| Broadside – Total | 5 | 3 | 5 |
| Injury (injuries) | 0 (0) | 0 (0) | 0 (0) |
| PDO | 5 | 3 | 5 |
| % Reduction in Total (Injuries/PDO) | | NA / 40% | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. However, as previously mentioned, it is not meaningful to provide benefit to cost analysis for this case because there was no measurable safety benefit realized from the construction. Therefore, no B/C report is provided for this location.



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

CDOT Project # 17528 06/02/2019
Exhibit 1

Job #: 20190602145037

Location: Accident History for 64TH and SIMMS **From:01/01/2006 To:12/31/2008**

| Severity | |
|---------------|--------------|
| PDO: | 22 |
| INJ: | 7 8 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 29 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 0 |
| Two Vehicles: | 28 |
| Three or More: | 1 |
| Unknown: | 0 |
| Total: | 29 |

| Location | |
|------------------|-----------|
| On Road: | 18 |
| Off Road Left: | 0 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 11 |
| Total: | 29 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 22 |
| Dawn or Dusk: | 2 |
| Dark - Lighted: | 4 |
| Dark - Unlighted: | 1 |
| Unknown: | 0 |
| Total: | 29 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 16 |
| Rain: | 2 |
| Snow/Sleet/Hail: | 1 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 10 |
| Total: | 29 |

| Crash Rates | |
|---------------|-------------------|
| PDO: | N/A * * MVMT |
| INJ: | N/A * ** 100 MVMT |
| FAT: | N/A ** |
| Total: | N/A * |

| Crash Type | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 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: | 14 | Delineator Post: | 0 |
| Sideswipe (Same): | 1 | Fence: | 0 |
| Sideswipe (Opposite): | 1 | Tree: | 0 |
| Approach Turn: | 5 | Large Boulders or Rocks: | 0 |
| Overtaking Turn: | 0 | 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: | 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: | 29 |
| Concrete Barrier: | 0 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | |
|-------------------------------|----|------------------------------|------------------|
| Mainline: | 29 | M: | 0 N: 0 O: 0 P: 0 |
| Crossroad (A): | 0 | | |
| Ramps | | Left Frontage Rd (L): | 0 |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 |
| D: 0 H: 0 T: 0 | | Unknown: | 0 |
| E: 0 I: 0 | | Total: | 29 |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 22 |
| At Driveway Access: | 0 |
| Intersection Related: | 7 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 29 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 26 |
| Wet: | 1 |
| Muddy: | 0 |
| Snowy: | 1 |
| Icy: | 0 |
| Slushy: | 1 |
| Foreign Material: | 0 |
| With Road Treatment: | 0 |
| Dry w/Icy Road Treatment: | 0 |
| Wet w/Icy Road Treatment: | 0 |
| Snowy w/Icy Road Treatment: | 0 |
| Icy w/Icy Road Treatment: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 29 |



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

CDOT Project # 17528 06/02/2019
Exhibit 1

Job #: 20190602145037

Location: Accident History for 64TH and SIMMS **From:01/01/2006 To:12/31/2008**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 21 | 17 | 1 |
| Passenger Car/Van w/Trl: | 0 | 1 | 0 |
| Pickup Truck/Utility Van: | 4 | 5 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 2 | 5 | 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 | 1 | 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: | 29 | 29 | 1 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 10 | 15 | 0 |
| Slowing: | 1 | 1 | 0 |
| Stopped in Traffic: | 0 | 10 | 1 |
| Making Right Turn: | 7 | 2 | 0 |
| Making Left Turn: | 8 | 0 | 0 |
| 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 | 1 | 0 |
| Changing Lanes: | 1 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 29 | 29 | 1 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 11 | 17 | 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: | 7 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 1 | 0 | 0 |
| Unknown: | 8 | 12 | 1 |
| Total: | 29 | 29 | 1 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 3 | 3 | 0 |
| Northeast: | 1 | 0 | 0 |
| East: | 8 | 8 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 7 | 6 | 0 |
| Southwest: | 1 | 0 | 0 |
| West: | 8 | 12 | 1 |
| Northwest: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 29 | 29 | 1 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 28 | 29 | 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: | 29 | 29 | 1 |



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

CDOT Project # 17528 06/02/2019

Exhibit 2

Job #: 20190602151246

Location: Accident History for 64TH and SIMMS **From:01/01/2012 To:12/31/2014**

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 32 | |
| INJ: | 9 | 11 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 41 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 3 |
| Two Vehicles: | 32 |
| Three or More: | 6 |
| Unknown: | 0 |
| Total: | 41 |

Location

| | |
|------------------|-----------|
| On Road: | 38 |
| Off Road Left: | 1 |
| Off Road Right: | 2 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 41 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 29 |
| Dawn or Dusk: | 0 |
| Dark - Lighted: | 11 |
| Dark - Unlighted: | 1 |
| Unknown: | 0 |
| Total: | 41 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 21 |
| Rain: | 2 |
| Snow/Sleet/Hail: | 1 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 1 |
| Unknown: | 16 |
| Total: | 41 |

Crash Rates

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

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 2 | Culvert/Headwall: | 0 |
| Broadside: | 3 | Embankment: | 0 |
| Head On: | 0 | Curb: | 1 |
| Rear End: | 18 | Delineator Post: | 0 |
| Sideswipe (Same): | 0 | Fence: | 0 |
| Sideswipe (Opposite): | 0 | Tree: | 0 |
| Approach Turn: | 13 | Large Boulders or Rocks: | 0 |
| Overtaking Turn: | 1 | Barricade: | 0 |
| Parked Motor Vehicle: | 0 | Wall/Building: | 0 |
| Railway Vehicle: | 0 | Crash Cushion: | 0 |
| Bicycle: | 1 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 0 |
| Domestic Animal: | 0 | Total Fixed Objects: | 3 |
| Wild Animal: | 0 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 1 | Vehicle Cargo/Debris: | 0 |
| Traffic Signal Pole: | 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: | 41 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----------------------|------------------------------------|
| Mainline: | 41 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | Left Frontage Rd (L): | 0 |
| C: 0 G: 0 K: 0 | Rt Frontage Rd (R): | 0 |
| D: 0 H: 0 T: 0 | HOV Lanes (V): | 0 |
| E: 0 I: 0 | Unknown: | 0 |
| | Total: | 41 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 26 |
| At Driveway Access: | 0 |
| Intersection Related: | 15 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 41 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 38 |
| Wet: | 2 |
| Muddy: | 0 |
| Snowy: | 0 |
| Icy: | 1 |
| Slushy: | 0 |
| Foreign Material: | 0 |
| With Road Treatment: | 0 |
| Dry w/Icy Road Treatment: | 0 |
| Wet w/Icy Road Treatment: | 0 |
| Snowy w/Icy Road Treatment: | 0 |
| Icy w/Icy Road Treatment: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 41 |



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

CDOT Project # 17528 06/02/2019
Exhibit 2

Job #: 20190602151246

Location: Accident History for 64TH and SIMMS **From:01/01/2012 To:12/31/2014**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 15 | 19 | 2 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 6 | 4 | 2 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 16 | 14 | 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: | 0 | 1 | 0 |
| Bicycle: | 1 | 0 | 0 |
| Motorized Bicycle: | 0 | 0 | 0 |
| Farm Equipment: | 0 | 0 | 0 |
| Hit and Run - Unknown: | 0 | 0 | 0 |
| Other: | 2 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 41 | 38 | 6 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 19 | 15 | 0 |
| Slowing: | 2 | 2 | 0 |
| Stopped in Traffic: | 1 | 16 | 6 |
| Making Right Turn: | 4 | 1 | 0 |
| Making Left Turn: | 13 | 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 | 1 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 2 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 41 | 38 | 6 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 3 | 21 | 2 |
| Asleep at the Wheel: | 0 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 7 | 0 | 0 |
| Driver Fatigue: | 1 | 0 | 0 |
| Driver Preoccupied: | 14 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 1 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 15 | 17 | 4 |
| Total: | 41 | 38 | 6 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 7 | 5 | 2 |
| Northeast: | 0 | 0 | 0 |
| East: | 13 | 14 | 3 |
| Southeast: | 0 | 0 | 0 |
| South: | 8 | 7 | 1 |
| Southwest: | 1 | 1 | 0 |
| West: | 12 | 11 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 41 | 38 | 6 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 40 | 38 | 6 |
| 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 | 38 | 6 |

Project Information

Project Name: SH 121A Raised Median

Project Description: Install a raised median

CDOT Region: 6 Project Def: 17529 County: Jefferson

Location: SH 121A Mile Points: 16.14 – 16.26 Length: 0.12 miles

Schedule: Work Start Date: Approx. 6/10 Completion Date: Approx. 5/11

Problem Description: The four-year crash history (2001 – 2004) showed that there was a total of 12 injury crashes, and 48 PDO driveway crashes along this corridor. Of the 60 crashes, 36 were approach turn type crashes.

Improvement Description: Between June 2010 and May 2011 a raised median was installed to extend the existing median from 45th Avenue to 44th Avenue. The cost of construction was \$72,352.

The FHEP application anticipated that an 20% reduction in crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 10.27.

Summary and Findings

The analysis of safety before and after the improvements along this corridor show a large decrease in crashes. There were 37 total driveway crashes during the three-year period before the improvements were made (2007 – 2009). In the three years after construction (2012 – 2014), the number of crashes was 6. The ADT decreased slightly from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a decrease in the number of approach turn and broadside crashes after the completion of the project. There was a large decrease in injury crashes and the number of injuries. There were 12 injury crashes in the three years before construction and 2 injury crashes in the three years after construction. The number of PDO went from 25 in the before period to 4 in the after period. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 20 years for this project is **119.12** to one. The result is an improvement that was justified from the safety improvement and cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after driveway crash records from MP 16.14 to 16.26 shows a significant decrease in the number of crashes from 37 during the three-year period (2007 to 2009) before the improvements to 6 during the three-year after period (2012 to 2014) (**Table 1**). The number of serious crashes also decreased in the after period:

- Before (2006 – 2009) – No fatal crashes and 12 injury crashes with 17 injuries
- After (2012 – 2014) – No fatal crashes and 2 injury crashes with 2 injuries

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|----------------------------|--------------------------------|--------------------------------|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) |
| AADT (SH 121A) | 45,650 vpd | 45,350 vpd |
| Filters: | Driveway | Driveway |
| Total Crashes | 37 | 6 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 12 (17) | 2 (2) |
| Property Damage Only | 25 | 4 |
| Crash Types: # (%) | | |
| Approach Turn | 28 (75.7%) | 1 (16.7%) |
| Broadside | 5 (13.5%) | 2 (33.3%) |
| Rear-End | 2 (5.4%) | 0 |
| Sideswipe Same Dir. | 1 (2.7%) | 2 (33.3%) |
| Sideswipe Opposite Dir. | 1 (2.7%) | 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 an urban corridor, so this analysis could not be completed.

A more detailed review of the before and after crash record shows the crash types that were most affected by the project. **Table 2** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: approach turn and broadside crashes. The improvement appears to have significantly reduced the number of approach turn crashes on the segment. The No-Build After crashes were estimated using the change in SH 121 traffic volumes between the before and after period, as found in **Table 1** (decrease is $1\% = |1-(45,650/45,650)|$).

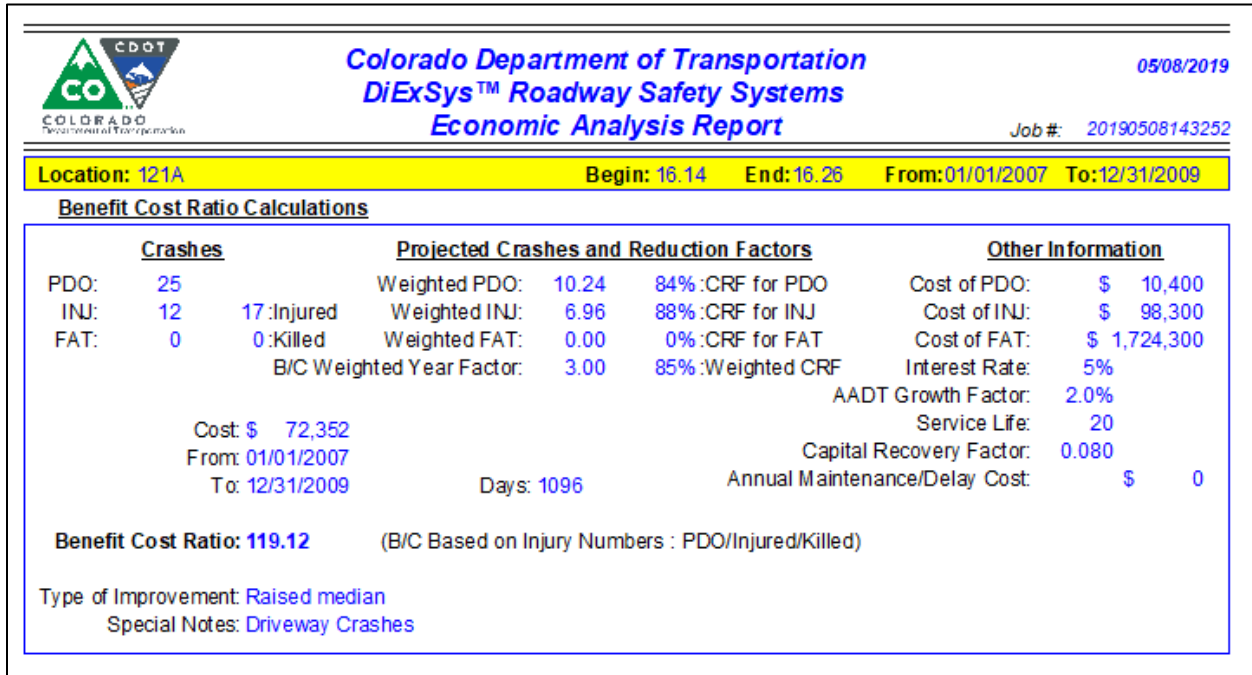
Table 2 – Results of Crash Analyses

| | Before | After | No-Build After |
|---|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 37 | 6 | 37 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 12 (17) | 2 (2) | 12 (17) |
| PDO | 25 | 4 | 25 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | NA / 88% / 84% | |
| Approach Turn – Total | 28 | 1 | 28 |
| Injury (injuries) | 10 (10) | 0 (0) | 10 (10) |
| PDO | 18 | 1 | 18 |
| % Reduction in Total (Injuries/PDO) | | 100% / 94% | |
| Broadside – Total | 5 | 2 | 5 |
| Injury (injuries) | 2 (7) | 1 (1) | 2 (7) |
| PDO | 3 | 1 | 3 |
| % Reduction in Total (Injuries/PDO) | | 86% / 67% | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 1** for all crashes at the intersection. **A calculated B/C ratio of 119.12 was ultimately realized.** This outcome displays that this safety improvement project was justified.

Following construction of the raised median and related closures of access points the traffic was likely rerouted to existing intersection. When all crashes on SH 121A MP 16.14-16.26 are examined in the before period and compared with the after we observe 9% reduction in PDO and 52% reduction in Injuries (34% in Injury crashes). Resulting B/C analysis would also suggest a highly effective safety project.

Figure 1 – Benefit Cost Analysis





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

CDOT Project # 17529 05/08/2019

Exhibit 1

Job #: 20190508132918

Location: 121A **Begin: 16.14** **End: 16.26** **From:01/01/2007** **To:12/31/2009**

| Severity | |
|---------------|---------------------|
| PDO: | 25 |
| INJ: | 12 17 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 37 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 0 |
| Two Vehicles: | 34 |
| Three or More: | 3 |
| Unknown: | 0 |
| Total: | 37 |

| Location | |
|------------------|-----------|
| On Road: | 26 |
| Off Road Left: | 0 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 11 |
| Total: | 37 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 36 |
| Dawn or Dusk: | 0 |
| Dark - Lighted: | 1 |
| Dark - Unlighted: | 0 |
| Unknown: | 0 |
| Total: | 37 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 35 |
| Rain: | 2 |
| Snow/Sleet/Hail: | 0 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 37 |

| Crash Rates | |
|---------------|-------------------------|
| PDO: | 4.20 * * MVMT |
| INJ: | 2.02 * ** 100 MVMT |
| FAT: | 0.00 ** |
| Total: | 6.22 * |

| Crash Type | |
|-----------------------------|-----------|
| Overtuning: | 0 |
| Other Non Collision: | 0 |
| Pedestrians: | 0 |
| Broadside: | 5 |
| Head On: | 0 |
| Rear End: | 2 |
| Sideswipe (Same): | 1 |
| Sideswipe (Opposite): | 1 |
| Approach Turn: | 28 |
| Overtaking Turn: | 0 |
| Parked Motor Vehicle: | 0 |
| Railway Vehicle: | 0 |
| Bicycle: | 0 |
| Motorized Bicycle: | 0 |
| Domestic Animal: | 0 |
| Wild Animal: | 0 |
| Light/Utility Pole: | 0 |
| Traffic Signal Pole: | 0 |
| Sign: | 0 |
| Bridge Rail: | 0 |
| Guard Rail: | 0 |
| Cable Rail: | 0 |
| Concrete Barrier: | 0 |
| Bridge Abutment: | 0 |
| Column/Pier: | 0 |
| Culvert/Headwall: | 0 |
| Embankment: | 0 |
| Curb: | 0 |
| Delineator Post: | 0 |
| Fence: | 0 |
| Tree: | 0 |
| Large Boulders or Rocks: | 0 |
| Barricade: | 0 |
| Wall/Building: | 0 |
| Crash Cushion: | 0 |
| Mailbox: | 0 |
| Other Fixed Object: | 0 |
| Total Fixed Objects: | 0 |
| Rocks in Roadway: | 0 |
| Vehicle Cargo/Debris: | 0 |
| Road Maintenance Equipment: | 0 |
| Involving Other Object: | 0 |
| Total Other Objects: | 0 |
| Unknown: | 0 |
| Total: | 37 |

| Mainline/Ramps/Frontage Roads | |
|------------------------------------|-----------|
| Mainline: | 37 |
| Crossroad (A): | 0 |
| Ramps | |
| B: 0 F: 0 J: 0 | |
| C: 0 G: 0 K: 0 | |
| D: 0 H: 0 T: 0 | |
| E: 0 I: 0 | |
| Frontage/Ramp Intersections | |
| M: 0 N: 0 O: 0 P: 0 | |
| Left Frontage Rd (L): | 0 |
| Rt Frontage Rd (R): | 0 |
| HOV Lanes (V): | 0 |
| Unknown: | 0 |
| Total: | 37 |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 0 |
| At Driveway Access: | 37 |
| Intersection Related: | 0 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 37 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 36 |
| 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: | 37 |

ADT: 45,633 Length: 0.11



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

CDOT Project # 17529 05/08/2019

Exhibit 1

Job #: 20190508132918

Location: 121A **Begin: 16.14** **End: 16.26** **From:01/01/2007** **To:12/31/2009**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 26 | 21 | 2 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 6 | 8 | 1 |
| Pickup Truck/Utility Van w/Trl: | 0 | 1 | 0 |
| SUV: | 4 | 5 | 0 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 0 | 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: | 0 | 0 | 0 |
| Other: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 37 | 37 | 3 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 3 | 30 | 0 |
| Slowing: | 0 | 2 | 0 |
| Stopped in Traffic: | 0 | 3 | 2 |
| Making Right Turn: | 3 | 0 | 0 |
| Making Left Turn: | 31 | 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 | 1 |
| Changing Lanes: | 0 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 37 | 37 | 3 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 27 | 37 | 3 |
| 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: | 2 | 0 | 0 |
| Driver Unfamiliar with Area: | 5 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 2 | 0 | 0 |
| Total: | 37 | 37 | 3 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 29 | 2 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 6 | 1 | 1 |
| Southeast: | 0 | 0 | 0 |
| South: | 2 | 34 | 2 |
| Southwest: | 0 | 0 | 0 |
| West: | 0 | 0 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 37 | 37 | 3 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 36 | 37 | 3 |
| 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: | 37 | 37 | 3 |

ADT: 45,633 **Length: 0.11**



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

CDOT Project # 17529 05/08/2019
Exhibit 2

Job #: 20190508133058

Location: 121A Begin: 16.14 End: 16.26 From:01/01/2012 To:12/31/2014

| Severity | |
|---------------|-------------------|
| PDO: | 4 |
| INJ: | 2 2 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 6 |

| Number of Vehicles | |
|--------------------|----------|
| One Vehicle: | 0 |
| Two Vehicles: | 4 |
| Three or More: | 2 |
| Unknown: | 0 |
| Total: | 6 |

| Location | |
|------------------|----------|
| On Road: | 6 |
| Off Road Left: | 0 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 6 |

| Lighting Conditions | |
|---------------------|----------|
| Daylight: | 6 |
| Dawn or Dusk: | 0 |
| Dark - Lighted: | 0 |
| Dark - Unlighted: | 0 |
| Unknown: | 0 |
| Total: | 6 |

| Weather Conditions | |
|--------------------|----------|
| None: | 6 |
| Rain: | 0 |
| Snow/Sleet/Hail: | 0 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 6 |

| Crash Rates | |
|---------------|-------------------------|
| PDO: | 0.68 * * MVMT |
| INJ: | 0.34 * ** 100 MVMT |
| FAT: | 0.00 ** |
| Total: | 1.01 * |

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

| Mainline/Ramps/Frontage Roads | |
|-------------------------------|----------|
| Mainline: | 6 |
| Crossroad (A): | 0 |
| Total: | 6 |

| Frontage/Ramp Intersections | |
|-----------------------------|----------|
| M: | 0 |
| N: | 0 |
| O: | 0 |
| P: | 0 |
| Total: | 6 |

| Ramps | |
|---------------|----------|
| B: | 0 |
| C: | 0 |
| D: | 0 |
| E: | 0 |
| F: | 0 |
| G: | 0 |
| H: | 0 |
| I: | 0 |
| J: | 0 |
| K: | 0 |
| L: | 0 |
| T: | 0 |
| Total: | 6 |

| Road Description | |
|-----------------------|----------|
| At Intersection: | 0 |
| At Driveway Access: | 6 |
| Intersection Related: | 0 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 6 |

| Road Conditions | |
|------------------------------|----------|
| Dry: | 6 |
| 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: | 6 |

ADT: 45,333 Length: 0.11



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

CDOT Project # 17529 05/08/2019
Exhibit 2

Job #: 20190508133058

Location: 121A Begin: 16.14 End: 16.26 From:01/01/2012 To:12/31/2014

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|----------|----------|----------|
| Passenger Car/Van: | 2 | 4 | 2 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 1 | 1 | 0 |
| Pickup Truck/Utility Van w/Trl: | 1 | 0 | 0 |
| SUV: | 1 | 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: | 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: | 6 | 6 | 2 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|----------|----------|----------|
| Going Straight: | 0 | 6 | 1 |
| Slowing: | 0 | 0 | 0 |
| Stopped in Traffic: | 0 | 0 | 1 |
| Making Right Turn: | 4 | 0 | 0 |
| Making Left Turn: | 0 | 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: | 1 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 6 | 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: | 0 | 0 | 0 |
| Driver Inexperience: | 2 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 0 | 0 | 0 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 1 | 0 | 0 |
| Total: | 6 | 6 | 2 |

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

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|----------|----------|----------|
| No Impairment Suspected: | 6 | 6 | 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: | 6 | 6 | 2 |

ADT: 45,333 Length: 0.11

Project Information

Project Name: LCR 27 Realignment at MP 21.8

Project Description: Curve realignment and Side Slope Flattening

CDOT Region: 2 Project Def: 17569 County: Larimer

Location: Larimer CR 27 at MP 21.8

Mile Points: 21.76 to 21.84 Length: 0.08

Schedule: Work Start Date: 2012 Completion Date: 9/25/2012

Problem Description: Off road crashes at the curve resulting in injuries.

Improvement Description: The curve at this location was realigned to a condition of mild curvature and side slopes were flattened. This construction was completed on September 25, 2012.

The FHEP application anticipated that an overall crash reduction of 35% would be realized by these improvements.

Summary and Findings

The realignment and flattening of side slopes appear to have improved safety on this stretch of Larimer County Road 27. The analysis of safety performance for 4 years before and 4 years after the improvements showed an 80% reduction in all crashes from five in the before period (2008 to 2011) to one in the after period (2013 to 2016). The number of crashes involving bodily injury showed a 100% reduction from four crashes in the before-period to zero in the after-period. Four people were injured in the before-period.

The improved alignment likely has contributed to the reduction in crashes. We have provided a benefit/cost analysis based on the comparison of crashes in the before period to those in the after period. The cost associated with the improvement was \$220,000. The resulting ratio of benefits and cost for this project shows that benefits outweigh the costs with a B/C ratio of **5.47** to one, showing that the improvement was cost effective in terms of safety benefits.

Results of Safety Analyses

Using VZS and crash history provided by Larimer County, the review of before and after crash records showed the number of crashes decreased between the two study periods. The total number of crashes was five during the four-year period (2008 to 2011) before the curve flattening and one during the four-year after period (2013 to 2016) (see **Table 1**). The number of severe crashes decreased from four in the before period to zero in the after period. There were no fatal crashes during either the before or the after-period.

- Before (2008 – 2011) – 4 injury crashes with 4 people injured
- After (2013 – 2016) – No injury crashes

The Larimer County Road Information web site indicates that the average ADT for the before period was about 375 vehicles per day and about 425 for the after period, an increase of about 13%. Based on these traffic volume estimates the crash rates for this 0.08 mile stretch of Larimer County Road 27 were as shown below.

- Before (2008 – 2011): 91 crashes per million vehicles miles travelled (MVMT)
- After (2013 – 2016): 16 crashes per MVMT

Table 1 - Results of Overall Crash Analyses

| | Before | After |
|----------------------------|---|---|
| Time Period: | 1/1/2008 to 12/31/2011 (4 yr.) | 1/1/2013 to 12/31/2016 (4 yr.) |
| AADT | 375 vpd | 425 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | | |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 4 (4) | 0 (0) |
| Property Damage Only | 1 | 1 |
| Crash Types: # (%) | | |
| Fixed Object | 3 (60%) | 1 (100%) |
| Overturning | 2 (40%) | 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 intersection. As shown, using the \$220,000 project cost as the cost basis, the safety related B/C ratio for the improvement is 5.47, showing that the improvement was cost effective from the safety standpoint.

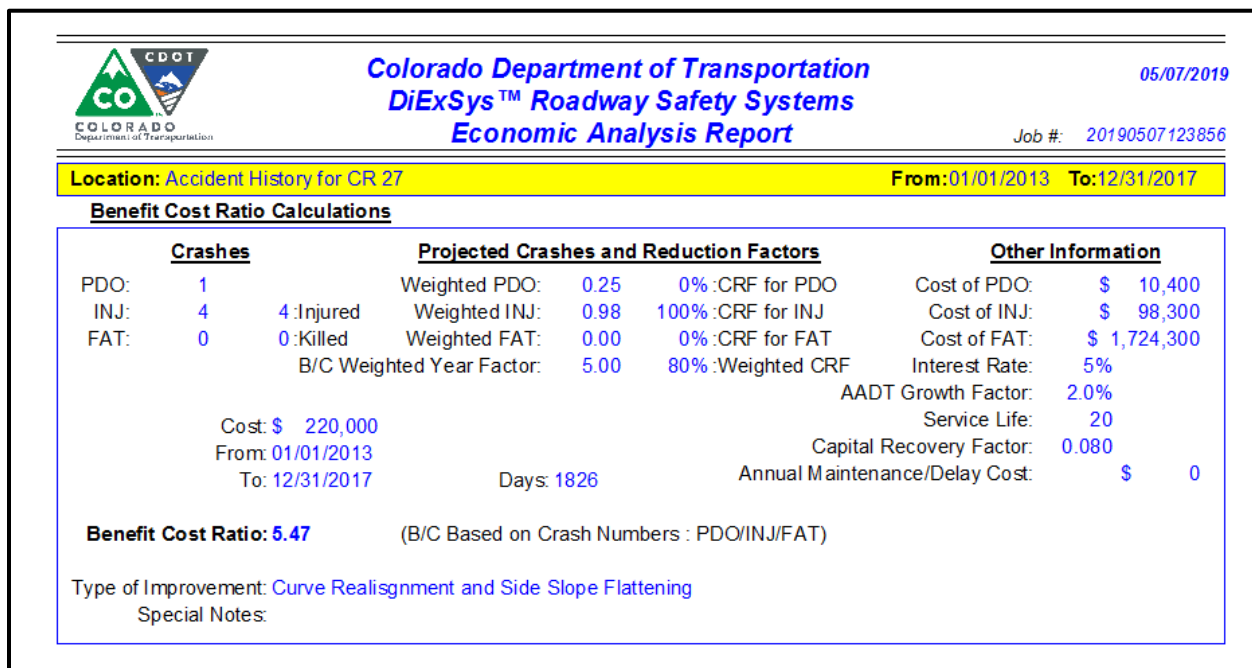


Figure 3 – Benefit Cost Analysis

The magnitude of safety problems on selected highway sections and intersections can typically 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, which allows for an assessment of the magnitude of the safety problem from a frequency standpoint. However, since this improvement applies to a localized cluster of crashes on a short stretch of roadway rather than a stretch of significant length or an intersection, it is not feasible to use the SPF methodology in this case. Accordingly, we are not providing a SPF analysis in this report.

A more detailed review of the before and after crash record shows the crash types that were most affected by the curve realignment. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: fixed object and overturning. The realignment substantially reduced the number of fixed object crashes, and overturning crashes were non-existent over the course of the after period (2013-2016). This is an expected outcome when eliminating relatively sharp curvature on a stretch of road. The No Build After crashes were estimated using the change in CR 27 traffic volumes between the before and after period, as found in **Table 1** (increase is 1.13 = 425/375).

| | Before | After | No Build After |
|--|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2008 to 12/31/2011 (4 yr.) | 1/1/2013 to 12/31/2016 (4 yr.) | 1/1/2013 to 12/31/2016 (4 yr.) |
| Crash Types: | | | |
| Total Crashes | 5 | 1 | 6 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 4 (4) | 0 (0) | 4 (4) |
| PDO | 1 | 1 | 1 |
| % Reduction in Total (Injuries/PDO) | | 80% (100% / 0%) | |
| Fixed Objects – Total | 3 | 1 | 3 |
| Injury (injuries) | 3 (3) | 0 (0) | 3 (3) |
| PDO | 0 | 1 | 0 |
| % Reduction in Total (Injuries/PDO) | | 67% (100% / N/A) | |
| Overturning – Total | 2 | 0 | 2 |
| Injury (injuries) | 1 (1) | 0 (0) | 1 (1) |
| PDO | 1 | 0 | 1 |
| % Reduction in Total (Injuries/PDO) | | 100% (100% / 100%) | |

Table 3 – Results of Crash Analyses

Project Information

Project Name: SH 287C / Pike Road Accel/Decel Lanes

Project Description: Install Accel/Decel Lanes

CDOT Region: 4 Project Def: 17574 County: Boulder

Location: SH 287C Mile Points: 313.90 Length: N/A

Schedule: Work Start Date: approx. 8/2010 Completion Date: 11/15/2012

Problem Description: The three-year crash history (2006 – 2008) showed that there was one fatal crash, 13 injury crashes, and 28 PDO crashes at this intersection. Of the 42 crashes, 26 were rear-end type crashes.

Improvement Description: Between August 2010 and November 15, 2012 the eastbound and westbound approach geometrics was reconfigured and a southbound acceleration lane was constructed. Additionally, the northbound and southbound left turns signals were changed from typical protected/permissive signal to a flashing yellow arrow. The cost of construction was \$303,184.

The FHEP application anticipated that an 30% reduction in rear-end crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 2.04.

Summary and Findings

The analysis of safety before and after the improvements at this intersection shows an increase in the total number of crashes and number of injuries. There were 42 total crashes during the three-year period before the improvements were made (2007 – 2009). In the three years after construction (2014 – 2016), the number of crashes was 47. The ADT increased from the before period to the after period.

A comparison of all crash types before and after the improvements were constructed showed that there was a decrease in the number of rear-ends and broadsides after the completion of the project. The number of approach turn crashes increased.

There was an approach turn fatality in the before period and no fatalities in the after period. There was an increase in injury crashes, the number of injuries increased from 22 injuries in the three years before construction to 30 injury in the three years after construction. The number of PDO went from 26 in the before period to 28 in the after period. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 10 years for this project is **2.48** to one. The result is an improvement that was justified from the safety improvement as well as cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records at the intersection of US 287C and Pike Road in Boulder County shows an increase in the number of crashes from 42 during the three-year period (2007 to 2009) before the improvements to 47 during the three-year after period (2014 to 2016) (**Table 1**). The number of serious crashes increased, although there were no fatalities in the after period:

- Before (2007 – 2009) – 1 fatal crash with 1 killed and 15 injury crashes with 22 injuries
- After (2014 – 2016) – No fatal crashes and 19 injury crashes with 30 injuries

The crash rate at this intersection decreased slightly in the after period:

- Before (2007 – 2009) – 1.30 crashes per million entering vehicles (cpmev)
- After (2014 – 2016) – 1.29 cpmev

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2007 to 12/31/209 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) |
| AADT (SH 287 / Pike Road) | 19,650 vpd / approx. 9,900 vpd | 22,700 vpd / approx. 10,600 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 42 | 47 |
| Fatal Crashes (Fatalities) | 1 (1) | 0 (0) |
| Injury Crashes (Injuries) | 15 (22) | 19 (30) |
| Property Damage Only | 26 | 28 |
| Crash Types: # (%) [significance] | | |
| Rear-End | 26 (61.9%) | 15 (31.9%) |
| Approach Turn | 11 (26.2%) [97.3%] | 26 (55.3%)[100%] |
| Broadside | 2 (4.8%) | 1 (2.1%) |

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 (Figures 1 and 2) and for fatal and injury crashes (Figures 3 and 4) reflect an increase in the crash record for this project. For both the frequency and severity of crashes, the intersection is LOSS IV in both the before and after periods. Table 2 provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes - Before
 SH 287C, MP 313.90 Pike Road
 Before: 2007 to 2009 After: 2014 to 2016

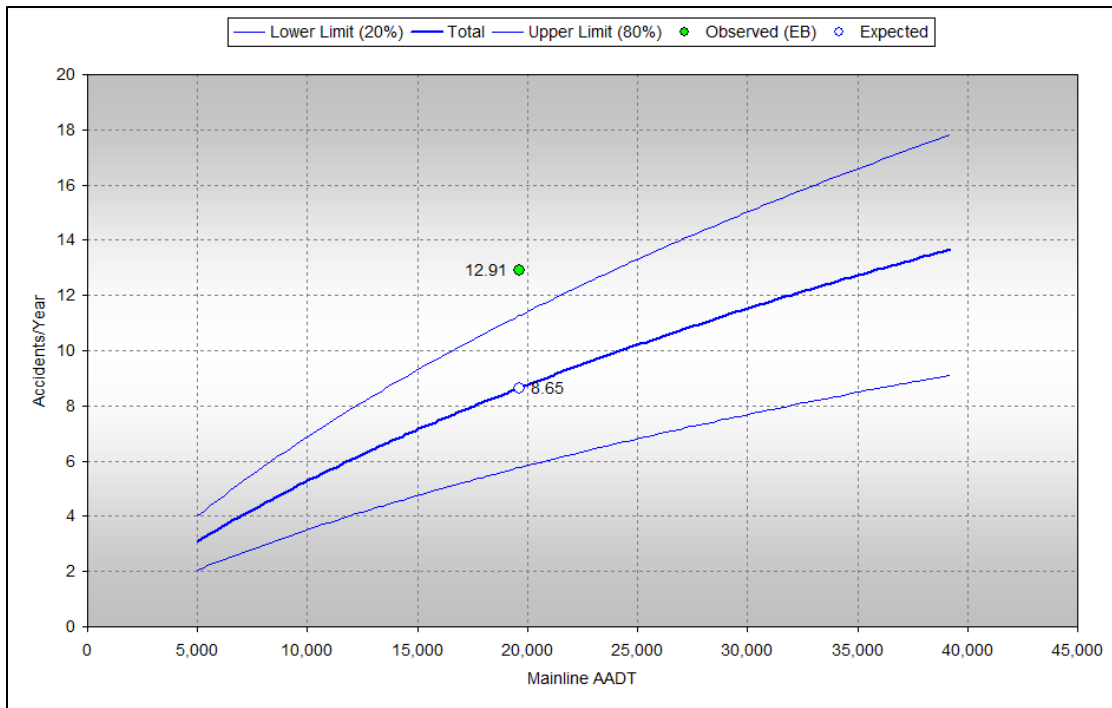


Figure 2 – SPF for Total Crashes - After
SH 287C, MP 313.90 Pike Road
 Before: 2007 to 2009 After: 2014 to 2016

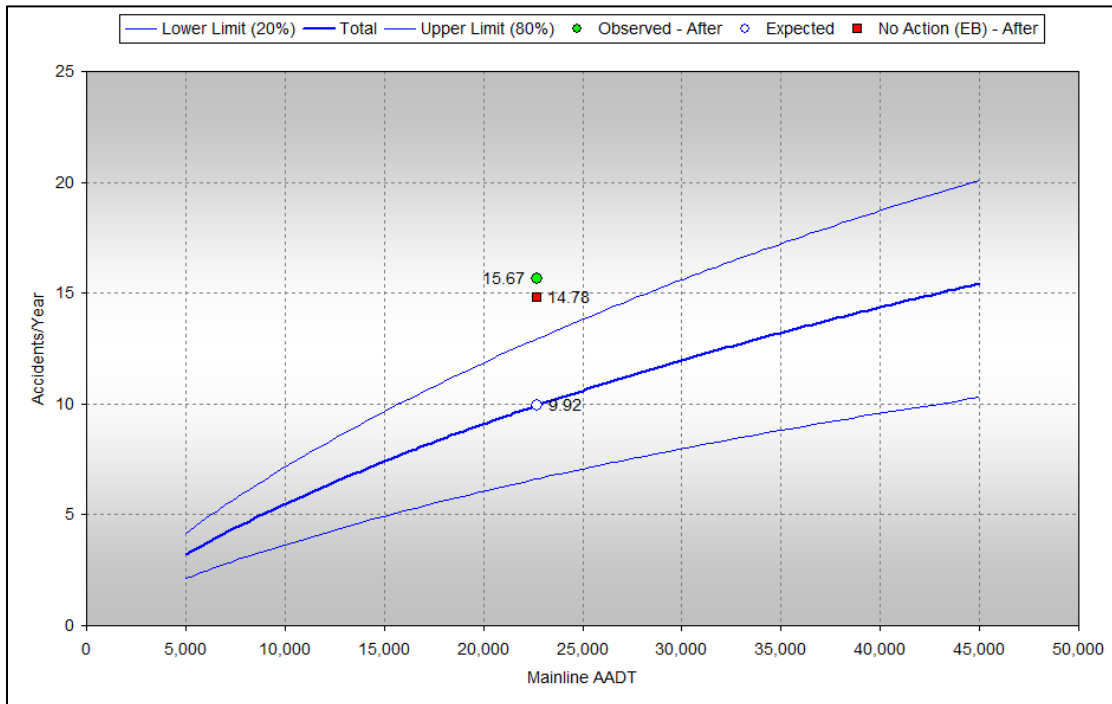


Figure 3 – SPF for Injury and Fatal Crashes - Before
SH 287C, MP 313.90 Pike Road
 Before: 2007 to 2009 After: 2014 to 2016

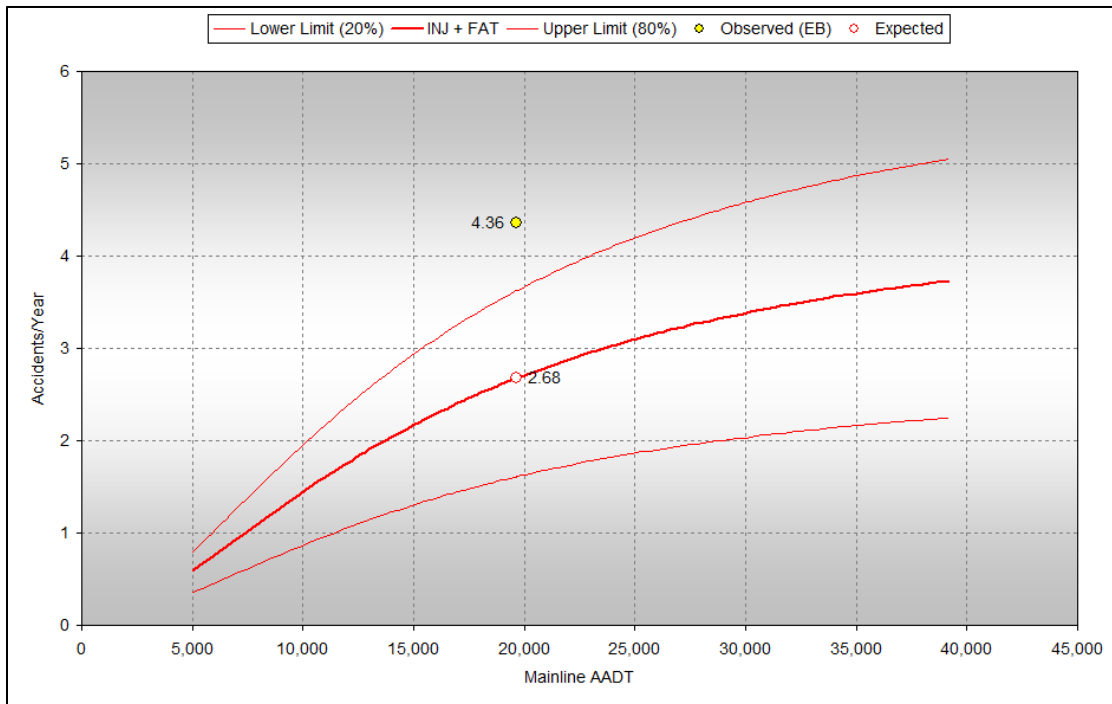


Figure 4 – SPF for Injury and Fatal Crashes - After

SH 287C, MP 313.90 Pike Road
 Before: 2007 to 2009 After: 2014 to 2016

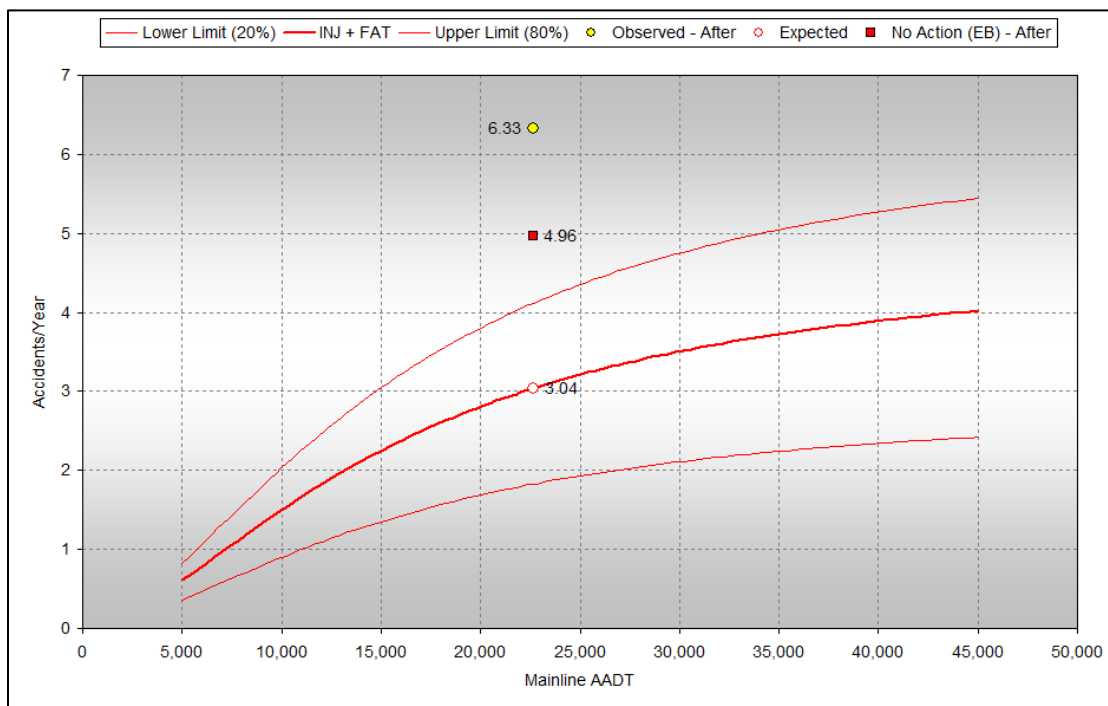


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action After |
|------------------------------------|---|---|---|
| EB Correction: | Yes | No | Yes |
| SPF Graph | Urban Divided Signalized 4-Lane 4- Leg Intersection | Urban Divided Signalized 4-Lane 4- Leg Intersection | Urban Divided Signalized 4-Lane 4- Leg Intersection |
| Total Crashes: | | | |
| LOSS | LOSS IV | LOSS IV | LOSS IV |
| CPY | 12.91 | 15.67 | 14.78 |
| Mean CPY | 8.65 | 9.92 | 9.92 |
| Proportion of Mean | 1.49 | 1.58 | 1.49 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS IV | LOSS IV | LOSS IV |
| CPY | 4.36 | 6.33 | 4.96 |
| Mean CPY | 2.68 | 3.04 | 3.04 |
| Proportion of Mean | 1.63 | 2.08 | 1.63 |

A more detailed review of the before and after crash record shows the crash types that were most affected by the signal upgrade. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: rear-end, approach turn, and broadside. After the signal upgrade, there was a significant decrease in rear-end crashes (most of which are property damage only). There was a slight decrease in

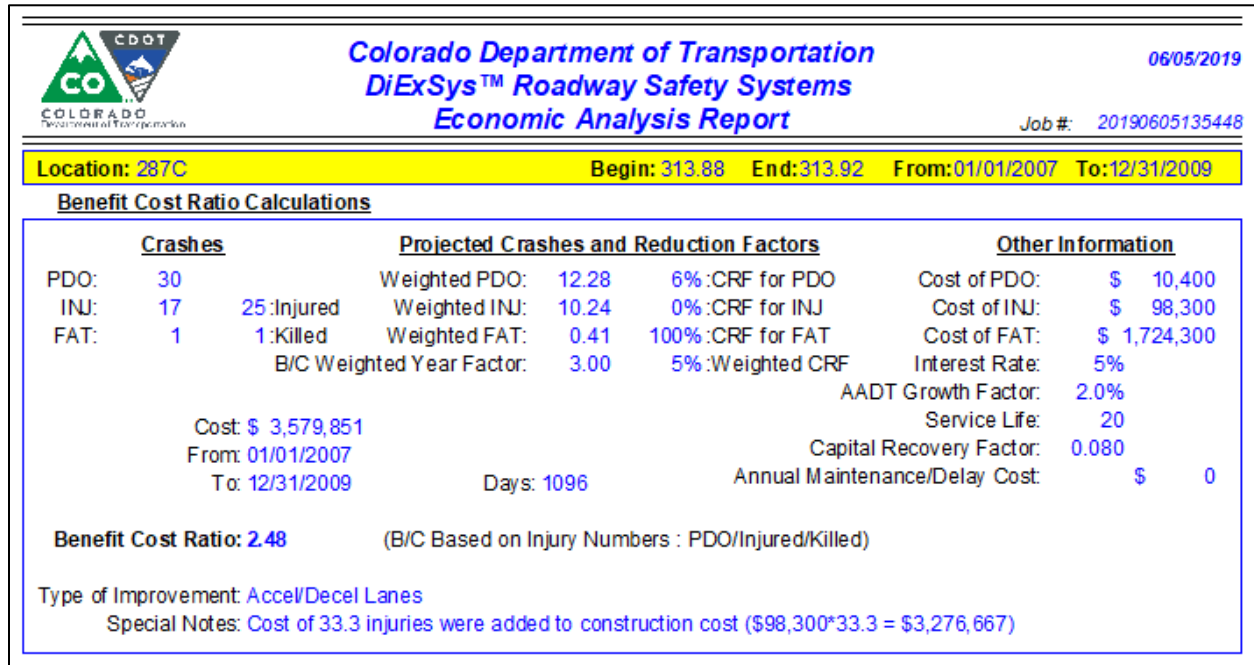
broadside type crashes. There was a significant increase in the number of approach turn crashes and the number of injuries, although there were no approach turn fatal crash in the after period. There was an overall increase in injuries. Over the design life of 20 years for the improvements, the increased cost of crashes would be \$3,276,667 (33.33 injuries * \$98,300 = \$3,276,667). The No-Build After crashes were estimated using the change in SH 287 traffic volumes between the before and after period, as found in **Table 1** (increase is 16% = $|1 - (22,700/19,650)|$).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|--|--------------------------------|--------------------------------|--------------------------------|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 42 | 47 | 48 |
| Fatal (fatalities) | 1 (1) | 0 (0) | 1 (1) |
| Injury (injuries) | 13 (22) | 19 (30) | 17 (25) |
| PDO | 26 | 28 | 30 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | 100% / -20% / 6% | |
| Rear-End – Total | 26 | 15 | 30 |
| Injury (injuries) | 3 (3) | 2 (3) | 3 (3) |
| PDO | 23 | 13 | 27 |
| % Reduction in Total (Injuries/PDO) | | 0% / 52% | |
| Approach Turn – Total | 11 | 26 | 13 |
| Fatal (fatalities) | 1 (1) | 0 (0) | 1 (1) |
| Injury (injuries) | 9 (16) | 14 (24) | 11 (18) |
| PDO | 1 | 12 | 1 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | 100% / -33 / -1100% | |
| Broadside – Total | 2 | 1 | 2 |
| Injury (injuries) | 1 (1) | 1 (1) | 1 (1) |
| PDO | 1 | 0 | 1 |
| % Reduction in Total (Injuries/PDO) | | 0% / 100% | |

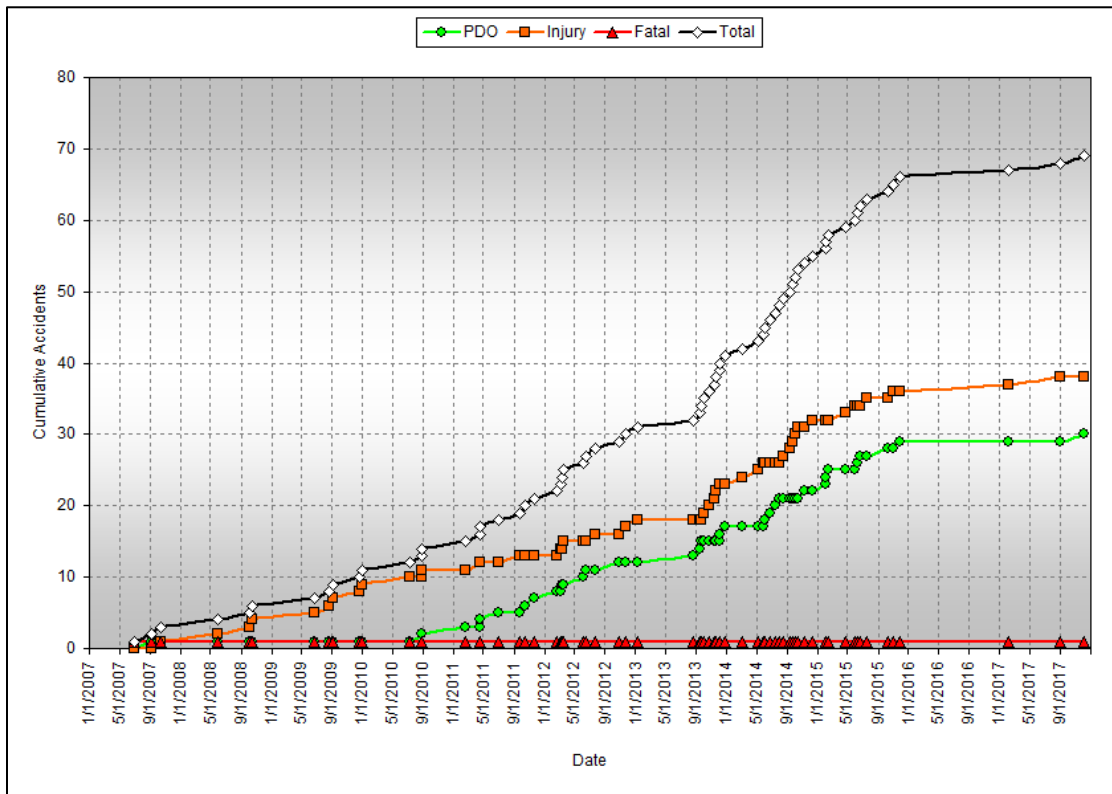
Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 2.48 was ultimately realized.** This outcome displays that this safety improvement project was likely justified. However, it should be noted that the primary driver in this large B/C ratio is the fatality that occurred in the before period, when there were no fatalities in the after period. There is some randomness in whether a severe crash becomes an injury or a fatality, especially when looking at a short three-year period. Therefore, it is difficult to say if the B/C is a good measure of the project improvement.

Figure 3 – Benefit Cost Analysis



It was noted that approach turn crashes increased in frequency in the after period. **Figure 4** provides an 11-year history of the approach turn crashes occurring in the northbound and southbound direction. The increase in frequency started in late 2013 and appears unrelated to the safety project. It is likely the signal phasing or timing was adjusted in late 2013 and then again in late 2015 after which there is a significant drop-off in the frequency of approach turn crashes.

Figure 4 – Northbound/Southbound Approach Turn Crashes - 11 Years





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

CDOT Project # 17574 06/05/2019
Exhibit 1

Job #: 20190605101610

Location: 287C Begin: 313.88 End: 313.92 From: 01/01/2007 To: 12/31/2009

| Severity | |
|---------------|---------------------|
| PDO: | 26 |
| INJ: | 15 22 :Injured |
| FAT: | 1 1 :Killed |
| Total: | 42 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 2 |
| Two Vehicles: | 37 |
| Three or More: | 3 |
| Unknown: | 0 |
| Total: | 42 |

| Location | |
|------------------|-----------|
| On Road: | 42 |
| Off Road Left: | 0 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 42 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 34 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 5 |
| Dark - Unlighted: | 2 |
| Unknown: | 0 |
| Total: | 42 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 41 |
| Rain: | 0 |
| Snow/Sleet/Hail: | 0 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 1 |
| Unknown: | 0 |
| Total: | 42 |

| Crash Rates | |
|---------------|-------------------------|
| PDO: | 34.49* * MVMT |
| INJ: | 19.90* ** 100 MVMT |
| FAT: | 132.67** |
| Total: | 55.72* |

| Crash Type | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 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: | 26 | Delineator Post: | 0 |
| Sideswipe (Same): | 1 | 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: | 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: | 42 |
| Concrete Barrier: | 0 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | |
|-------------------------------|----|------------------------------|------------------|
| Mainline: | 42 | M: | 0 N: 0 O: 0 P: 0 |
| Crossroad (A): | 0 | | |
| Ramps | | Left Frontage Rd (L): | 0 |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 |
| D: 0 H: 0 T: 0 | | Unknown: | 0 |
| E: 0 I: 0 | | Total: | 42 |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 37 |
| At Driveway Access: | 0 |
| Intersection Related: | 5 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 42 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 39 |
| Wet: | 1 |
| 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: | 0 |
| Snowy w/Icy Road Treatment: | 0 |
| Icy w/Icy Road Treatment: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 42 |

ADT: 19,650 Length: 0.03



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

CDOT Project # 17574 06/05/2019
Exhibit 1

Job #: 20190605101610

Location: 287C Begin: 313.88 End: 313.92 From: 01/01/2007 To: 12/31/2009

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 26 | 29 | 2 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 6 | 2 | 1 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 8 | 6 | 0 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 0 | 2 | 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: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 42 | 40 | 3 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 14 | 14 | 0 |
| Slowing: | 1 | 2 | 0 |
| Stopped in Traffic: | 3 | 16 | 3 |
| Making Right Turn: | 12 | 7 | 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: | 0 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 42 | 40 | 3 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 32 | 39 | 3 |
| 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: | 5 | 1 | 0 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 3 | 0 | 0 |
| Total: | 42 | 40 | 3 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 12 | 2 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 23 | 24 | 3 |
| Southeast: | 1 | 1 | 0 |
| South: | 6 | 12 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 0 | 1 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 42 | 40 | 3 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 41 | 39 | 3 |
| Alcohol Involved: | 1 | 0 | 0 |
| RX, Medication, or Drugs Involved: | 0 | 1 | 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: | 42 | 40 | 3 |

ADT: 19,650 Length: 0.03



Location: 287C Begin: 313.88 End: 313.92 From: 01/01/2014 To: 12/31/2016

| Severity | |
|---------------|----------------|
| PDO: | 28 |
| INJ: | 19 30 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 47 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 0 |
| Two Vehicles: | 41 |
| Three or More: | 6 |
| Unknown: | 0 |
| Total: | 47 |

| Location | |
|------------------|-----------|
| On Road: | 47 |
| Off Road Left: | 0 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 47 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 42 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 4 |
| Dark - Unlighted: | 0 |
| Unknown: | 0 |
| Total: | 47 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 47 |
| Rain: | 0 |
| Snow/Sleet/Hail: | 0 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 47 |

| Crash Rates | |
|---------------|---------------------|
| PDO: | 32.18 * * MVMT |
| INJ: | 21.83 * ** 100 MVMT |
| FAT: | 0.00 ** |
| Total: | 54.01 * |

| Crash Type | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 1 | Column/Pier: | 0 |
| Pedestrians: | 1 | Culvert/Headwall: | 0 |
| Broadside: | 1 | Embankment: | 0 |
| Head On: | 1 | Curb: | 0 |
| Rear End: | 15 | Delineator Post: | 0 |
| Sideswipe (Same): | 1 | Fence: | 0 |
| Sideswipe (Opposite): | 0 | Tree: | 0 |
| Approach Turn: | 26 | 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: | 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: | 47 |
| Concrete Barrier: | 0 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | |
|-------------------------------|----|------------------------------|------------------|
| Mainline: | 47 | M: | 0 N: 0 O: 0 P: 0 |
| Crossroad (A): | 0 | | |
| Ramps | | Left Frontage Rd (L): | 0 |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 |
| D: 0 H: 0 T: 0 | | Unknown: | 0 |
| E: 0 I: 0 | | Total: | 47 |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 34 |
| At Driveway Access: | 0 |
| Intersection Related: | 13 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 47 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 45 |
| 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: | 2 |
| Icy w/Icy Road Treatment: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 47 |

ADT: 22,686 Length: 0.03



Location: 287C **Begin: 313.88** **End: 313.92** **From: 01/01/2014** **To: 12/31/2016**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 23 | 26 | 2 |
| Passenger Car/Van w/Trl: | 0 | 1 | 0 |
| Pickup Truck/Utility Van: | 8 | 6 | 1 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 15 | 11 | 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 | 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 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 47 | 47 | 6 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 11 | 27 | 0 |
| Slowing: | 4 | 2 | 0 |
| Stopped in Traffic: | 2 | 12 | 4 |
| Making Right Turn: | 2 | 1 | 2 |
| Making Left Turn: | 26 | 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: | 0 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 1 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 47 | 47 | 6 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 22 | 42 | 6 |
| 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: | 4 | 1 | 0 |
| Driver Unfamiliar with Area: | 2 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 11 | 4 | 0 |
| Total: | 47 | 47 | 6 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 29 | 10 | 1 |
| Northeast: | 0 | 0 | 0 |
| East: | 8 | 6 | 3 |
| Southeast: | 0 | 0 | 0 |
| South: | 9 | 27 | 2 |
| Southwest: | 0 | 0 | 0 |
| West: | 1 | 4 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 47 | 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: | 0 | 0 | 0 |
| Illegal Drugs Involved: | 0 | 0 | 0 |
| Alcohol and Drugs Involved: | 0 | 0 | 0 |
| Driver/Pedestrian not Observed: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 47 | 47 | 6 |

ADT: 22,686 **Length: 0.03**

Project Information

Project Name: SH 257A / 37th Street Signal Install

Project Description: Install Signal and Turn Lanes

CDOT Region: 4 Project Def: 17557 County: Weld

Location: SH 257A Mile Points: 3.15 Length: N/A

Schedule: Work Start Date: approx. 8/2010 Completion Date: 6/14/2011

Problem Description: The five-year crash history (2000 – 2004) showed that there was a total of 11 injury crashes and 14 PDO crashes at this intersection. Of the 25 crashes, 22 were broadside type crashes.

Improvement Description: Between August 2010 and June 14, 2011 a signal was installed. Left turn lanes were also installed on 37th Street. The cost of construction was \$430,074.

The FHEP application anticipated that an 80% reduction in broadside crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 2.44.

Summary and Findings

The analysis of safety before and after the improvements at this intersection shows a reduction in the total number of crashes and the number of injury crashes and injuries, but the number of fatalities increased. There were 18 total crashes during the three-year period before the improvements were made (2007 – 2009). In the three years after construction (2012 – 2014), the number of crashes was 11. The ADT increased from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a decrease in the number of broadside crashes after the completion of the project. The number of broadside crashes was significantly reduced, and the number of rear-end and approach turn crashes increased, each by one crash each.

There was a broadside fatality in the before period and one in the after period. In the after period, the second fatality involved an approach turn fatality. There was a significant reduction in injury crashes, the number of injuries decreased from 16 injuries in the three years before construction to only 4 injuries in the three years after construction (all in the same broadside crash). The number of PDO went from 10 in the before period to 8 in the after period. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 10 years for this project is **0.69** to one. However, it should be noted that the primary driver in this small B/C ratio is the second fatality that occurred in the after period, when there were only one fatality in the before period. There is some randomness in whether a severe crash becomes an injury or a fatality, especially when looking at a short three-year period. Therefore, it is difficult to say if the B/C is a good measure of this project improvement.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records at the intersection of SH 257A and 37th Street shows a decrease in the number of crashes from 18 during the three-year period (2007 to 2009) before the improvements to 11 during the three-year after period (2012 to 2014) (**Table 1**). The number of serious crashes (involving injuries) decreased although the number of fatalities increased from one to two in the after period:

- Before (2007 – 2009) – One fatal crash with 1 killed and 7 injury crashes with 16 injuries
- After (2012 – 2014) – Two fatal crashes with 2 killed and 1 injury crash with 4 injuries

The crash rate at this intersection decreased in the after period:

- Before (2007 – 2009) – 1.84 crashes per million entering vehicles (cpmev)
- After (2012 – 2014) – 1.01 cpmev

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2007 to 12/31/209 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) |
| AADT (SH 257 / 37 th Street) | 5,250 vpd / approx. 3,700 vpd | 6,200 vpd / approx. 3,700 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 18 | 11 |
| Fatal Crashes (Fatalities) | 1 (1) | 2 (2) |
| Injury Crashes (Injuries) | 7 (16) | 1 (4) |
| Property Damage Only | 10 | 8 |
| Crash Types: # (%) [significance] | | |
| Broadside | 14 (77.8%) [99.6%] | 4 (36.4%) |
| Rear-End | 3 (16.7%) | 4 (36.4%) |
| Approach Turn | 1 (5.6%) | 2 (9.1%) |

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 (**Figures 1**) and for fatal and injury crashes (**Figures 2**) reflect mixed improvement results in the crash record for this project. For the frequency of crashes, the intersection is LOSS IV in both the before and after periods. In the graph, it appears that the after period is worse than the before period. This is because the Empirical Bayes method for Regression to the Mean bias was applied to the before period, but not after period, as explained in **Appendix A**. For the severity of crashes, the intersection is LOSS IV in the before period and LOSS II/III in the after period. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes
SH 257A, MP 3.15 37th Avenue
 Before: 2007 to 2009 After: 2012 to 2014

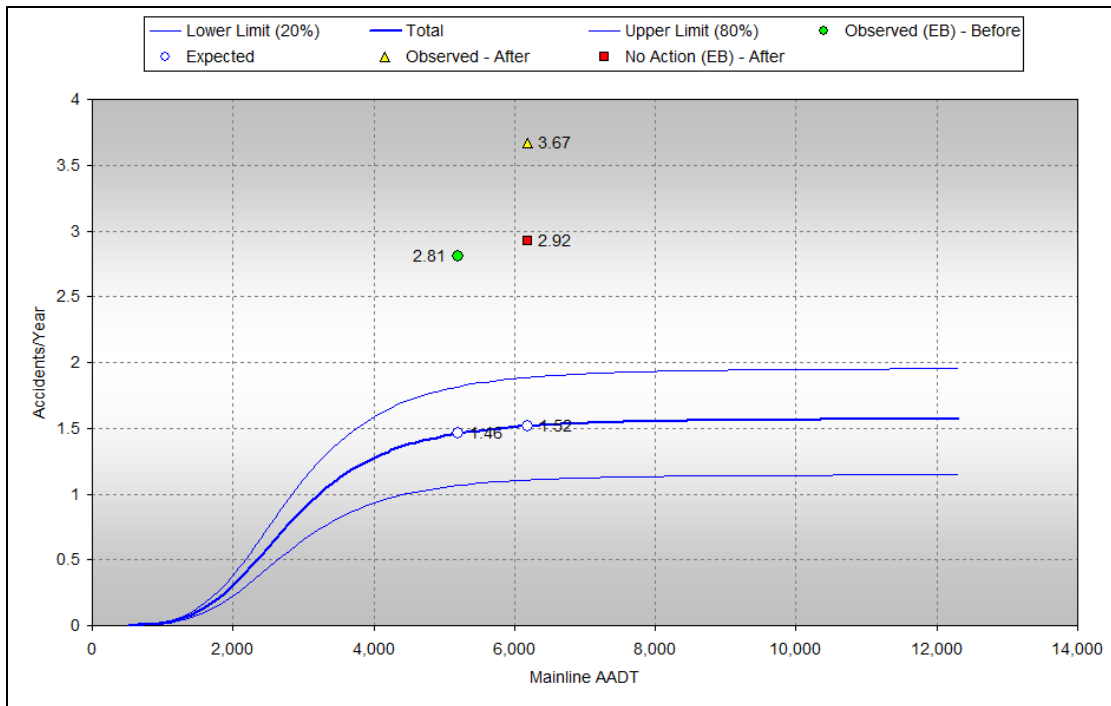


Figure 2 – SPF for Injury and Fatal Crashes

SH 257A, MP 3.15 37th Avenue

Before: 2007 to 2009 After: 2012 to 2014

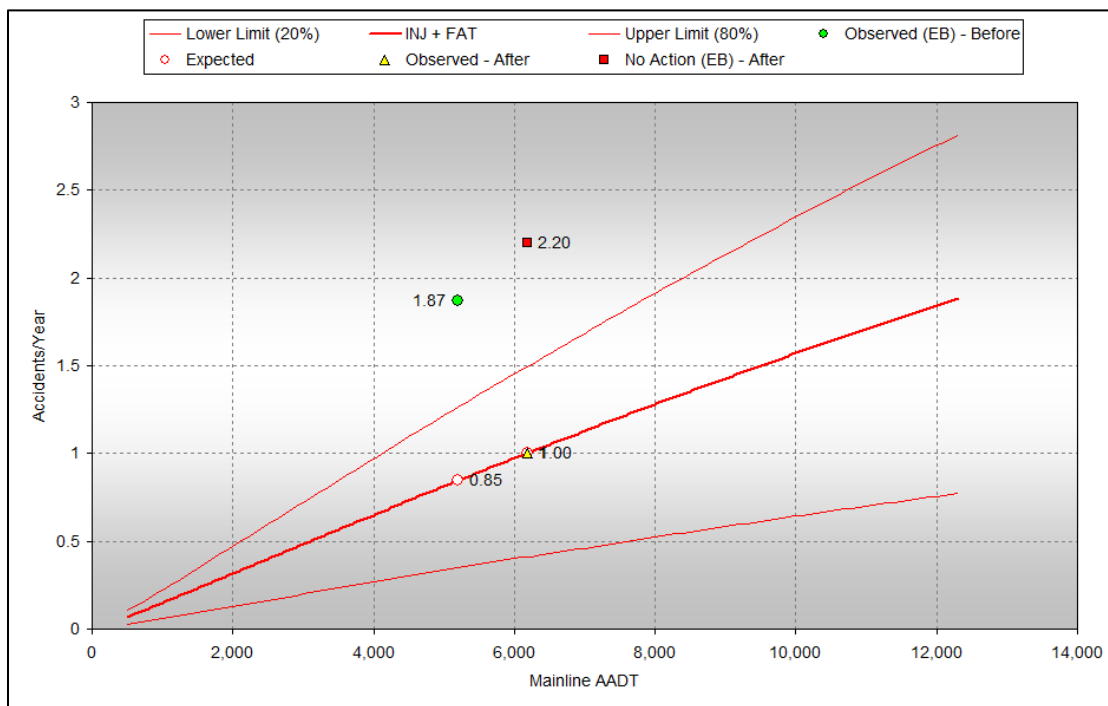


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action After |
|------------------------------------|--|--|--|
| EB Correction: | Yes | No | Yes |
| SPF Graph | Rural Divided Unsignalized 4-Lane 4-Leg Intersection | Rural Divided Unsignalized 4-Lane 4-Leg Intersection | Rural Divided Unsignalized 4-Lane 4-Leg Intersection |
| Total Crashes: | | | |
| LOSS | LOSS IV | LOSS IV | LOSS IV |
| CPY | 2.81 | 3.67 | 2.92 |
| Mean CPY | 1.46 | 1.52 | 1.52 |
| Proportion of Mean | 1.92 | 2.41 | 1.92 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS IV | LOSS II/III | LOSS IV |
| CPY | 1.87 | 1.00 | 2.20 |
| Mean CPY | 0.85 | 1.00 | 1.00 |
| Proportion of Mean | 2.20 | 1.00 | 2.20 |

A more detailed review of the before and after crash record shows the broadside crash type was most affected by the signal upgrade, as expected in the initial justification for the project. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: rear-end, broadside, and approach turn crashes. After the signal upgrade, there was a decrease in broadside crashes. There was an increase in rear-end and approach turn type crashes, and there was an increase in fatal crashes. Over the

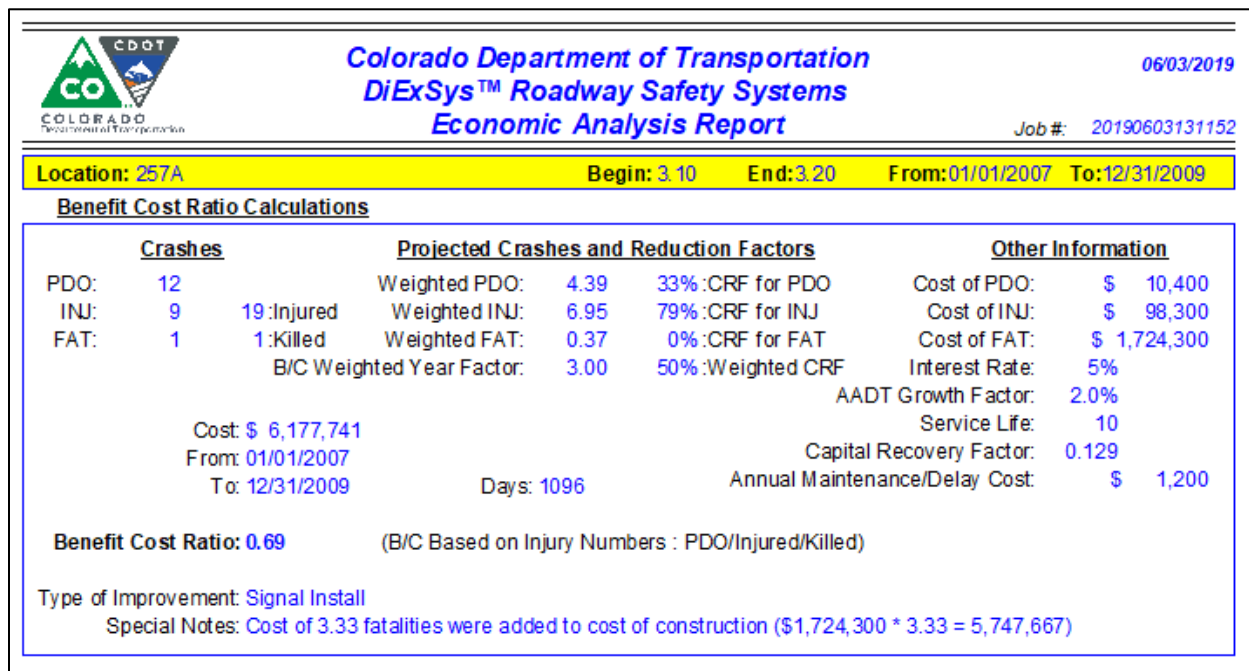
design life of 10 years for the improvements, the increased cost of crashes would be \$5,747,667 (3.33 FAT * \$1,724,300 = \$5,747,667). The No-Build After crashes were estimated using the change in SH 257 traffic volumes between the before and after period, as found in **Table 1** (increase is 18% = |1-(6,200/5,250)|).

Table 3 – Results of Crash Analyses

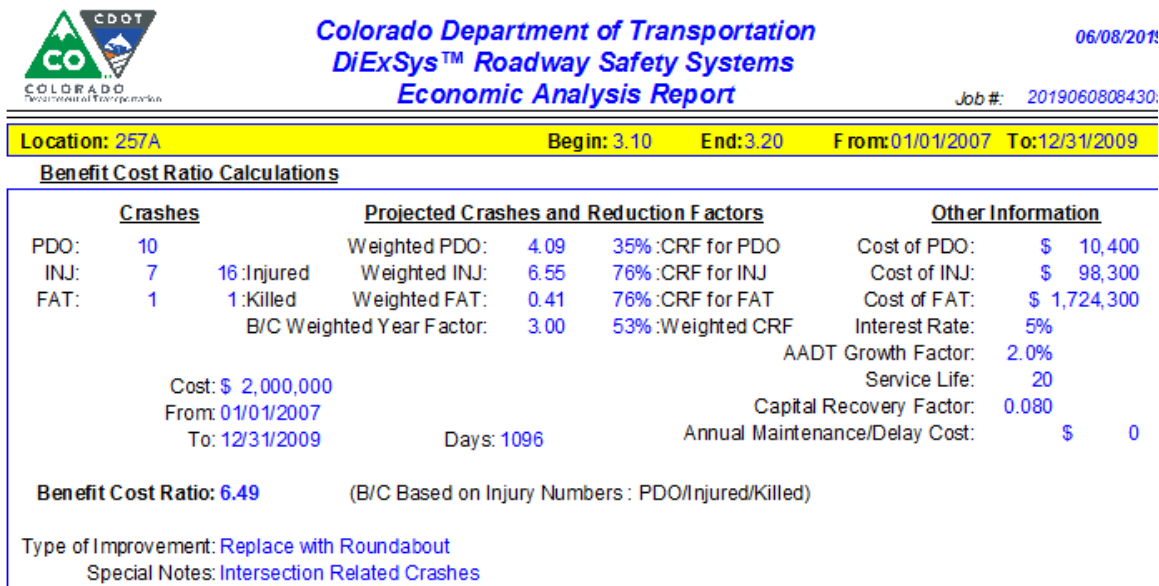
| | Before | After | No-Build After |
|--|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 18 | 11 | 21 |
| Fatal (fatalities) | 1 (1) | 2 (2) | 1 (1) |
| Injury (injuries) | 7 (16) | 1 (4) | 9 (19) |
| PDO | 10 | 8 | 12 |
| % Reduction in Total (Injuries/PDO) | | -100% / 79% / 33% | |
| Broadside – Total | 14 | 4 | 17 |
| Fatal (fatalities) | 1 (1) | 1 (1) | 1 (1) |
| Injury (injuries) | 7 (16) | 1 (4) | 9 (19) |
| PDO | 6 | 2 | 7 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | NA / 79% / 71% | |
| Rear-End – Total | 3 | 4 | 3 |
| Injury (injuries) | 0 (0) | 0 (0) | 0 (0) |
| PDO | 3 | 4 | 3 |
| % Reduction in Total (Injuries/PDO) | | NA / -33% | |
| Approach Turn – Total | 1 | 2 | 1 |
| Fatal (fatalities) | 0 (0) | 1 (1) | 0 (0) |
| Injury (injuries) | 0 (0) | 0 (0) | 0 (0) |
| PDO | 1 | 1 | 1 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | NA / NA / 0% | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 3** for all crashes at the intersection. **A calculated B/C ratio of 0.69 was ultimately realized.** As analyzed, this outcome displays that this safety improvement project was likely not justified. However, it should be noted that the primary driver in this poor B/C ratio is the additional fatality that occurred in the after period, when there were one fatality in the before period. There is some randomness in whether a severe crash becomes an injury or a fatality, especially when looking at a short three-year period. In reality, the project did a fairly good job of reducing broadside crashes and injuries. If not for the second fatality, the B/C ratio would have been 9.75. Therefore, it is difficult to say if the B/C is a good measure of the project improvement.

Figure 3 – Benefit Cost Analysis



In retrospect we can observe that signaling high speed rural 2 lane intersection may not be an optimal strategy to address a broadside pattern. An intersection such as this lends itself well to converting it to a roundabout. **Figure 4** below shows that a roundabout would've been a cost-effective alternative.



In its present configuration this is an isolated signal in a rural area, we recommend installation of a dilemma zone preemption on all four approaches if not currently in place.



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

CDOT Project # 17577 06/03/2019

Exhibit 1

Job #: 20190603102022

Location: 257A Begin: 3.10 End: 3.20 From:01/01/2007 To:12/31/2009

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 10 | |
| INJ: | 7 | 16 :Injured |
| FAT: | 1 | 1 :Killed |
| Total: | 18 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 0 |
| Two Vehicles: | 15 |
| Three or More: | 3 |
| Unknown: | 0 |
| Total: | 18 |

Location

| | |
|------------------|-----------|
| On Road: | 18 |
| Off Road Left: | 0 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 18 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 15 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 0 |
| Dark - Unlighted: | 2 |
| Unknown: | 0 |
| Total: | 18 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 14 |
| Rain: | 3 |
| Snow/Sleet/Hail: | 1 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 18 |

Crash Rates

| | | |
|---------------|---------------|-------------|
| PDO: | 17.45* | * MVMT |
| INJ: | 12.21* | ** 100 MVMT |
| FAT: | 174.49** | |
| Total: | 31.41* | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 14 | 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: | 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: | 18 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----------------------|------------------------------------|
| Mainline: | 18 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | Left Frontage Rd (L): | 0 |
| C: 0 G: 0 K: 0 | Rt Frontage Rd (R): | 0 |
| D: 0 H: 0 T: 0 | HOV Lanes (V): | 0 |
| E: 0 I: 0 | Unknown: | 0 |
| | Total: | 18 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 16 |
| At Driveway Access: | 0 |
| Intersection Related: | 2 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 18 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 16 |
| 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: | 0 |
| Total: | 18 |

ADT: 5,229 Length: 0.10



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

CDOT Project # 17577 06/03/2019

Exhibit 1

Job #: 20190603102022

Location: 257A **Begin: 3.10** **End: 3.20** **From:01/01/2007** **To:12/31/2009**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 10 | 10 | 0 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 4 | 5 | 1 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 4 | 1 | 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: | 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: | 18 | 18 | 3 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 15 | 14 | 1 |
| Slowing: | 0 | 0 | 0 |
| Stopped in Traffic: | 0 | 4 | 2 |
| Making Right Turn: | 1 | 0 | 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 | 0 | 0 |
| Changing Lanes: | 0 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 18 | 18 | 3 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 13 | 18 | 3 |
| 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: | 0 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 4 | 0 | 0 |
| Total: | 18 | 18 | 3 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 0 | 5 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 5 | 3 | 2 |
| Southeast: | 0 | 0 | 0 |
| South: | 2 | 9 | 1 |
| Southwest: | 0 | 0 | 0 |
| West: | 11 | 1 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 18 | 18 | 3 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 17 | 18 | 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: | 18 | 18 | 3 |

ADT: 5,229 **Length: 0.10**



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

CDOT Project # 17577 06/03/2019
 Exhibit 2

Job #: 20190603122505

Location: 257A Begin: 3.10 End: 3.20 From:01/01/2012 To:12/31/2014

| Severity | |
|---------------|-------------------|
| PDO: | 8 |
| INJ: | 1 4 :Injured |
| FAT: | 2 2 :Killed |
| Total: | 11 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 0 |
| Two Vehicles: | 11 |
| Three or More: | 0 |
| 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: | 7 |
| Dawn or Dusk: | 0 |
| Dark - Lighted: | 1 |
| Dark - Unlighted: | 3 |
| Unknown: | 0 |
| Total: | 11 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 9 |
| Rain: | 0 |
| Snow/Sleet/Hail: | 1 |
| Fog: | 1 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 11 |

| Crash Rates | |
|---------------|-------------------------|
| PDO: | 11.78 * * MVMT |
| INJ: | 1.47 * ** 100 MVMT |
| FAT: | 294.61 ** |
| Total: | 16.20 * |

| Crash Type | | | |
|-----------------------|---|-----------------------------|-----------|
| Overturing: | 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: | 4 | 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: | 11 |
| Concrete Barrier: | 0 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | | | |
|-------------------------------|----|-----------------------------|---|---------------|-----------|
| Mainline: | 11 | M: | 0 | N: | 0 |
| Crossroad (A): | 0 | O: | 0 | P: | 0 |
| Ramps | | Left Frontage Rd (L): | 0 | | |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 | | |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 | | |
| D: 0 H: 0 T: 0 | | Unknown: | 0 | Total: | 11 |
| E: 0 I: 0 | | | | | |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 9 |
| At Driveway Access: | 0 |
| Intersection Related: | 2 |
| 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: | 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: | 11 |

ADT: 6,194 Length: 0.10



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

CDOT Project # 17577 06/03/2019
 Exhibit 2

Job #: 20190603122505

Location: 257A **Begin: 3.10** **End: 3.20** **From:01/01/2012** **To:12/31/2014**

| 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: | 2 | 4 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 6 | 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: | 1 | 0 | 0 |
| Hit and Run - Unknown: | 0 | 0 | 0 |
| Other: | 0 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 11 | 11 | 0 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 7 | 8 | 0 |
| Slowing: | 1 | 0 | 0 |
| Stopped in Traffic: | 1 | 2 | 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 | 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 |
| Wrong Way: | 0 | 1 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 11 | 11 | 0 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 5 | 11 | 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: | 3 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 1 | 0 | 0 |
| Unknown: | 1 | 0 | 0 |
| Total: | 11 | 11 | 0 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 3 | 3 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 2 | 3 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 1 | 4 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 5 | 1 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 11 | 11 | 0 |

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

ADT: 6,194 **Length: 0.10**

Project Information

Project Name: Signal at Purcell and Spaulding

Project Description: Install a Signal at Signal at Purcell and Spaulding

CDOT Region: 2 Project Def: 17602 County: Pueblo

Location: Purcell and Spaulding in Pueblo West

Schedule: Work Start Date: 1/17/2011 Completion Date: 4/29/2011

Problem Description: During the evaluation period the intersection at Purcell and Spaulding was a divided unsignalized urban 4-lane. The crash history from VZS for the evaluation period of 2006 to 2010 shows 23 intersection related crashes at this intersection. Seven (7) of the crashes resulted in injuries, injuring 10 people, while the remaining 16 were property damage only crashes. 14 of the crashes were broadsides. The intersection was performing at LOSS-IV in terms of both frequency and severity.

Improvement Description: Between January 17, 2011 and April 29, 2011 signal were installed. The cost of construction was \$253,550. The predicted benefit/cost ratio was estimated to be 3.55.

The FHEP application anticipated that broadside crashes would be impacted by this improvement. It was anticipated that there would be an 80% crash reduction for these crashes.

Summary and Findings

The analysis of safety performance before and after signalization of the intersection of Purcell and Spaulding showed the expected reduction of broadside crashes. There were 14 such crashes in the evaluation, or before, period and only one (1) in the after period. There were increases in other crash types, specifically rear ends and approach turns, which is also an anticipated effect of signalization.

The expectation is that the net effect of these decreases and increases will be an overall reduction in accident severity, and accordingly in bodily injury. There was in fact a small reduction in the number of injury related crashes from 7 crashes to 6 crashes, with the resulting number of injured parties dropping from 10 to 6. It is difficult to assert that a one-crash reduction is genuinely reflective of an increase in safety rather than a random fluctuation. However, when the number of people injured and the severity of those injuries is examined in more detail, a reduction in crash severity becomes more evident. In the 7 injury crashes of the before period, three of them, or 43% resulted in injuries to two parties, while none of the 6 crashes in the after period resulted in injury to more than one person. Furthermore, there were 5 people in the before period with level III or IV injury severity and only 1 person in the after period with injuries at those levels. This closer examination supports the conclusion that the overall crash severity has decreased since the improvement. The resulting ratio of benefits and cost for this project shows that benefits outweigh the costs with a B/C ratio of **5.01** to one, showing that the improvement was cost effective in terms of safety benefits.

Results of Safety Analyses

Using VZS, the review of before and after crash records showed the number of crashes decreased between the two study periods. The total number of crashes was 23 during the five-year period (2006 to 2010) before the intersection was signalized and 20 during the five-year after period (2012 to 2016) (see **Table 1**). The number of severe crashes decreased in the five-year period after the improvements. There were no fatal crashes in either period.

- Before (2006 – 2010) – no fatal crashes and 7 injury crashes with 10 people injured
- After (2012 – 2016) – no fatal crashes and 6 injury crashes with 6 people injured

There was no measurable change in traffic volumes at the intersection from the before period to the after period that we could determine from the available sources (MS2 and City of Pueblo Traffic Map). As a result, the same volumes are used to compute the crash rates in the both the before and after periods. If there were in fact an increasing trend in the volume of traffic, the conclusions that follow would show a somewhat more pronounced degree of safety improvement.

- Before (2006 – 2010): 0.58 crashes per million entering vehicles (cpmev)
- After (2012 – 2016): 0.50 cpmev

Table 1 - Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2006 to 12/31/2010 (5 yr.) | 1/1/2012 to 12/31/2016 (5 yr.) |
| AADT (Purcell/Spaulding) | 18,500/3,278 vpd | 18,500/3,278 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 23 | 20 |
| Fatal Crashes (Fatalities) | 0 | 0 |
| Injury Crashes (Injuries) | 7 (10) | 6 (6) |
| Property Damage Only | 16 | 14 |
| Crash Types: # (%) [cumulative probability] | | |
| Broadside | 14 (61%) [97.27%] | 1 (5%) |
| Approach Turn | 0 | 3 (15%) |
| Rear-End | 3 (13%) | 11 (55%) |

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

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service uses qualitative measures that characterize

safety of a roadway segment in reference to its expected performance and severity. If the level of safety predicted by the SPF represents a normal or expected number of crashes at a specific level of ADT, then the degree of deviation from the normal can be stratified to represent specific levels of safety.

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

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

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. Both the frequency and severity of crashes were reduced in the after period (see **Table 2**).

Figure 1 – SPF for Total Crashes – Before/After/No Action After
 SH 82A (MP 3.55)
 Before:2006 to 2010 After:2012 to 2016

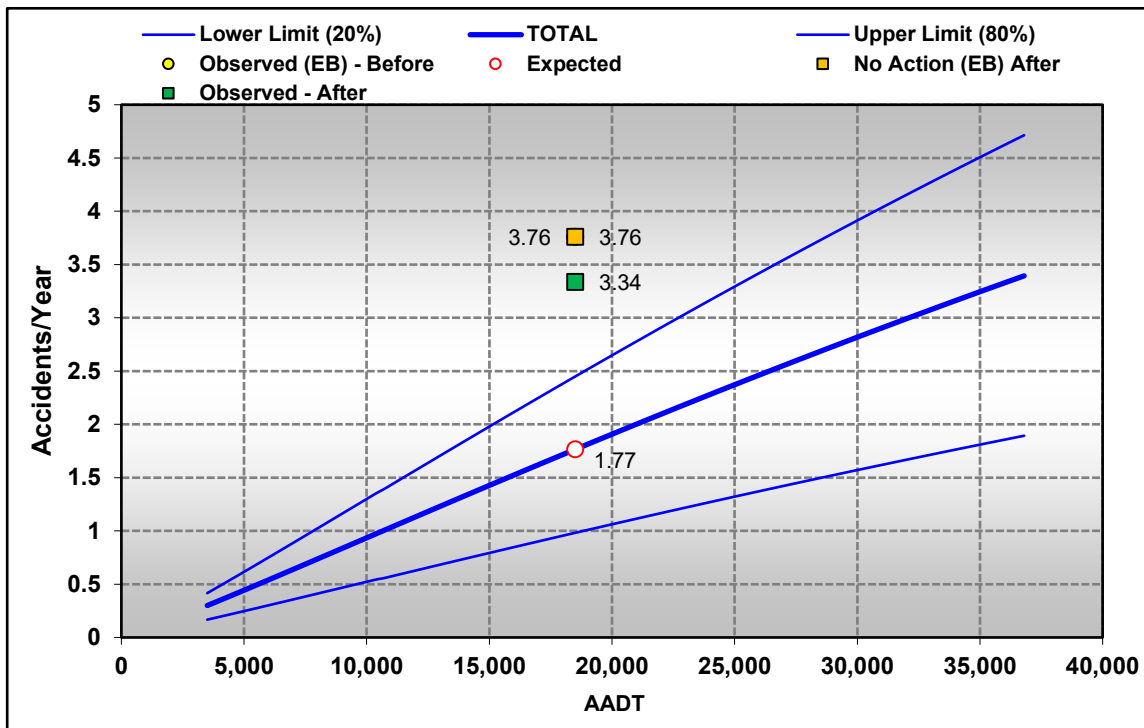


Figure 2 – SPF for Injury and Fatal Crashes – Before/After/No Action After
 SH 82A (MP 3.55)
 Before:2006 to 2010 After:2012 to 2016

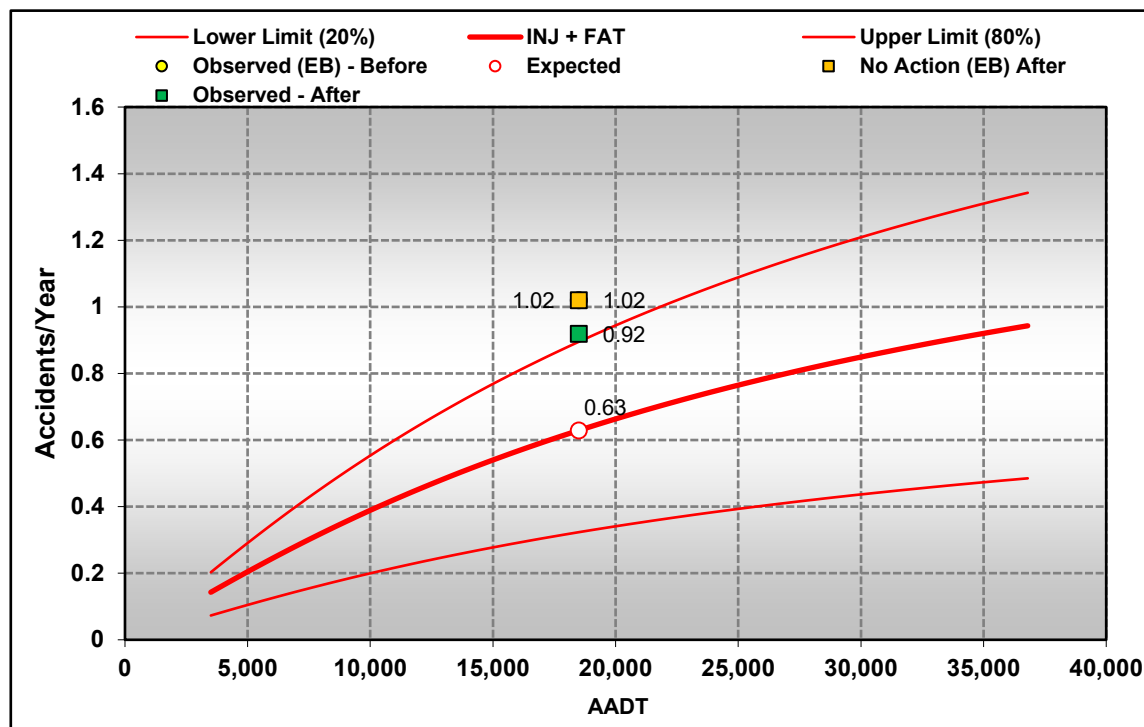


Table 2 – Safety Performance Function (SPF)

| | 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 IV | N/A | LOSS IV |
| CPY | 3.76 | 3.34 | 3.76 |
| Mean CPY | 1.77 | 1.77 | 1.77 |
| Proportion of Mean | 2.60 | 2.26 | 2.60 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS IV | N/A | LOSS IV |
| CPY | 1.02 | 0.92 | 1.02 |
| Mean CPY | 0.63 | 0.63 | 0.63 |
| Proportion of Mean | 2.22 | 1.91 | 2.22 |

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

A more detailed review of the before and after crash record shows the crash types that were most affected by the signal installation. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: broadside, approach turn and rear-end. The installation of the signal reduced the number of broadside crashes, but increased the number of approach turns and rear-ends. This is an expected outcome when signaling an intersection. The number of crashes does not necessarily decrease, but the crash types become less severe by reducing the broadside crashes. The “No Build After” crashes numbers were estimated to be the same as those for the before period since there was no change in traffic volume that we can determine.

Table 3 – Results of Crash Analyses

| | Before | After | No Build After |
|---|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2006 to 12/31/2010 (5 yr.) | 1/1/2012 to 12/31/2016 (5 yr.) | 1/1/2012 to 12/31/2016 (5 yr.) |
| Crash Types: | | | |
| Total Crashes | 23 | 20 | 23 |
| Fatal (fatalities) | 0 | 0 | 0 |
| Injury (injuries) | 7 (10) | 6 (6) | 7 (10) |
| PDO | 16 | 14 | 16 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | 13% (N/A, 14%(40%), 13%) | |
| Broadside – Total | 14 | 1 | 14 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 6 (9) | 1 (1) | 6 (9) |
| PDO | 8 | 0 | 8 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | 93% (N/A,88% /100%) | |
| Approach Turns – Total | 0 | 3 | 0 |
| Injury (injuries) | 0 | 2 (2) | 0 |
| PDO | 0 | 1 | 0 |
| % Reduction in Total (Injuries/PDO) | | All Increased | |
| Rear Ends – Total | 3 | 11 | 3 |
| Injury (injuries) | 0 (0) | 1 (1) | 0 (0) |
| PDO | 3 | 10 | 0 |
| % Reduction in Total (Injuries/PDO) | | All Increased | |

Vision Zero Suite (VZS) includes benefit/cost (B/C) analyses within its procedures. **Table 4**, below, shows such an analysis for the signal installation at Purcell and Spaulding. As shown, using the actual construction cost of \$253,550 as the cost basis, the safety related B/C ratio is 5.01 to 1, showing that the improvement was cost effective from the safety standpoint.


| | | | | | | | | |
|---|----|---|---------------|---|--------------------------------|--------------|--------|-----------|
|  | | Colorado Department of Transportation DiExSys™ Roadway Safety Systems Economic Analysis Report | | 04/10/2019 Job #: 20190410140310 | | | | |
| Location: Accident History for PURCELL and SPAULDING | | From: 01/01/2012 To: 12/31/2016 | | | | | | |
| Benefit Cost Ratio Calculations | | | | | | | | |
| Crashes | | Projected Crashes and Reduction Factors | | Other Information | | | | |
| PDO: | 16 | Weighted PDO: | 3.93 | 13% :CRF for PDO | Cost of PDO: | \$ | 10,400 | |
| INJ: | 7 | 10 :Injured | Weighted INJ: | 2.46 | 40% :CRF for INJ | Cost of INJ: | \$ | 98,300 |
| FAT: | 0 | 0 :Killed | Weighted FAT: | 0.00 | 10% :CRF for FAT | Cost of FAT: | \$ | 1,724,300 |
| | | B/C Weighted Year Factor: | 5.00 | 21% :Weighted CRF | Interest Rate: | 5% | | |
| | | | | | AADT Growth Factor: | 2.0% | | |
| | | | | | Service Life: | 20 | | |
| | | Cost: \$ | 253,550 | | Capital Recovery Factor: | 0.080 | | |
| | | From: | 01/01/2012 | | Annual Maintenance/Delay Cost: | \$ | 0 | |
| | | To: | 12/31/2016 | Days: 1827 | | | | |
| Benefit Cost Ratio: 5.01 | | (B/C Based on Injury Numbers : PDO/Injured/Killed) | | | | | | |
| Type of Improvement: Signal Installation | | | | | | | | |
| Special Notes: Purcell Blvd at E. Spaulding Ave. in Pueblo West | | | | | | | | |

Table 4: Benefit Cost Analysis based on Before and After Periods for Signal Installation.



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

CDOT Project #17602 06/17/2019
Exhibit 1

Job #: 20190617093407

Location: Accident History for PURCELL and SPAULDING **From:01/01/2006 To:12/31/2010**

| Severity | |
|---------------|---------------|
| PDO: | 18 |
| INJ: | 7 10 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 25 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 1 |
| Two Vehicles: | 22 |
| Three or More: | 2 |
| Unknown: | 0 |
| Total: | 25 |

| Location | |
|------------------|-----------|
| On Road: | 22 |
| Off Road Left: | 1 |
| Off Road Right: | 1 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 1 |
| Total: | 25 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 17 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 2 |
| Dark - Unlighted: | 4 |
| Unknown: | 1 |
| Total: | 25 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 16 |
| Rain: | 3 |
| Snow/Sleet/Hail: | 0 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 6 |
| Total: | 25 |

| Crash Rates | |
|-------------|----------------------------|
| PDO: | N/A * * MVMT |
| INJ: | N/A * ** 100 MVMT |
| FAT: | N/A ** Total: N/A * |

| Crash Type | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 1 | Bridge Abutment: | 0 |
| Other Non Collision: | 1 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 14 | 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: | 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: | 5 |
| Cable Rail: | 0 | Total: | 25 |
| Concrete Barrier: | 0 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | | | |
|-------------------------------|----|-----------------------------|---|---------------|-----------|
| Mainline: | 25 | M: | 0 | N: | 0 |
| Crossroad (A): | 0 | O: | 0 | P: | 0 |
| Ramps | | Left Frontage Rd (L): | 0 | | |
| B: 0 F: 0 J: 0 | | Rt Frontage Rd (R): | 0 | | |
| C: 0 G: 0 K: 0 | | HOV Lanes (V): | 0 | | |
| D: 0 H: 0 T: 0 | | Unknown: | 0 | Total: | 25 |
| E: 0 I: 0 | | | | | |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 21 |
| At Driveway Access: | 0 |
| Intersection Related: | 2 |
| Non Intersection: | 1 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 1 |
| Total: | 25 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 22 |
| 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: | 1 |
| Total: | 25 |



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

CDOT Project #17602 06/17/2019
 Exhibit 1

Job #: 20190617093407

Location: Accident History for PURCELL and SPAULDING **From:01/01/2006 To:12/31/2010**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 12 | 13 | 1 |
| Passenger Car/Van w/Trl: | 1 | 1 | 0 |
| Pickup Truck/Utility Van: | 6 | 5 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 1 | 0 |
| SUV: | 3 | 2 | 1 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 1 | 1 | 0 |
| School Bus < 15 People: | 0 | 0 | 0 |
| Non School Bus < 15 People: | 0 | 0 | 0 |
| Motorhome: | 0 | 0 | 0 |
| Motorcycle: | 0 | 0 | 0 |
| Bicycle: | 0 | 0 | 0 |
| Motorized Bicycle: | 0 | 0 | 0 |
| Farm Equipment: | 0 | 0 | 0 |
| Hit and Run - Unknown: | 1 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 1 | 1 | 0 |
| Total: | 25 | 24 | 2 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 9 | 17 | 1 |
| Slowing: | 1 | 1 | 0 |
| Stopped in Traffic: | 0 | 2 | 1 |
| Making Right Turn: | 2 | 0 | 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: | 0 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 2 | 0 | 0 |
| Unknown: | 1 | 2 | 0 |
| Total: | 25 | 24 | 2 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 5 | 16 | 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: | 2 | 0 | 0 |
| Driver Preoccupied: | 2 | 0 | 0 |
| Driver Unfamiliar with Area: | 2 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 1 | 0 | 0 |
| Unknown: | 13 | 8 | 0 |
| Total: | 25 | 24 | 2 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 2 | 5 | 1 |
| Northeast: | 0 | 0 | 0 |
| East: | 17 | 3 | 1 |
| Southeast: | 0 | 0 | 0 |
| South: | 1 | 13 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 3 | 1 | 0 |
| Northwest: | 1 | 0 | 0 |
| Unknown: | 1 | 2 | 0 |
| Total: | 25 | 24 | 2 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 23 | 24 | 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: | 25 | 24 | 2 |



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

CDOT Project #17602 06/17/2019
Exhibit 2

Job #: 20190617093701

Location: Accident History for PURCELL and SPAULDING

From:01/01/2012 To:12/31/2016

Severity

PDO: 14
 INJ: 6 6 :Injured
 FAT: 0 0 :Killed

Total: 20

Number of Vehicles

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

Total: 20

Location

On Road: 19
 Off Road Left: 1
 Off Road Right: 0
 Off Road at Tee: 0
 Off in Median: 0
 Unknown: 0

Total: 20

Lighting Conditions

Daylight: 11
 Dawn or Dusk: 1
 Dark - Lighted: 8
 Dark - Unlighted: 0
 Unknown: 0

Total: 20

Weather Conditions

None: 13
 Rain: 0
 Snow/Sleet/Hail: 2
 Fog: 0
 Dust: 0
 Wind: 0
 Unknown: 5

Total: 20

Crash Rates

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

Crash Type

| | |
|-------------------------|-------------------------------|
| Overtuning: 1 | 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: 11 | Delineator Post: 0 |
| Sideswipe (Same): 1 | Fence: 0 |
| Sideswipe (Opposite): 1 | Tree: 0 |
| Approach Turn: 3 | Large Boulders or Rocks: 1 |
| Overtaking Turn: 0 | Barricade: 0 |
| Parked Motor Vehicle: 0 | Wall/Building: 0 |
| Railway Vehicle: 0 | Crash Cushion: 0 |
| Bicycle: 0 | Mailbox: 0 |
| Motorized Bicycle: 0 | Other Fixed Object: 0 |
| Domestic Animal: 0 | Total Fixed Objects: 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 | |
| Concrete Barrier: 0 | |

Total: 20

Mainline/Ramps/Frontage Roads

Mainline: 20
 Crossroad (A): 0

Frontage/Ramp Intersections

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

Ramps

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

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

Total: 20

Road Description

At Intersection: 18
 At Driveway Access: 0
 Intersection Related: 2
 Non Intersection: 0
 In Alley: 0
 Roundabout: 0
 Ramp: 0
 Parking Lot: 0
 Unknown: 0

Total: 20

Road Conditions

Dry: 17
 Wet: 1
 Muddy: 0
 Snowy: 0
 Icy: 1
 Slushy: 0
 Foreign Material: 1
 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



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

CDOT Project #17602 06/17/2019
 Exhibit 2

Job #: 20190617093701

Location: Accident History for PURCELL and SPAULDING **From:01/01/2012 To:12/31/2016**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 8 | 12 | 0 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 7 | 3 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 1 | 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 | 1 | 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: | 20 | 17 | 0 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 10 | 10 | 0 |
| Slowing: | 0 | 1 | 0 |
| Stopped in Traffic: | 1 | 6 | 0 |
| Making Right Turn: | 1 | 0 | 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: | 1 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 2 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 20 | 17 | 0 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 7 | 9 | 0 |
| 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: | 2 | 1 | 0 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 |
| Driver Emotionally Upset: | 1 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 5 | 7 | 0 |
| Total: | 20 | 17 | 0 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 7 | 7 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 5 | 4 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 7 | 4 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 1 | 2 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 20 | 17 | 0 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 19 | 17 | 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: | 20 | 17 | 0 |

Project Information

Project Name: SH 6G Wildlife Fencing

Project Description: Install wildlife fencing

CDOT Region: 6 Project Def: 17656 County: Jefferson

Location: SH 6G Mile Points: 272.64 – 273.96 Length: 1.32 miles

Schedule: Work Start Date: 6/30/2010 Completion Date: 3/11/2011

Problem Description: The five-year crash history (2000 – 2004) showed that there was a total of one fatal crash, 81 injury crashes, and 279 PDO crashes along this corridor. Of the 361 crashes, 53 were wild animal type crashes.

Improvement Description: Between June 30, 2010 and March 11, 2011 a wildlife fence was installed. The cost of construction was \$590,423.

The FHEP application anticipated that an 60% reduction in wild animal crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 1.47.

Summary and Findings

The analysis of safety before and after the improvements along this corridor show a slight decrease in crashes. There were 90 total crashes during the three-year period before the improvements were made (2007 – 2009). In the three years after construction (2012 – 2014), the number of crashes was 86. The ADT increased slightly from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a decrease in the number of wildlife crashes after the completion of the project. There was a slight decrease in injury crashes and the number of injuries. There were 19 injury crashes in the three years before construction to 14 injury crashes in the three years after construction. The number of PDO went from 71 in the before period to 72 in the after period. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 10 years for this project is **1.70** to one. The result is an improvement that was justified from the safety improvement or cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 272.64 to 273.96 shows a slight decrease in the number of crashes from 90 during the three-year period (2007 to 2009) before the improvements to 86 during the three-year after period (2012 to 2014) (Table 1). The number of serious crashes decreased in the after period:

- Before (2006 – 2009) – No fatal crashes and 19 injury crashes with 23 injuries
- After (2012 – 2014) – No fatal crashes and 14 injury crashes with 18 injuries

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|--------------------------------|--------------------------------|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) |
| AADT (SH 6G) | 35,500 vpd | 37,000 vpd |
| Filters: | Non-Intersection | Non-Intersection |
| Total Crashes | 90 | 86 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 19 (23) | 14 (18) |
| Property Damage Only | 71 | 72 |
| Crash Types: # (%) [significance] | | |
| Wild Animal | 48 (53.3%) [100.0%] | 41 (47.7%) [100.0%] |
| Rear-End | 16 (17.8%) | 27 (31.4%) [100.0%] |
| Sideswipe Same Direction | 10 (11.1%) | 4 (4.7%) |
| Fixed Object | 9 (10.0%) | 8 (9.3%) |

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 of safety uses qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 SPF plot for total crashes (**Figure 1**) reflects no improvement in the crash record for this project, with LOSS IV in both the before and after periods. The SPF plot for fatal and injury crashes (**Figure 2**) shows slight improvement with LOSS IV in the before period and LOSS III/IV in the after period. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes
US 6, MP 272.64 to 273.96
Before: 2007 to 2009 After: 2012 to 2014

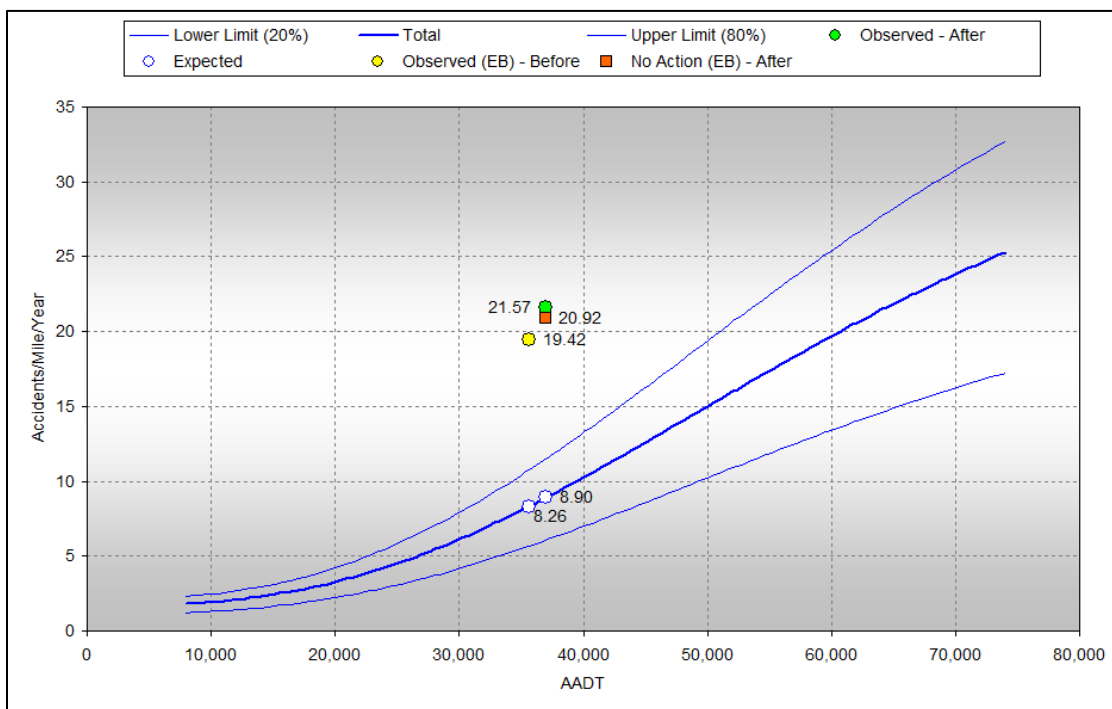


Figure 2 – SPF for Injury and Fatal Crashes
US 6, MP 272.64 to 273.96
Before: 2007 to 2009 After: 2012 to 2014

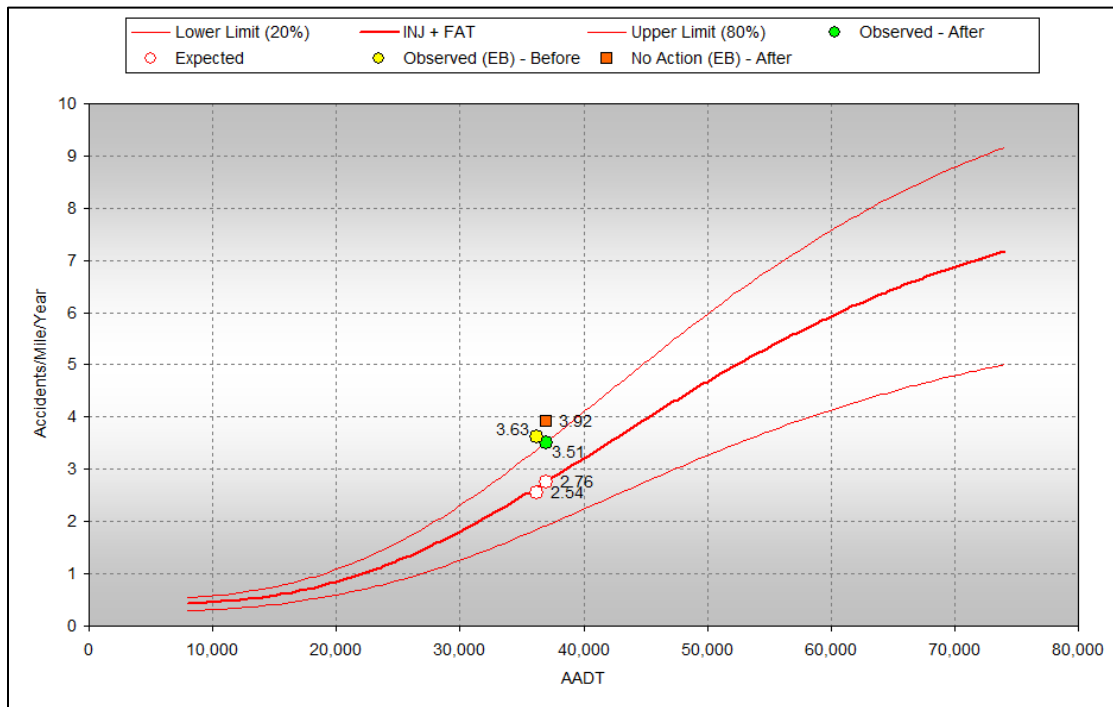


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action After |
|------------------------------------|----------------------|----------------------|----------------------|
| EB Correction: | Yes | No | Yes |
| SPF Graph | Urban 4-Lane Freeway | Urban 4-Lane Freeway | Urban 4-Lane Freeway |
| Total Crashes: | | | |
| LOSS | LOSS IV | LOSS IV | LOSS IV |
| CPY | 19.42 | 21.57 | 20.92 |
| Mean CPY | 8.26 | 8.90 | 8.90 |
| Proportion of Mean | 2.35 | 2.42 | 2.35 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS IV | LOSS III/IV | LOSS IV |
| CPY | 3.63 | 3.51 | 3.92 |
| Mean CPY | 2.54 | 2.76 | 2.76 |
| Proportion of Mean | 1.42 | 1.27 | 1.42 |

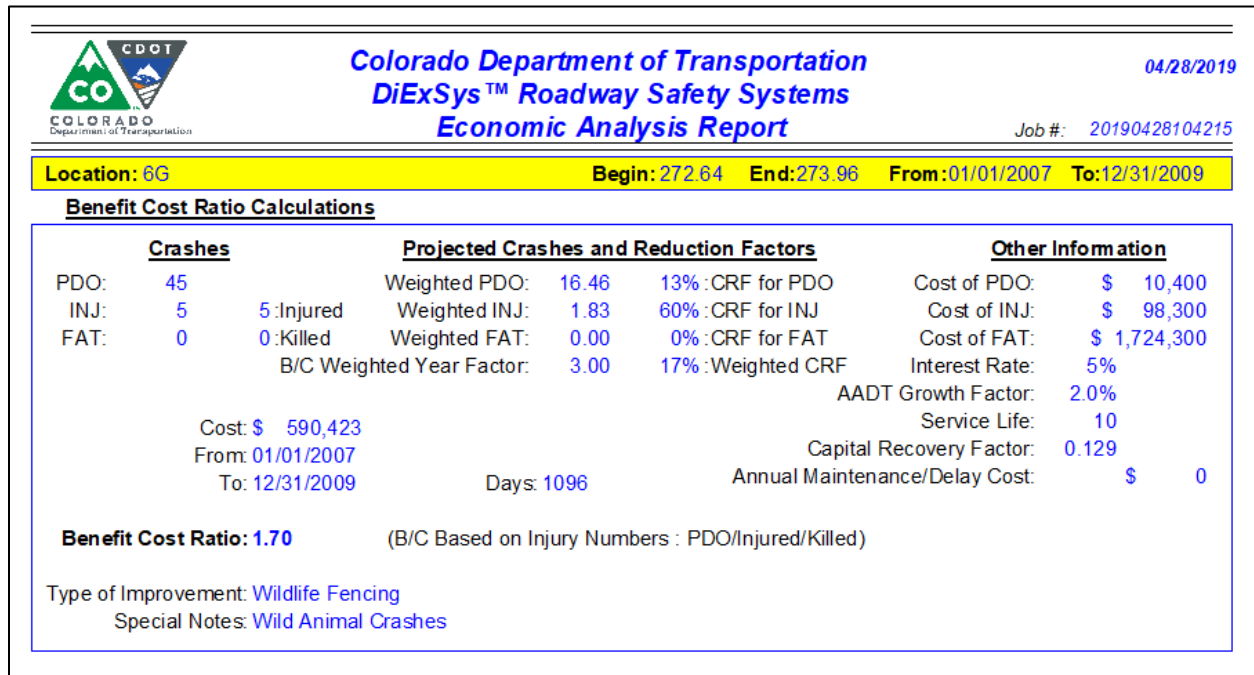
A more detailed review of the before and after crash record shows the crash types that were most affected by the project. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: wildlife. The improvement appears to have only slightly reduced the number of wildlife crashes on the segment. The No-Build After crashes were estimated using the change in US 6 traffic volumes between the before and after period, as found in **Table 1** (increase is 4% = $|1-(37,000/35,500)|$).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|---|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2007 to 12/31/2009 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) | 1/1/2012 to 12/31/2014 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 90 | 86 | 94 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 19 (23) | 14 (18) | 20 (24) |
| PDO | 71 | 72 | 74 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | NA / 25% / 3% | |
| Wildlife – Total | 48 | 41 | 50 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 5 (5) | 2 (2) | 5 (5) |
| PDO | 43 | 39 | 45 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | NA / 60% / 13% | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 1.70 was ultimately realized.** Even though this outcome displays that this safety improvement project was likely justified, reduction in the number of wild animal collisions is lower than expected 60%. We recommend that the design of the wild animal fence is reexamined and possible entry points of wild animals are identified.

Figure 5 – Benefit Cost Analysis





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

CDOT Project # 17656 04/26/2019

Exhibit 1

Job #: 20190426122554

Location: 6G **Begin: 272.64** **End: 273.96** **From: 01/01/2007** **To: 12/31/2009**

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 71 | |
| INJ: | 19 | 23 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 90 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 57 |
| Two Vehicles: | 30 |
| Three or More: | 3 |
| Unknown: | 0 |
| Total: | 90 |

Location

| | |
|------------------|-----------|
| On Road: | 59 |
| Off Road Left: | 1 |
| Off Road Right: | 11 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 19 |
| Total: | 90 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 26 |
| Dawn or Dusk: | 8 |
| Dark - Lighted: | 5 |
| Dark - Unlighted: | 50 |
| Unknown: | 1 |
| Total: | 90 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 76 |
| Rain: | 2 |
| Snow/Sleet/Hail: | 10 |
| Fog: | 1 |
| Dust: | 0 |
| Wind: | 1 |
| Unknown: | 0 |
| Total: | 90 |

Crash Rates

| | | |
|---------------|---------------|-------------|
| PDO: | 1.26 * | * MVMT |
| INJ: | 0.34 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 1.60 * | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 4 | Bridge Abutment: | 0 |
| Other Non Collision: | 1 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 0 | Embankment: | 3 |
| Head On: | 1 | Curb: | 0 |
| Rear End: | 16 | Delineator Post: | 1 |
| Sideswipe (Same): | 10 | Fence: | 0 |
| Sideswipe (Opposite): | 0 | Tree: | 2 |
| Approach Turn: | 0 | Large Boulders or Rocks: | 0 |
| Overtaking Turn: | 0 | Barricade: | 0 |
| Parked Motor Vehicle: | 0 | Wall/Building: | 0 |
| Railway Vehicle: | 0 | Crash Cushion: | 0 |
| Bicycle: | 0 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 0 |
| Domestic Animal: | 0 | Total Fixed Objects: | 9 |
| Wild Animal: | 48 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 0 | Vehicle Cargo/Debris: | 1 |
| Traffic Signal Pole: | 0 | Road Maintenance Equipment: | 0 |
| Sign: | 2 | Involving Other Object: | 0 |
| Bridge Rail: | 0 | Total Other Objects: | 1 |
| Guard Rail: | 1 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 90 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----------------------|------------------------------------|
| Mainline: | 90 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | Left Frontage Rd (L): | 0 |
| C: 0 G: 0 K: 0 | Rt Frontage Rd (R): | 0 |
| D: 0 H: 0 T: 0 | HOV Lanes (V): | 0 |
| E: 0 I: 0 | Unknown: | 0 |
| | Total: | 90 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 90 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 90 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 72 |
| Wet: | 6 |
| Muddy: | 0 |
| Snowy: | 2 |
| Icy: | 8 |
| 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: | 90 |

ADT: 38,900 **Length: 1.32**



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

CDOT Project # 17656 04/26/2019

Exhibit 1

Job #: 20190426122554

Location: 6G **Begin: 272.64** **End: 273.96** **From: 01/01/2007** **To: 12/31/2009**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 51 | 20 | 2 |
| Passenger Car/Van w/Trl: | 2 | 0 | 0 |
| Pickup Truck/Utility Van: | 11 | 8 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 18 | 4 | 0 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 6 | 1 | 0 |
| School Bus < 15 People: | 0 | 0 | 0 |
| Non School Bus < 15 People: | 0 | 0 | 0 |
| Motorhome: | 0 | 0 | 0 |
| Motorcycle: | 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 | 1 |
| Total: | 90 | 33 | 3 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 74 | 18 | 0 |
| Slowing: | 2 | 4 | 0 |
| Stopped in Traffic: | 1 | 10 | 2 |
| 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: | 7 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 1 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 4 | 1 | 0 |
| Unknown: | 0 | 0 | 1 |
| Total: | 90 | 33 | 3 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 69 | 32 | 3 |
| Asleep at the Wheel: | 1 | 0 | 0 |
| Illness: | 2 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 8 | 0 | 0 |
| Driver Fatigue: | 1 | 0 | 0 |
| Driver Preoccupied: | 2 | 0 | 0 |
| Driver Unfamiliar with Area: | 2 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 1 | 0 | 0 |
| Unknown: | 4 | 1 | 0 |
| Total: | 90 | 33 | 3 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 16 | 3 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 19 | 7 | 0 |
| Southeast: | 14 | 7 | 0 |
| South: | 7 | 6 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 19 | 5 | 2 |
| Northwest: | 15 | 5 | 0 |
| Unknown: | 0 | 0 | 1 |
| Total: | 90 | 33 | 3 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 89 | 33 | 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: | 90 | 33 | 3 |

ADT: 38,900 **Length: 1.32**



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

CDOT Project # 17656 04/26/2019
Exhibit 2

Job #: 20190426132222

Location: 6G Begin: 272.64 End: 273.96 From: 01/01/2012 To: 12/31/2014

| Severity | |
|---------------|----------------|
| PDO: | 72 |
| INJ: | 14 18 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 86 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 53 |
| Two Vehicles: | 27 |
| Three or More: | 6 |
| Unknown: | 0 |
| Total: | 86 |

| Location | |
|------------------|-----------|
| On Road: | 77 |
| Off Road Left: | 5 |
| Off Road Right: | 4 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 86 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 42 |
| Dawn or Dusk: | 5 |
| Dark - Lighted: | 14 |
| Dark - Unlighted: | 25 |
| Unknown: | 0 |
| Total: | 86 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 74 |
| Rain: | 5 |
| Snow/Sleet/Hail: | 7 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 86 |

| Crash Rates | |
|---------------|--------------------|
| PDO: | 1.34 * * MVMT |
| INJ: | 0.26 * ** 100 MVMT |
| FAT: | 0.00 ** |
| Total: | 1.60 * |

| Crash Type | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 3 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 0 | Embankment: | 2 |
| Head On: | 0 | Curb: | 1 |
| Rear End: | 27 | Delineator Post: | 1 |
| Sideswipe (Same): | 4 | Fence: | 0 |
| 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: | 1 | Total Fixed Objects: | 8 |
| Wild Animal: | 41 | 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: | 1 |
| Bridge Rail: | 0 | Total Other Objects: | 2 |
| Guard Rail: | 0 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 86 |
| Concrete Barrier: | 0 | | |

| Mainline/Ramps/Frontage Roads | | Frontage/Ramp Intersections | | | |
|-------------------------------|----|-----------------------------|---|----|---|
| Mainline: | 86 | M: | 0 | N: | 0 |
| Crossroad (A): | 0 | O: | 0 | P: | 0 |
| Ramps | | Total: 86 | | | |
| B: | 0 | F: | 0 | J: | 0 |
| C: | 0 | G: | 0 | K: | 0 |
| D: | 0 | H: | 0 | T: | 0 |
| E: | 0 | I: | 0 | | |
| | | Left Frontage Rd (L): | 0 | | |
| | | Rt Frontage Rd (R): | 0 | | |
| | | HOV Lanes (V): | 0 | | |
| | | Unknown: | 0 | | |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 86 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 86 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 67 |
| Wet: | 10 |
| Muddy: | 0 |
| Snowy: | 5 |
| 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: | 86 |

ADT: 37,000 Length: 1.32



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

CDOT Project # 17656 04/26/2019
Exhibit 2

Job #: 20190426132222

Location: 6G Begin: 272.64 End: 273.96 From: 01/01/2012 To: 12/31/2014

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 48 | 18 | 1 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 10 | 4 | 1 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 22 | 10 | 3 |
| 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: | 5 | 1 | 0 |
| Bicycle: | 0 | 0 | 0 |
| Motorized Bicycle: | 0 | 0 | 0 |
| Farm Equipment: | 0 | 0 | 0 |
| Hit and Run - Unknown: | 1 | 0 | 1 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 86 | 33 | 6 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 70 | 9 | 3 |
| Slowing: | 5 | 8 | 1 |
| Stopped in Traffic: | 0 | 15 | 2 |
| Making Right Turn: | 0 | 0 | 0 |
| Making Left Turn: | 0 | 0 | 0 |
| Making U-Turn: | 0 | 0 | 0 |
| Passing: | 1 | 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: | 4 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 1 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 4 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 86 | 33 | 6 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 56 | 31 | 5 |
| Asleep at the Wheel: | 2 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 2 | 0 | 0 |
| Driver Inexperience: | 5 | 0 | 1 |
| Driver Fatigue: | 1 | 0 | 0 |
| Driver Preoccupied: | 9 | 0 | 0 |
| Driver Unfamiliar with Area: | 3 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 8 | 2 | 0 |
| Total: | 86 | 33 | 6 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 15 | 7 | 2 |
| Northeast: | 0 | 0 | 0 |
| East: | 19 | 6 | 1 |
| Southeast: | 11 | 4 | 0 |
| South: | 9 | 3 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 16 | 3 | 1 |
| Northwest: | 16 | 10 | 2 |
| Unknown: | 0 | 0 | 0 |
| Total: | 86 | 33 | 6 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 84 | 33 | 6 |
| 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: | 86 | 33 | 6 |

ADT: 37,000 Length: 1.32

Project Information

Project Name: SH 82 at Brush Creek Signal Improvements

Project Description: Upgrade Existing Signals

CDOT Region: 2 Project Def: 17657 County: Pitkin

Location: SH 82 at Bush Creek

Mile Points: 35.22 to 35.29 Length: 0..07 Mile

Schedule: Work Start Date: 1/17/2011 Completion Date: 4/29/2011

Problem Description: The crash history from VZS for the evaluation period of 2001 to 2005 shows 34 crashes. There were 11 injury crashes and one fatal crash with 26 people injured and one killed. The most prevalent crash type was rear ends with 22 crashes. There were also 4 fixed object crashes, 3 broadsides, 3 sideswipes and 2 approach turns. This intersection was performing at LOSS-IV in terms of both crash frequency and crash severity. Patterns were identified for rear end crashes and for snowy and icy conditions.

Improvement Description: Between January 17, 2011 and April 29, 2011 the signals were upgraded (8" heads upgraded to 12" LED heads with backing plates). In addition, dilemma zone preemption, for which equipment was already in place but not in use, was activated. The cost of construction was \$318,317. The predicted B/C ratio was estimated to be 1.12.

The FHEP application anticipated an overall crash reduction of 15% would be realized by these improvements.

Summary and Findings

The signal upgrades and dilemma zone preemption appear to have improved safety at the intersection of SH 82 and Bush Creek Road. The analysis of safety performance before and after the signal upgrade at the intersection showed a 44% reduction in total crashes from 34 in the before-period (2001 to 2005) to 19 in the after-period (2012 to 2016). The number of crashes involving bodily injury showed an 83% reduction from 12 crashes in the before-period to only 2 in the after-period. There were only two people injured in the after-period and none killed compared to 26 injuries and 1 death in the before-period.

As expected, the highest crash reduction rear end crashes, which fell from 22 in the before-period to 11 in the after-period. Reductions were also seen in sideswipes and approach turn crashes.

The upgrades likely have contributed to decreases in the number of rear end crashes and total crashes. We have provided a benefit/cost analysis based on the comparison of crashes in the before period to those in the after period. The cost associated with the improvement was \$318,318. The resulting ratio of benefits and cost for this project shows that benefits outweigh the costs with a B/C ratio of almost 40 to one, showing that the improvement was cost effective in terms of safety benefits.

Results of Safety Analyses

Using VZS, the review of before and after crash records showed the number of crashes decreased between the two study periods. The total number of crashes was 34 during the five-year period (2001 to 2005) before the signal upgrades and 19 during the five-year after period (2012 to 2016) (see **Table 1**). The number of severe crashes decreased in the five-year period after the improvements, and there were no fatal crashes in the after-period while there was 1 fatal crash in the before-period.

- Before (2001 – 2005) – 1 fatal crashes and 11 injury crashes with 26 people injured and 1 person killed
- After (2012 – 2016) – No fatal crashes and 2 injury crashes with 2 people injured

There was an increase in traffic volumes at the intersection from the before period to the after period of approximately 6.2%. As a result, the proportional decrease in crash rates is even greater than the decrease in crash numbers:

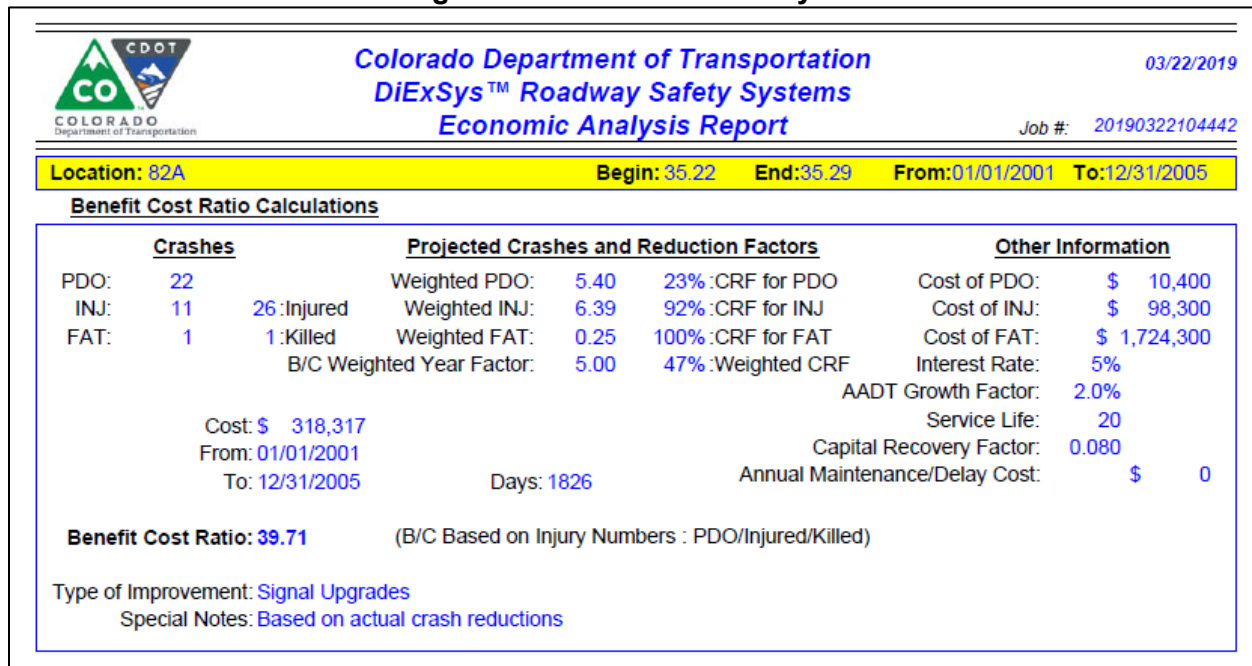
- Before (2001 – 2005): 1.03 crashes per million entering vehicles (cpmev)
- After (2012 – 2016): 0.54 cpmev

Table 1 - Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2001 to 12/31/2005 (5 yr.) | 1/1/2012 to 12/31/2016 (5 yr.) |
| AADT (SH 82/Bush Cr. Rd) | 16,493/estimated 1,649 vpd | 17,512/estimated 1,751 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 34 | 19 |
| Fatal Crashes (Fatalities) | 1 (1) | 0 (0) |
| Injury Crashes (Injuries) | 11 (26) | 2 (2) |
| Property Damage Only | 22 | 17 |
| Crash Types: # (%) [cumulative probability] | | |
| Rear End | 22 (39.8%) [99.71%] | 11 (57.9%) [82.3%] |
| Broadside | 3 (8.8%) | 3 (15.8%) |
| Sideswipe | 3 (8.8%) | 0 (0%) |
| Approach Turn | 2 (5.9%) | 1 (5.3%) |

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. As shown, using the \$317,318 project cost as the cost basis, the safety related B/C ratio for the improvement is 39.71, showing that the improvement was cost effective from the safety standpoint.

Figure 3 – Benefit Cost Analysis



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

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

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

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

SPF plots for both total crashes (see **Figure 1**) and for fatal and injury crashes (see **Figure 2**) also reflect the change in the crash record. The frequency of crashes moved from the LOSS III category for the before-period to the LOSS-I/II category boundary in the after-period. The severity of crashes moved from the LOSS III category for the before-period to the LOSS-I category in the after-period. (see **Table 2**).

Figure 1 – SPF for Total Crashes – Before/After/No Action After
 SH 82A at Bush Cr Rd (MP 35.22 to 35.29)
 Before:2001 to 2005 After:2012 to 2016

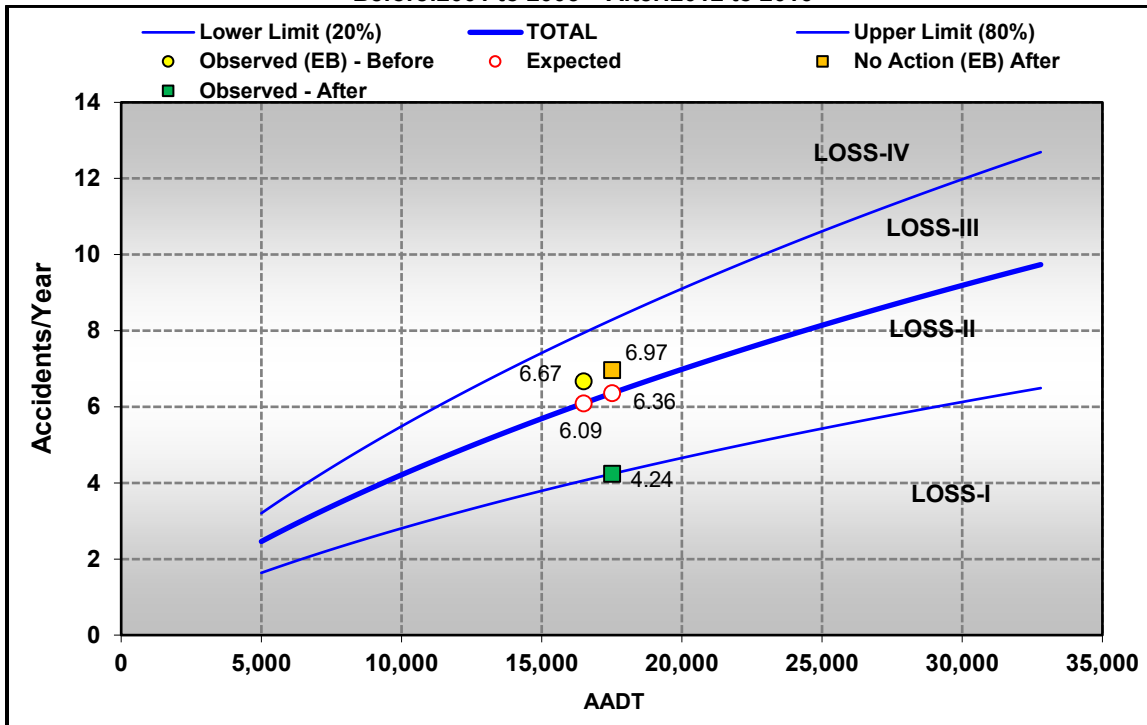


Figure 2 – SPF for Injury and Fatal Crashes – Before/After/No Action After
 SH 82A at Bush Cr Rd (MP 35.22 to 35.29)
 Before:2001 to 2005 After:2012 to 2016

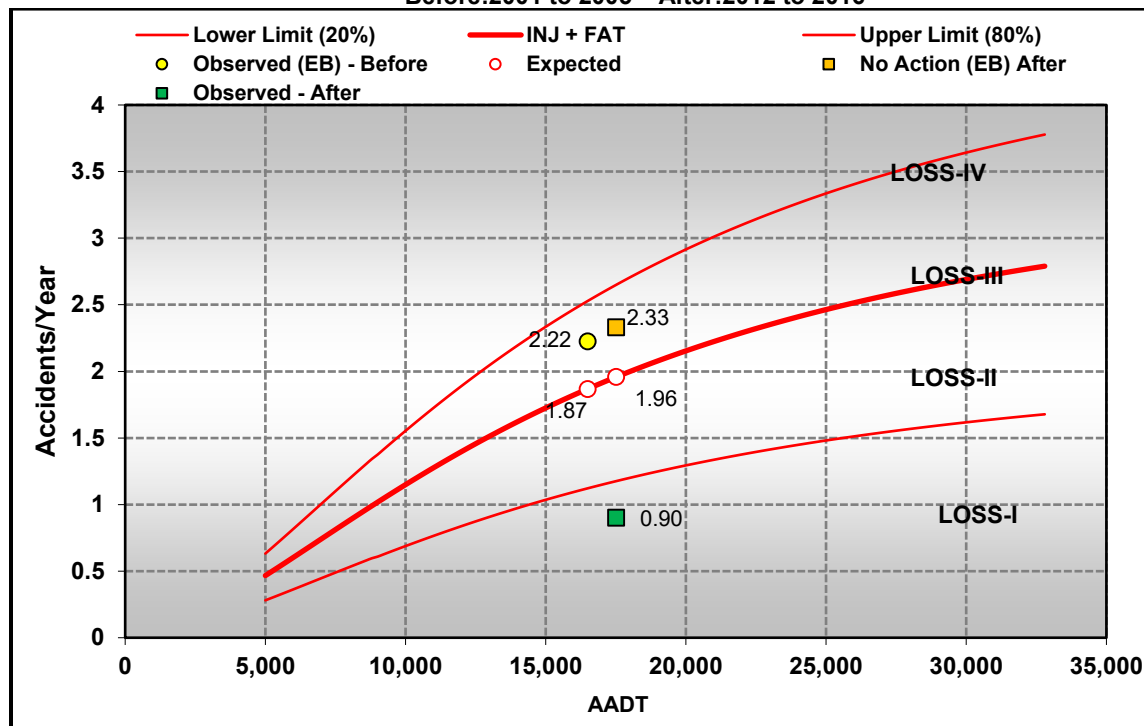


Table 2 – Safety Performance Function (SPF)

| | Before | After | No Build After |
|------------------------------------|---|---|---|
| EB Correction: | Yes | Yes | 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/II | LOSS III |
| CPY | 6.67 | 4.64 | 6.97 |
| Mean CPY | 6.09 | 6.36 | 6.36 |
| Proportion of Mean | 1.10 | 0.73 | 1.10 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS III | LOSS I | LOSS III |
| CPY | 2.22 | 0.90 | 2.33 |
| Mean CPY | 1.87 | 1.96 | 1.96 |
| Proportion of Mean | 1.19 | 0.46 | 1.19 |

*SH 82 at Bush Creek Road is of a rural character. However, due the relative scarcity of rural 4-lane divided, signalized intersection in Colorado, there are not specific SPF norms for that intersection type. It is expected that the mean levels would be somewhat higher for a rural model, however since the analysis is based on comparison of before to after period, any small potential differences in the norms for urban versus rural should not affect the conclusions of the analysis.

A more detailed review of the before and after crash record shows the crash types that were most affected by the signal installation. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: rear-end, sideswipe and approach turn. The signal improvements substantially reduced the number of rear end crashes. This is an expected outcome when increasing the visibility of traffic signals. The No Build After crashes were estimated using the change in SH 82 traffic volumes between the before and after period, as found in **Table 1** (increase is 1.062 = 17,512/16,493).

Table 3 – Results of Crash Analyses

| | Before | After | No Build After |
|---|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2001 to 12/31/2005 (5 yr.) | 1/1/2012 to 12/31/2016 (5 yr.) | 1/1/2012 to 12/31/2016 (5 yr.) |
| Crash Types: | | | |
| Total Crashes | 34 | 19 | 36 |
| Fatal (fatalities) | 1 (1) | 0 (0) | 1 (1) |
| Injury (injuries) | 11 (26) | 2 (2) | 12 (28) |
| PDO | 22 | 17 | 23 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | 44% (100%/92%/23%) | |
| Rear Ends – Total | 22 | 11 | 23 |
| Injury (injuries) | 8 (14) | 1 (1) | 8 (15) |
| PDO | 14 | 10 | 15 |
| % Reduction in Total (Injuries/PDO) | | 50% (93%/29%) | |
| Sideswipes – Total | 3 | 0 | 3 |
| Injury (injuries) | 0 (0) | 0 (0) | 0 (0) |
| PDO | 3 | 0 | 3 |
| % Reduction in Total (PDO) | | 100% (100%) | |
| Approach Turns – Total | 2 | 1 | 2 |
| Fatal (Fatalities) | 1 (1) | 0 (0) | 1 (1) |
| Injury (injuries) | 1 (9) | 1 (1) | 1 (10) |
| PDO | 0 | 0 | 0 |
| % Reduction in Total (Fatalities/Injuries/PDO) | | 50% (100%/89%/NA) | |



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

CDOT Project #17657 06/17/2019
Exhibit 1

Job #: 20190617121708

Location: 82A **Begin: 35.22** **End: 35.29** **From:01/01/2001** **To:12/31/2005**

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 22 | |
| INJ: | 11 | 26 :Injured |
| FAT: | 1 | 1 :Killed |
| Total: | 34 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 4 |
| Two Vehicles: | 26 |
| Three or More: | 4 |
| Unknown: | 0 |
| Total: | 34 |

Location

| | |
|------------------|-----------|
| On Road: | 31 |
| Off Road Left: | 2 |
| Off Road Right: | 1 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 34 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 27 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 5 |
| Dark - Unlighted: | 1 |
| Unknown: | 0 |
| Total: | 34 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 27 |
| Rain: | 0 |
| Snow/Sleet/Hail: | 6 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 1 |
| Unknown: | 0 |
| Total: | 34 |

Crash Rates

| | | |
|---------------|----------------|-------------|
| PDO: | 10.44 * | * MVMT |
| INJ: | 5.22 * | ** 100 MVMT |
| FAT: | 47.44 ** | |
| Total: | 16.13 * | |

Crash Type

| | | | |
|-----------------------|----|------------------------------|-----------|
| Overtuning: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 3 | Embankment: | 0 |
| Head On: | 0 | Curb: | 1 |
| Rear End: | 22 | Delineator Post: | 0 |
| Sideswipe (Same): | 3 | 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: | 4 |
| Wild Animal: | 0 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 0 | Vehicle Cargo/Debris: | 0 |
| Traffic Signal Pole: | 1 | Green 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: | 34 |
| Concrete Barrier: | 1 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----------------------|------------------------------------|
| Mainline: | 34 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | Left Frontage Rd (L): | 0 |
| C: 0 G: 0 K: 0 | Rt Frontage Rd (R): | 0 |
| D: 0 H: 0 T: 0 | HOV Lanes (V): | 0 |
| E: 0 I: 0 | Unknown: | 0 |
| | Total: | 34 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 22 |
| At Driveway Access: | 0 |
| Intersection Related: | 12 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 34 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 19 |
| Wet: | 3 |
| Muddy: | 0 |
| Snowy: | 6 |
| Icy: | 4 |
| 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: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 34 |

ADT: 16,493 **Length: 0.07**



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

CDOT Project #17657 06/17/2019
Exhibit 1

Job #: 20190617121708

Location: 82A **Begin: 35.22** **End: 35.29** **From:01/01/2001** **To:12/31/2005**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 24 | 18 | 3 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 8 | 8 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 0 | 0 | 0 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 2 | 4 | 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 | 1 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 34 | 30 | 4 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 15 | 4 | 0 |
| Slowing: | 13 | 5 | 0 |
| Stopped in Traffic: | 0 | 16 | 3 |
| Making Right Turn: | 2 | 2 | 0 |
| Making Left Turn: | 2 | 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 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 1 |
| Total: | 34 | 30 | 4 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 15 | 28 | 3 |
| Asleep at the Wheel: | 0 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 1 | 0 | 0 |
| Driver Inexperience: | 3 | 0 | 0 |
| Driver Fatigue: | 1 | 0 | 0 |
| Driver Preoccupied: | 12 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 2 | 2 | 1 |
| Total: | 34 | 30 | 4 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 2 | 4 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 17 | 13 | 2 |
| Southeast: | 0 | 0 | 0 |
| South: | 0 | 0 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 15 | 13 | 1 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 1 |
| Total: | 34 | 30 | 4 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 32 | 29 | 4 |
| Alcohol Involved: | 2 | 0 | 0 |
| RX, Medication, or Drugs Involved: | 0 | 1 | 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: | 34 | 30 | 4 |

ADT: 16,493 **Length: 0.07**



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

CDOT Project #17657 06/17/2019
Exhibit 2

Job #: 20190617121739

Location: 82A Begin: 35.22 End: 35.29 From:01/01/2012 To:12/31/2016

Severity

| | | |
|---------------|-----------|------------|
| PDO: | 17 | |
| INJ: | 2 | 2 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 19 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 4 |
| Two Vehicles: | 14 |
| Three or More: | 1 |
| Unknown: | 0 |
| Total: | 19 |

Location

| | |
|------------------|-----------|
| On Road: | 15 |
| Off Road Left: | 3 |
| Off Road Right: | 1 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 19 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 10 |
| Dawn or Dusk: | 3 |
| Dark - Lighted: | 6 |
| Dark - Unlighted: | 0 |
| Unknown: | 0 |
| Total: | 19 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 16 |
| Rain: | 0 |
| Snow/Sleet/Hail: | 3 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 19 |

Crash Rates

| | | |
|---------------|--------------|-------------|
| PDO: | 7.59* | * MVMT |
| INJ: | 0.89* | ** 100 MVMT |
| FAT: | 0.00** | |
| Total: | 8.48* | |

Crash Type

| | | | |
|-----------------------|----|------------------------------|-----------|
| Overtuning: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 3 | Embankment: | 0 |
| Head On: | 0 | Curb: | 1 |
| Rear End: | 11 | 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: | 4 |
| Wild Animal: | 0 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 0 | Vehicle Cargo/Debris: | 0 |
| Traffic Signal Pole: | 1 | Green Maintenance Equipment: | 0 |
| Sign: | 0 | Involving Other Object: | 0 |
| Bridge Rail: | 0 | Total Other Objects: | 0 |
| Guard Rail: | 2 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 19 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----------------------|------------------------------------|
| Mainline: | 19 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | Left Frontage Rd (L): | 0 |
| C: 0 G: 0 K: 0 | Rt Frontage Rd (R): | 0 |
| D: 0 H: 0 T: 0 | HOV Lanes (V): | 0 |
| E: 0 I: 0 | Unknown: | 0 |
| | Total: | 19 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 13 |
| At Driveway Access: | 0 |
| Intersection Related: | 6 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 19 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 9 |
| Wet: | 1 |
| Muddy: | 0 |
| Snowy: | 1 |
| Icy: | 6 |
| Slushy: | 0 |
| Foreign Material: | 0 |
| With Road Treatment: | 0 |
| Dry w/Icy Road Treatment: | 0 |
| Wet w/Icy Road Treatment: | 0 |
| Snowy w/Icy Road Treatment: | 2 |
| Icy w/Icy Road Treatment: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 19 |

ADT: 17,512 Length: 0.07



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

CDOT Project #17657 06/17/2019
 Exhibit 2

Job #: 20190617121739

Location: 82A **Begin: 35.22** **End: 35.29** **From:01/01/2012** **To:12/31/2016**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 7 | 7 | 1 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 2 | 3 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 8 | 4 | 0 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 1 | 0 | 0 |
| School Bus < 15 People: | 0 | 0 | 0 |
| Non School Bus < 15 People: | 1 | 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: | 19 | 15 | 1 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 8 | 1 | 0 |
| Slowing: | 5 | 1 | 0 |
| Stopped in Traffic: | 0 | 9 | 1 |
| Making Right Turn: | 2 | 1 | 0 |
| Making Left Turn: | 2 | 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: | 1 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 19 | 15 | 1 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 9 | 13 | 1 |
| Asleep at the Wheel: | 1 | 0 | 0 |
| Illness: | 1 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 1 | 0 | 0 |
| Driver Fatigue: | 1 | 0 | 0 |
| Driver Preoccupied: | 2 | 1 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 4 | 1 | 0 |
| Total: | 19 | 15 | 1 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 1 | 1 | 0 |
| Northeast: | 1 | 1 | 0 |
| East: | 7 | 2 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 0 | 3 | 0 |
| Southwest: | 1 | 1 | 0 |
| West: | 8 | 7 | 1 |
| Northwest: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 19 | 15 | 1 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 18 | 14 | 1 |
| 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: | 19 | 15 | 1 |

ADT: 17,512 **Length: 0.07**

Project Information

Project Name: SH 30A / Oneida Way Signal Upgrade

Project Description: Upgrade signal

CDOT Region: 6 Project Def: 17659 County: Denver

Location: SH 30A Mile Points: 0.52 Length: N/A

Schedule: Work Start Date: 6/1/2011 Completion Date: 12/28/2013

Problem Description: The five-year crash history (2000 – 2004) showed that there was a total of one fatal crash, 14 injury crashes, and 26 PDO crashes at this intersection. Of the 41 crashes, 10 were broadside type crashes.

Improvement Description: Between June 1, 2011 and December 28, 2013, the signal was replaced. This replaced a diagonal span wire with 12-8-8 signal heads with mast arms on each approach and 12 inch signal heads. The cost of construction was \$274,119.

The FHEP application anticipated that an 24% reduction in crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 4.28.

Summary and Findings

The analysis of safety before and after the improvements at this intersection shows no overall change in crashes with a slight decrease in injuries. There were 20 total crashes during the three-year period before the improvements were made (2008 – 2010). In the three years after construction (2014 – 2016), the number of crashes was also 20. The ADT increased slightly from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a decrease in the number of broadside crashes after the completion of the project. The number of approach turn and rear-end crashes increased in the after period.

There was a slight decrease in injury crashes and the number of injuries. There were 10 injuries in the three years before construction to 9 injury in the three years after construction. The number of PDO went from 12 in the before period to 14 in the after period. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 10 years for this project is **0.67** to one. The result is an improvement that was not justified from the safety improvement or cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 0.50 to 0.54 shows no change in the number of crashes from 20 during the three-year period (2008 to 2010) before the improvements to 20 during the three-year after period (2014 to 2016) (**Table 1**). The number of serious crashes decreased in the after period:

- Before (2008 – 2010) – No fatal crashes and 8 injury crashes with 10 injuries
- After (2014 – 2016) – No fatal crashes and 6 injury crashes with 9 injuries

The crash rate at this intersection decreased slightly in the after period:

- Before (2008 – 2010) – 0.39 crashes per million entering vehicles (cpmev)
- After (2014 – 2016) – 0.38 cpmev

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) |
| AADT (SH 30A/Oneida Way) | 43,000 vpd / approx. 4,300 vpd | 43,650 vpd / approx. 4,350 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 20 | 20 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 8 (10) | 6 (9) |
| Property Damage Only | 12 | 14 |
| Crash Types: # (%) [significance] | | |
| Rear-End | 9 (45.0%) | 12 (60.0%) |
| Broadside | 6 (30.0%) [99.5%] | 1 (5.0%) |
| Approach Turn | 2 (10.0%) | 5 (25.0%) |

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

Development of the SPF lends itself well to the conceptual formulation of the Levels of Service of Safety (LOSS). The concept of level of service of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 (**Figures 1 and 2**) and for fatal and injury crashes (**Figures 3 and 4**) reflect a slight improvement in the crash record for this project. For the frequency of crashes, the intersection is LOSS II in the before period and LOSS I in the after periods. For the severity of crashes, the intersection is LOSS II for both the before and after periods. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes – Before
SH 30A, MP 0.521
Before: 2008 to 2010 After: 2014 to 2016

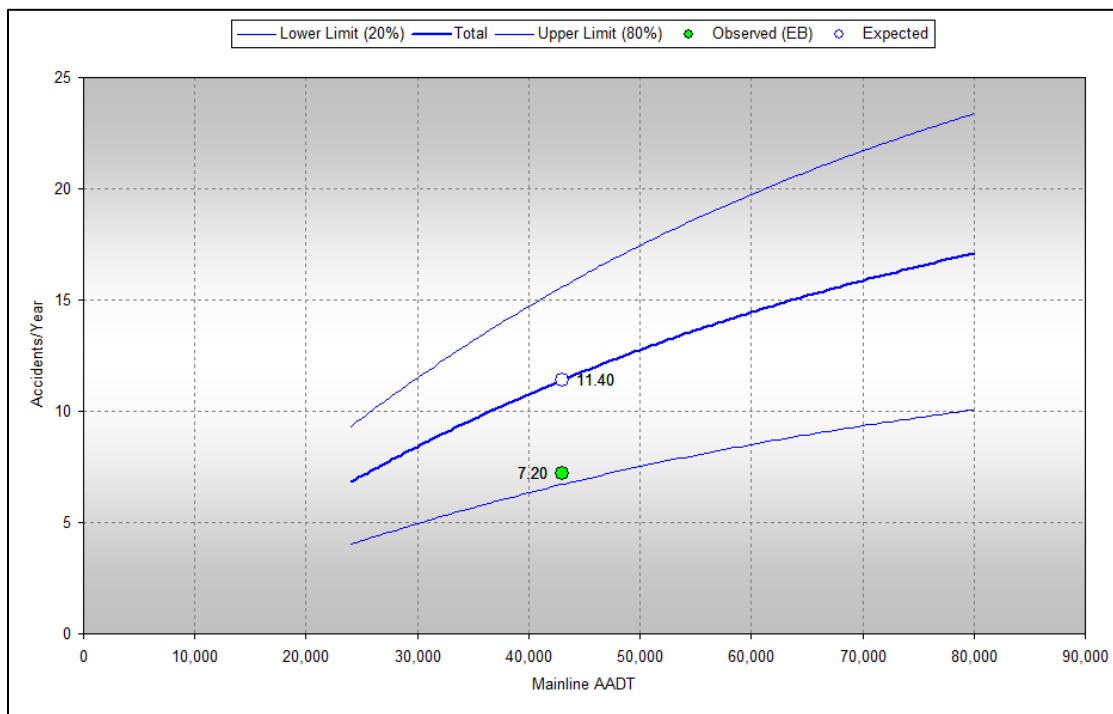


Figure 2 – SPF for Total Crashes – After/No Action After

SH 30A, MP 0.52I

Before: 2008 to 2010 After: 2014 to 2016

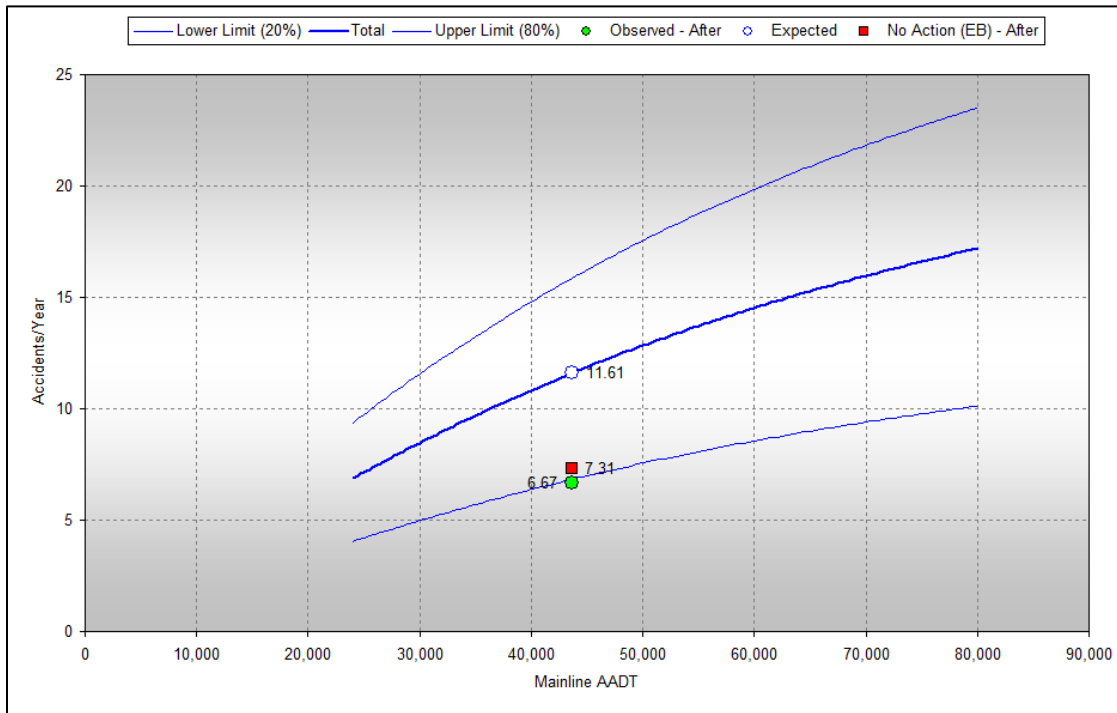


Figure 3 – SPF for Injury and Fatal Crashes – Before

SH 30A, MP 0.52I

Before: 2008 to 2010 After: 2014 to 2016

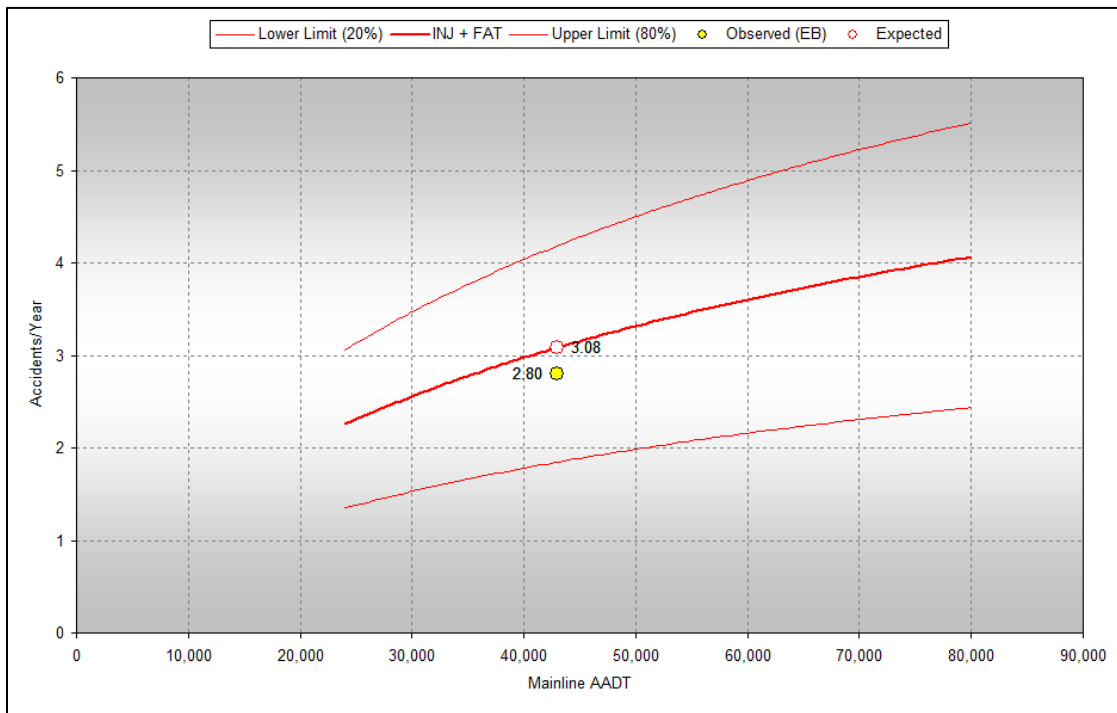


Figure 4 – SPF for Injury and Fatal Crashes – After/No Action After

SH 30A, MP 0.521

Before: 2008 to 2010 After: 2014 to 2016

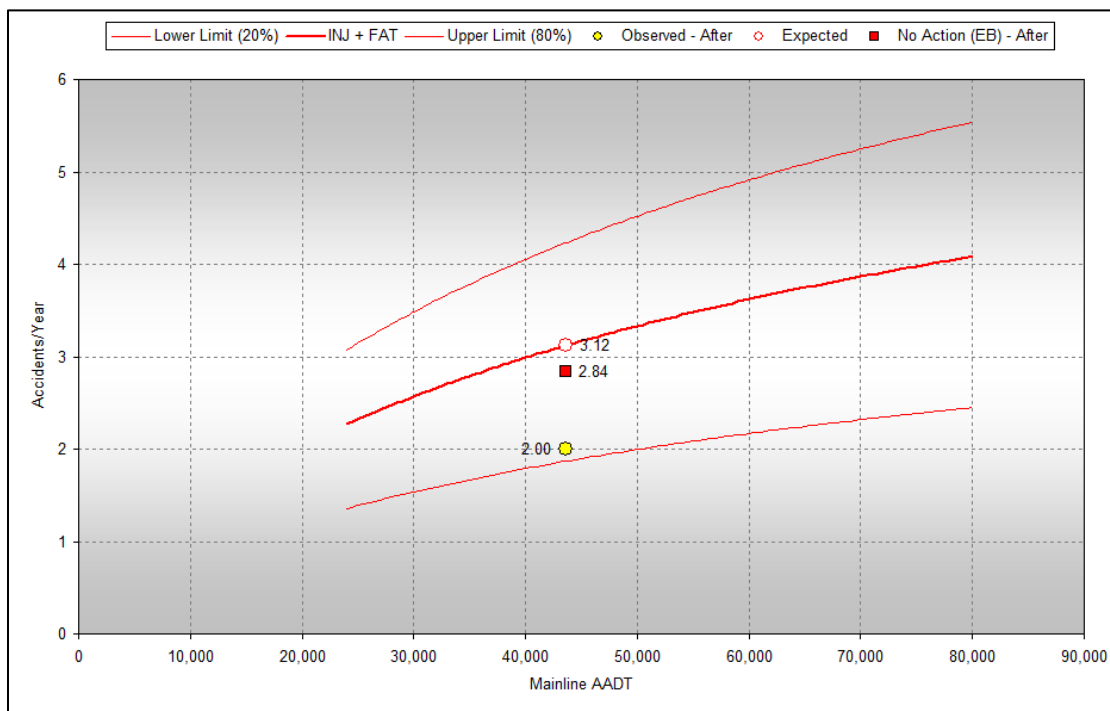


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action After |
|------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| EB Correction: | Yes | No | Yes |
| SPF Graph | Signalized 6-Lane 4-Leg Intersection | Signalized 6-Lane 4-Leg Intersection | Signalized 6-Lane 4-Leg Intersection |
| Total Crashes: | | | |
| LOSS | LOSS II | LOSS I | LOSS II |
| CPY | 7.20 | 6.67 | 7.31 |
| Mean CPY | 11.40 | 11.61 | 11.61 |
| Proportion of Mean | 0.63 | 0.57 | 0.63 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS II | LOSS II | LOSS II |
| CPY | 2.80 | 2.00 | 2.84 |
| Mean CPY | 3.08 | 3.12 | 3.12 |
| Proportion of Mean | 0.91 | 0.64 | 0.91 |

A more detailed review of the before and after crash record shows the crash types that were most affected by the signal upgrade. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: rear-end, broadside, and approach turn. After the signal upgrade, there was a decrease in broadside crashes. There was an increase in approach turn and rear-end type crashes. As a result, there was an overall increase in property damage only crashes. Over the design life of 10 years for the improvements, the increased cost of crashes would be \$138,667 (13.33 PDO = \$138,667).

The No-Build After crashes were estimated using the change in SH 30A traffic volumes between the before and after period, as found in **Table 1** (increase is 2% = |1-(43,650/43,000)|).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|--|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 20 | 20 | 20 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 8 (10) | 6 (9) | 8 (10) |
| PDO | 12 | 14 | 12 |
| % Reduction in Total (Injuries/PDO) | | 10% / -16% | |
| Rear-End – Total | 9 | 12 | 9 |
| Injury (injuries) | 3 (4) | 3 (3) | 3 (4) |
| PDO | 6 | 9 | 6 |
| % Reduction in Total (Injuries/PDO) | | 25% / -50% | |
| Broadside – Total | 6 | 1 | 6 |
| Injury (injuries) | 2 (2) | 1 (1) | 2 (2) |
| PDO | 4 | 0 | 4 |
| % Reduction in Total (Injuries/PDO) | | 50% / 100% | |
| Approach Turn – Total | 2 | 5 | 2 |
| Injury (injuries) | 2 (2) | 1 (4) | 2 (2) |
| PDO | 0 | 4 | 0 |
| % Reduction in Total (Injuries/PDO) | | -100% / NA | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 0.67 was ultimately realized.** This outcome displays that this safety improvement project was likely not justified.

It has been noted that using the number of injury crashes may be a more accurate methodology for this analysis because the number of injuries in a given crash can vary a lot depending on the number of people in a vehicle. **Figure 6** provides the results of this revised methodology and shows a B/C ratio of 1.35.

Figure 5 – Benefit Cost Analysis – Number of Injuries

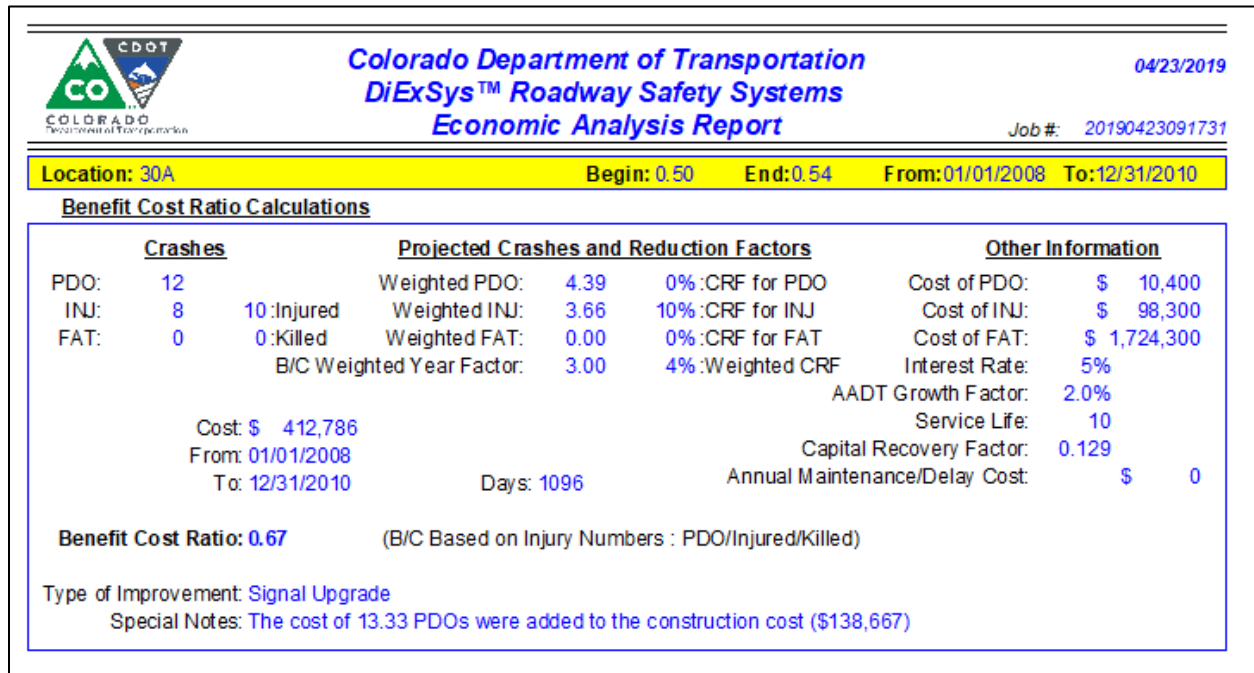
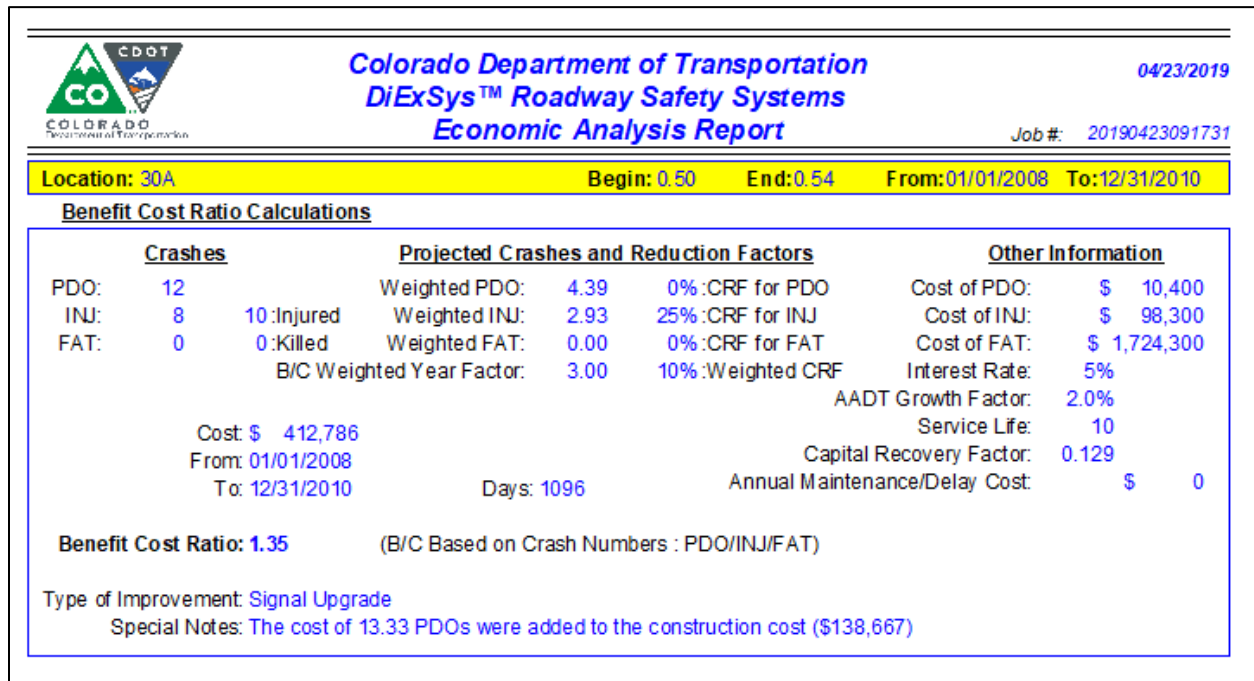


Figure 6 – Benefit Cost Analysis – Number of Injury Crashes





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

CDOT Project # 17659 04/22/2019
Exhibit 1

Job #: 20190422204522

Location: 30A Begin: 0.50 End: 0.54 From:01/01/2008 To:12/31/2010

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 12 | |
| INJ: | 8 | 10 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 20 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 0 |
| Two Vehicles: | 18 |
| Three or More: | 2 |
| 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: | 12 |
| Dawn or Dusk: | 2 |
| Dark - Lighted: | 5 |
| Dark - Unlighted: | 1 |
| Unknown: | 0 |
| Total: | 20 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 16 |
| Rain: | 1 |
| Snow/Sleet/Hail: | 3 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 20 |

Crash Rates

| | | |
|---------------|----------------|-------------|
| PDO: | 6.53 * | * MVMT |
| INJ: | 4.35 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 10.88 * | |

Crash Type

| | | | |
|-----------------------|---|-----------------------------|-----------|
| Overtuning: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 1 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 6 | Embankment: | 0 |
| Head On: | 0 | Curb: | 0 |
| Rear End: | 9 | Delineator Post: | 0 |
| Sideswipe (Same): | 1 | 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: | 1 | 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: | 20 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | | Left Frontage Rd (L): 0 |
| C: 0 G: 0 K: 0 | | Rt Frontage Rd (R): 0 |
| D: 0 H: 0 T: 0 | | HOV Lanes (V): 0 |
| E: 0 I: 0 | | Unknown: 0 |
| | | Total: 20 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 19 |
| At Driveway Access: | 0 |
| Intersection Related: | 1 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 20 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 15 |
| Wet: | 1 |
| Muddy: | 0 |
| Snowy: | 3 |
| 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: | 1 |
| Icy w/Icy Road Treatment: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 20 |

ADT: 43,000 Length: 0.03



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

CDOT Project # 17659 04/22/2019
Exhibit 1

Job #: 20190422204522

Location: 30A Begin: 0.50 End: 0.54 From:01/01/2008 To:12/31/2010

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 10 | 12 | 1 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 2 | 2 | 0 |
| Pickup Truck/Utility Van w/Trl: | 1 | 0 | 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: | 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: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 20 | 20 | 2 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 14 | 3 | 0 |
| Slowing: | 4 | 3 | 0 |
| Stopped in Traffic: | 0 | 8 | 2 |
| Making Right Turn: | 1 | 2 | 0 |
| Making Left Turn: | 1 | 4 | 0 |
| Making U-Turn: | 0 | 0 | 0 |
| Passing: | 0 | 0 | 0 |
| Backing: | 0 | 0 | 0 |
| Enter/Leave Parked Position: | 0 | 0 | 0 |
| Starting in Traffic: | 0 | 0 | 0 |
| Parked: | 0 | 0 | 0 |
| Changing Lanes: | 0 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 20 | 20 | 2 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 12 | 20 | 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: | 5 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 2 | 0 | 1 |
| Total: | 20 | 20 | 2 |

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

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 19 | 20 | 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: | 20 | 20 | 2 |

ADT: 43,000 Length: 0.03



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

CDOT Project # 17659 04/22/2019
Exhibit 2
 Job #: 20190422204254

Location: 30A **Begin: 0.50** **End: 0.54** **From:01/01/2014** **To:12/31/2016**

Severity

| | | |
|---------------|-----------|------------|
| PDO: | 14 | |
| INJ: | 6 | 9 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 20 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 0 |
| Two Vehicles: | 15 |
| Three or More: | 5 |
| 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: | 16 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 3 |
| Dark - Unlighted: | 0 |
| Unknown: | 0 |
| Total: | 20 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 18 |
| Rain: | 2 |
| Snow/Sleet/Hail: | 0 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 20 |

Crash Rates

| | | |
|---------------|----------------|-------------|
| PDO: | 7.50 * | * MVMT |
| INJ: | 3.21 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 10.72 * | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 1 | Culvert/Headwall: | 0 |
| Broadside: | 1 | Embankment: | 0 |
| Head On: | 0 | Curb: | 0 |
| Rear End: | 12 | Delineator Post: | 0 |
| Sideswipe (Same): | 1 | Fence: | 0 |
| Sideswipe (Opposite): | 0 | Tree: | 0 |
| Approach Turn: | 5 | Large Boulders or Rocks: | 0 |
| Overtaking Turn: | 0 | Barricade: | 0 |
| Parked Motor Vehicle: | 0 | Wall/Building: | 0 |
| Railway Vehicle: | 0 | Crash Cushion: | 0 |
| Bicycle: | 0 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 0 |
| Domestic Animal: | 0 | Total Fixed Objects: | 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: | 20 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | Left Frontage Rd (L): | 0 |
| C: 0 G: 0 K: 0 | Rt Frontage Rd (R): | 0 |
| D: 0 H: 0 T: 0 | HOV Lanes (V): | 0 |
| E: 0 I: 0 | Unknown: | 0 |
| | Total: | 20 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 12 |
| At Driveway Access: | 0 |
| Intersection Related: | 8 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 20 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 17 |
| 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: | 20 |

ADT: 43,667 **Length: 0.03**



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

CDOT Project # 17659 04/22/2019

Exhibit 2

Job #: 20190422204254

Location: 30A **Begin: 0.50** **End: 0.54** **From:01/01/2014** **To:12/31/2016**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 13 | 8 | 3 |
| 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: | 5 | 9 | 2 |
| 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 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 20 | 20 | 5 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 13 | 5 | 0 |
| Slowing: | 0 | 2 | 0 |
| Stopped in Traffic: | 0 | 10 | 5 |
| Making Right Turn: | 0 | 0 | 0 |
| Making Left Turn: | 5 | 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 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 1 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 20 | 20 | 5 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 11 | 19 | 4 |
| 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: | 3 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 4 | 1 | 1 |
| Total: | 20 | 20 | 5 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 0 | 0 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 7 | 4 | 2 |
| Southeast: | 0 | 0 | 0 |
| South: | 1 | 2 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 12 | 14 | 3 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 20 | 20 | 5 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 20 | 20 | 5 |
| 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: | 20 | 20 | 5 |

ADT: 43,667 Length: 0.03

Project Information

Project Name: SH 95A / Florida Street Signal Upgrade

Project Description: Upgrade signal

CDOT Region: 6 Project Def: 17659 County: Denver

Location: SH 95A Mile Points: 2.51 Length: N/A

Schedule: Work Start Date: 6/1/2011 Completion Date: 12/28/2013

Problem Description: The three-year crash history (2002 – 2004) showed that there was a total of 12 injury crashes and 22 PDO crashes at this intersection. Of the 34 crashes, 13 were approach turn type crashes.

Improvement Description: Between June 1, 2011 and December 28, 2013, the signal was replaced. This replaced span wires with mast arms on each approach. The cost of construction was \$274,119.

The FHEP application anticipated that an 24% reduction in crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 2.80.

Summary and Findings

The analysis of safety before and after the improvements at this intersection shows an overall increase in crashes with a slight decrease in injuries. There were 27 total crashes during the three-year period before the improvements were made (2008 – 2010). In the three years after construction (2014 – 2016), the number of crashes was 46. The ADT increased from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a decrease in the number of broadside and pedestrian crashes after the completion of the project. The number of approach turn and rear-end crashes increased in the after period.

There was a slight increase in injury crashes, while the number of injuries decreased from 18 injuries in the three years before construction to 15 injury in the three years after construction. The number of PDO went from 17 in the before period to 33 in the after period. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 10 years for this project is **2.33** to one. The result is an improvement that was justified from the safety improvement as well as cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 2.49 to 2.53 shows an increase in the number of crashes from 27 during the three-year period (2008 to 2010) before the improvements to 46 during the three-year after period (2014 to 2016) (**Table 1**). The number of serious crashes increased, although there was a decrease in injuries in the after period:

- Before (2008 – 2010) – No fatal crashes and 10 injury crashes with 18 injuries
- After (2014 – 2016) – No fatal crashes and 13 injury crashes with 15 injuries

The crash rate at this intersection increased in the after period:

- Before (2008 – 2010) – 0.58 crashes per million entering vehicles (cpmev)
- After (2014 – 2016) – 0.85 cpmev

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) |
| AADT (SH 95A/Florida St) | 34,550 vpd / approx. 8,000 vpd | 40,450 vpd / approx. 9,000vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 27 | 46 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 10 (16) | 13 (15) |
| Property Damage Only | 17 | 33 |
| Crash Types: # (%) [significance] | | |
| Broadside | 7 (25.9%) [99.5%] | 3 (6.5%) |
| Approach Turn | 7 (25.9%) | 13 (28.3%) [99.1%] |
| Rear-End | 7 (25.9%) | 25 (54.3%) |
| Pedestrian | 3 (11.1%) | 0 |
| Sideswipe Same Direction | 2 (7.4%) | 4 (8.7%) |

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 (**Figures 1 and 2**) and for fatal and injury crashes (**Figures 3 and 4**) reflect no improvement in the crash record for this project. For the frequency of crashes, the intersection is LOSS II in the before period and LOSS III in the after periods. For the severity of crashes, the intersection is LOSS III for both the before and after periods. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes – Before
SH 95A, MP 2.51
Before: 2008 to 2010 After: 2014 to 2016

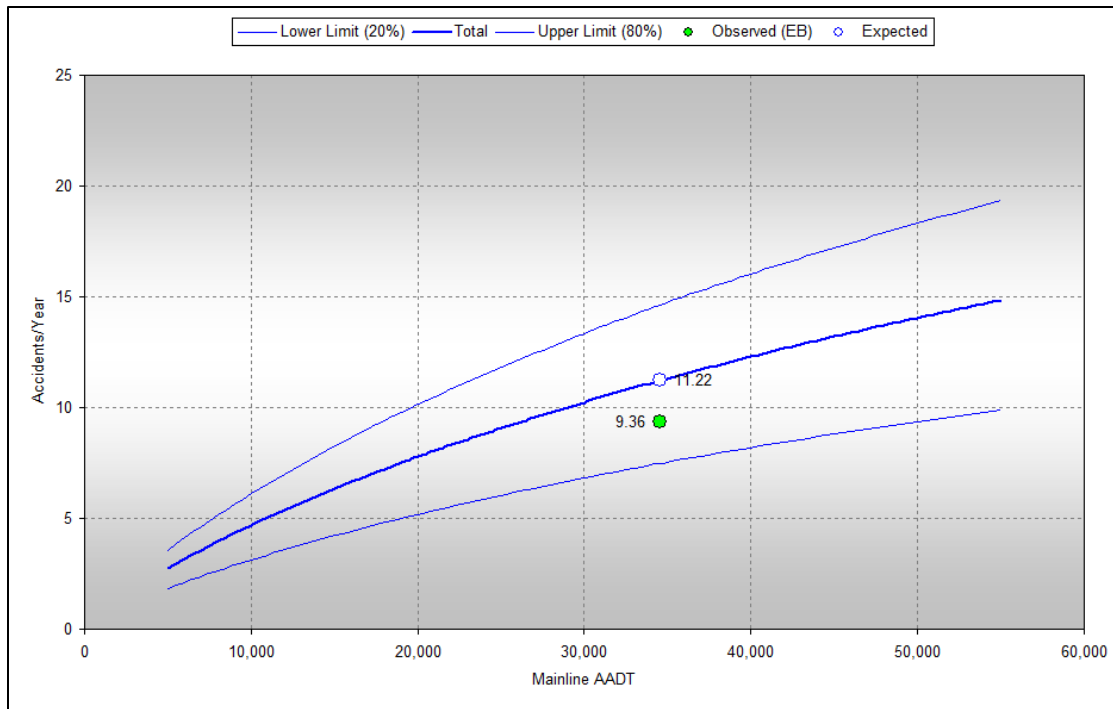


Figure 2 – SPF for Total Crashes – After/No Action After

SH 95A, MP 2.511

Before: 2008 to 2010 After: 2014 to 2016

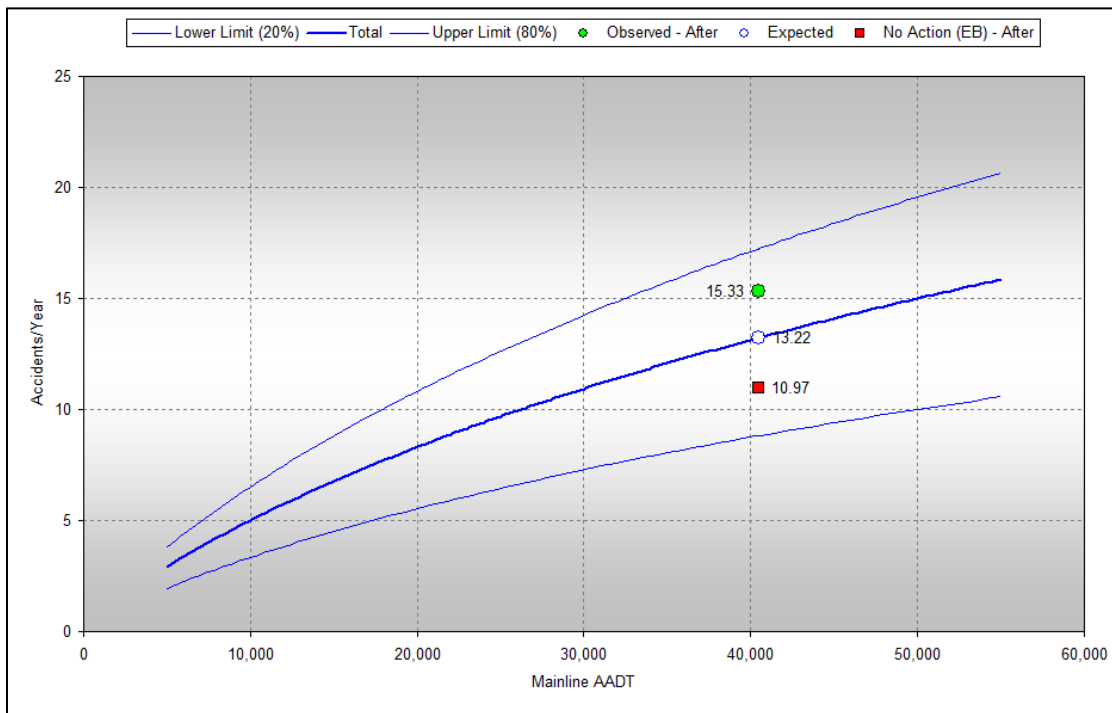


Figure 3 – SPF for Injury and Fatal Crashes – Before

SH 95A, MP 2.511

Before: 2008 to 2010 After: 2014 to 2016

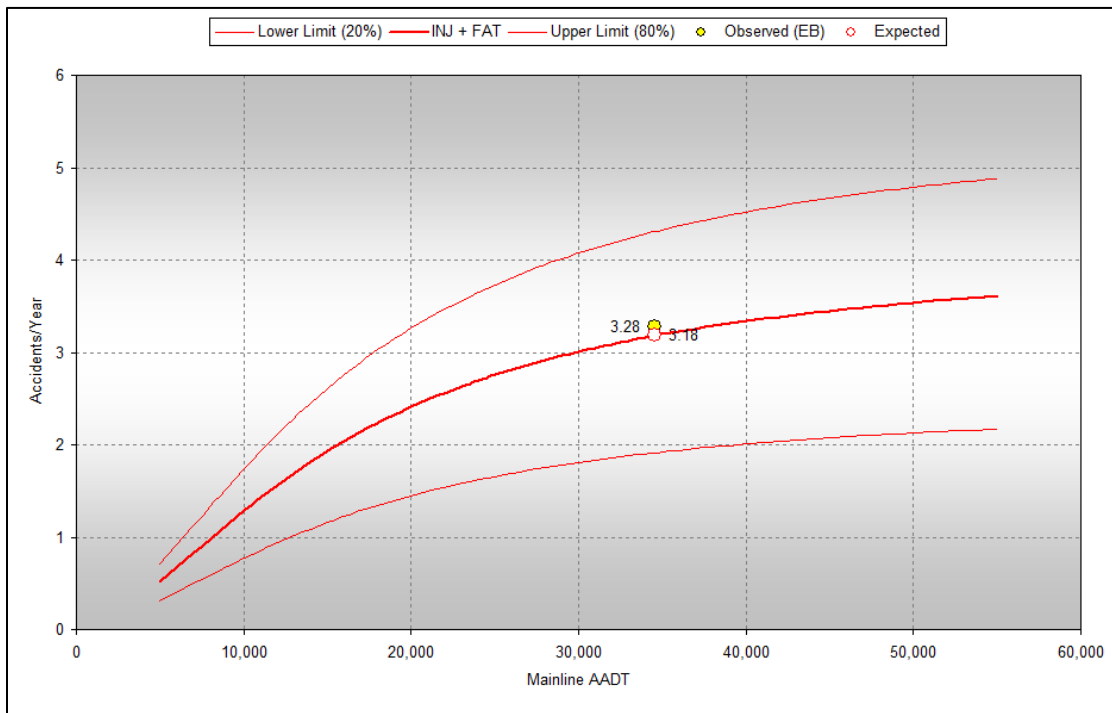


Figure 4 – SPF for Injury and Fatal Crashes – After/No Action After

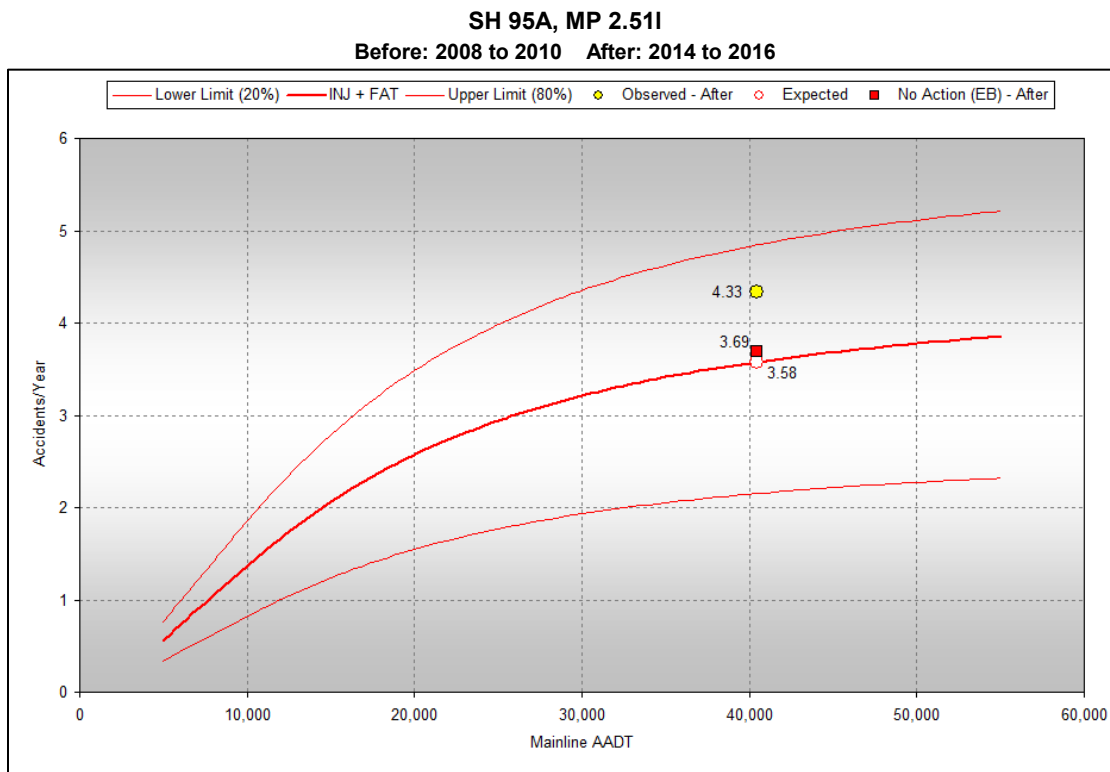


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action After |
|------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| EB Correction: | Yes | No | Yes |
| SPF Graph | Signalized 4-Lane 4-Leg Intersection | Signalized 4-Lane 4-Leg Intersection | Signalized 4-Lane 4-Leg Intersection |
| Total Crashes: | | | |
| LOSS | LOSS II | LOSS III | LOSS II |
| CPY | 9.36 | 15.33 | 10.97 |
| Mean CPY | 11.22 | 13.22 | 13.22 |
| Proportion of Mean | 0.83 | 1.16 | 0.83 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS III | LOSS III | LOSS III |
| CPY | 3.28 | 4.33 | 3.69 |
| Mean CPY | 3.18 | 3.58 | 3.58 |
| Proportion of Mean | 1.03 | 1.21 | 1.03 |

A more detailed review of the before and after crash record shows the crash types that were most affected by the signal upgrade. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: rear-end, broadside, approach turn, and pedestrian. After the signal upgrade, there was a decrease in broadside and pedestrian crashes. There was an increase in approach turn and rear-end type crashes. As a result there was an overall increase in property damage only crashes. Over the design life of 10 years for the improvements, the increased cost of crashes would be \$450,216 (43.29 PDO = \$450,216). The No-Build After crashes were estimated using the change in SH

95A traffic volumes between the before and after period, as found in **Table 1** (increase is 17% = |1-(40,450/34,550)|).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|--|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 27 | 46 | 32 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 10 (16) | 13 (15) | 12 (19) |
| PDO | 17 | 33 | 20 |
| % Reduction in Total (Injuries/PDO) | | 29% / -65% | |
| Broadside – Total | 7 | 3 | 8 |
| Injury (injuries) | 3 (8) | 2 (2) | 3 (9) |
| PDO | 4 | 1 | 5 |
| % Reduction in Total (Injuries/PDO) | | 77% / 80% | |
| Approach Turn – Total | 7 | 13 | 8 |
| Injury (injuries) | 3 (3) | 6 (8) | 3 (3) |
| PDO | 4 | 7 | 5 |
| % Reduction in Total (Injuries/PDO) | | -167% / -40% | |
| Rear-End – Total | 7 | 25 | 8 |
| Injury (injuries) | 1 (1) | 3 (3) | 1 (1) |
| PDO | 6 | 22 | 7 |
| % Reduction in Total (Injuries/PDO) | | -200% / -214% | |
| Pedestrian – Total | 3 | 0 | 4 |
| Injury (injuries) | 3 (4) | 0 (0) | 4 (5) |
| PDO | 0 | 0 | 0 |
| % Reduction in Total (Injuries/PDO) | | 100% / 0% | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 2.33 was ultimately realized.** This outcome displays that this safety improvement project was justified.

Figure 6 – Cumulative Approach Turn Crashes Over 15 Years

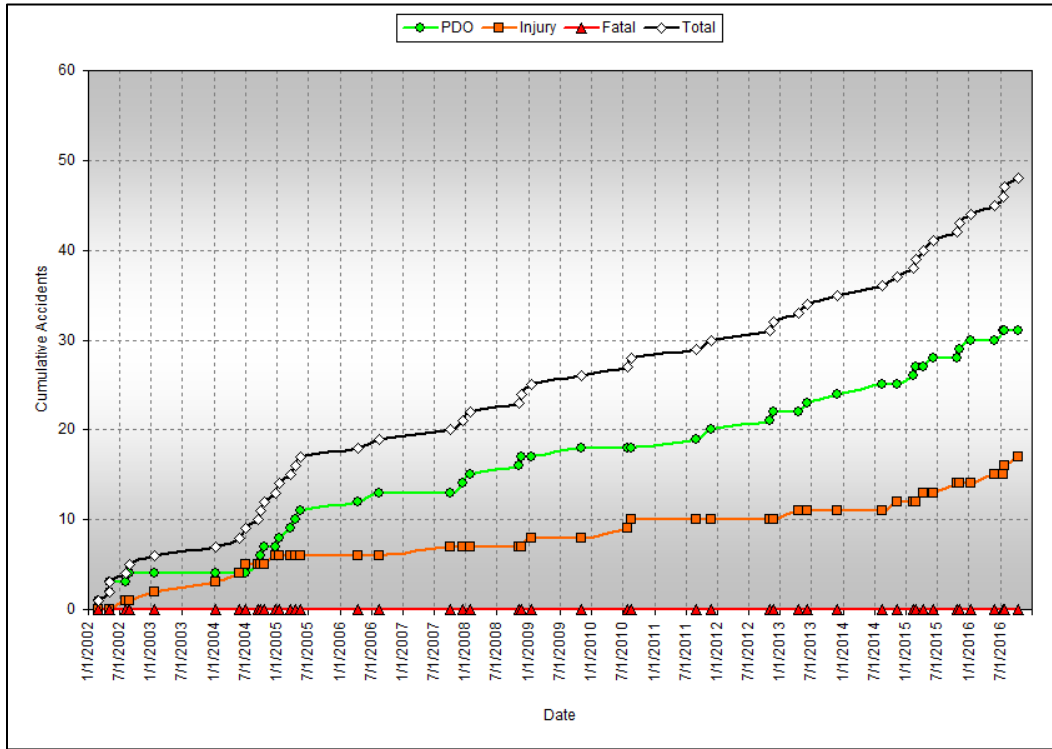
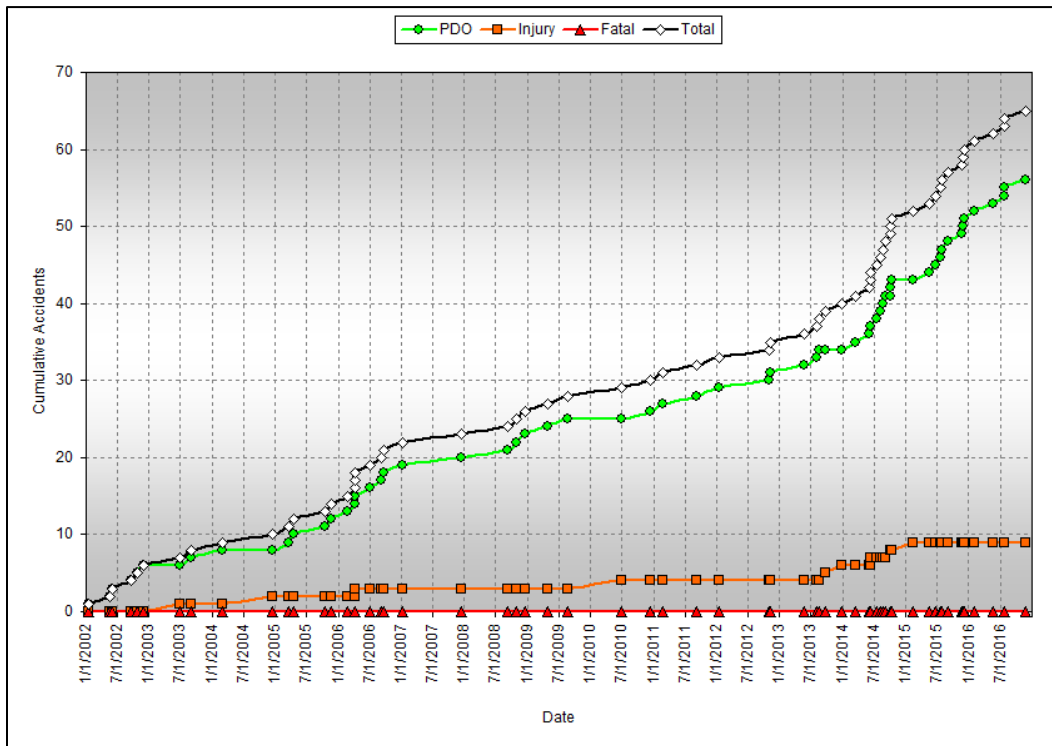


Figure 7 – Cumulative Rear-End Crashes Over 15 Years





Location: 95A **Begin: 2.49** **End: 2.53** **From:01/01/2008** **To:12/31/2010**

| Severity | |
|---------------|---------------------|
| PDO: | 17 |
| INJ: | 10 16 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 27 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 1 |
| Two Vehicles: | 21 |
| Three or More: | 5 |
| Unknown: | 0 |
| Total: | 27 |

| Location | |
|------------------|-----------|
| On Road: | 26 |
| Off Road Left: | 0 |
| Off Road Right: | 1 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 27 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 15 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 10 |
| Dark - Unlighted: | 1 |
| Unknown: | 0 |
| Total: | 27 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 26 |
| Rain: | 1 |
| Snow/Sleet/Hail: | 0 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 27 |

| Crash Rates | |
|---------------|------------------------|
| PDO: | 11.22* * MVMT |
| INJ: | 6.60* ** 100 MVMT |
| FAT: | 0.00** |
| Total: | 17.83* |

| Crash Type | | | |
|-----------------------|---|-----------------------------|-----------|
| Overtuning: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 3 | Culvert/Headwall: | 0 |
| Broadside: | 7 | Embankment: | 0 |
| Head On: | 0 | Curb: | 1 |
| 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: | 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 | | Frontage/Ramp Intersections | | | |
|-------------------------------|----|-----------------------------|---|----|---|
| Mainline: | 27 | M: | 0 | N: | 0 |
| Crossroad (A): | 0 | O: | 0 | P: | 0 |
| Ramps | | Total: 27 | | | |
| B: | 0 | F: | 0 | J: | 0 |
| C: | 0 | G: | 0 | K: | 0 |
| D: | 0 | H: | 0 | T: | 0 |
| E: | 0 | I: | 0 | | |
| | | Left Frontage Rd (L): | 0 | | |
| | | Rt Frontage Rd (R): | 0 | | |
| | | HOV Lanes (V): | 0 | | |
| | | Unknown: | 0 | | |

| 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: | 26 |
| 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: | 27 |

ADT: 34,551 **Length: 0.04**



Location: 95A **Begin: 2.49** **End: 2.53** **From:01/01/2008** **To:12/31/2010**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 14 | 18 | 3 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 7 | 1 | 1 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 4 | 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: | 1 | 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 | 3 | 1 |
| Unknown: | 0 | 0 | 0 |
| Total: | 27 | 26 | 5 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 13 | 17 | 3 |
| Slowing: | 1 | 0 | 0 |
| Stopped in Traffic: | 0 | 5 | 2 |
| Making Right Turn: | 4 | 2 | 0 |
| Making Left Turn: | 8 | 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: | 1 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 27 | 26 | 5 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 14 | 26 | 5 |
| 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: | 3 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 8 | 0 | 0 |
| Total: | 27 | 26 | 5 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 5 | 7 | 1 |
| Northeast: | 0 | 0 | 0 |
| East: | 8 | 6 | 1 |
| Southeast: | 0 | 0 | 0 |
| South: | 10 | 7 | 2 |
| Southwest: | 0 | 0 | 0 |
| West: | 4 | 6 | 1 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 27 | 26 | 5 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 25 | 26 | 5 |
| 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: | 27 | 26 | 5 |

ADT: 34,551 **Length: 0.04**



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

CDOT Project # 17659 04/09/2019
Exhibit 2

Job #: 20190409201054

Location: 95A Begin: 2.49 End: 2.53 From:01/01/2014 To:12/31/2016

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 33 | |
| INJ: | 13 | 15 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 46 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 0 |
| Two Vehicles: | 42 |
| Three or More: | 4 |
| Unknown: | 0 |
| Total: | 46 |

Location

| | |
|------------------|-----------|
| On Road: | 46 |
| Off Road Left: | 0 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 46 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 29 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 16 |
| Dark - Unlighted: | 0 |
| Unknown: | 0 |
| Total: | 46 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 39 |
| Rain: | 4 |
| Snow/Sleet/Hail: | 2 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 1 |
| Total: | 46 |

Crash Rates

| | | |
|---------------|----------------|-------------|
| PDO: | 18.61 * | * MVMT |
| INJ: | 7.33 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 25.93 * | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 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: | 25 | Delineator Post: | 0 |
| Sideswipe (Same): | 4 | Fence: | 0 |
| Sideswipe (Opposite): | 0 | Tree: | 0 |
| Approach Turn: | 13 | 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: | 46 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|----|------------------------------------|
| Mainline: | 46 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | | Left Frontage Rd (L): 0 |
| C: 0 G: 0 K: 0 | | Rt Frontage Rd (R): 0 |
| D: 0 H: 0 T: 0 | | HOV Lanes (V): 0 |
| E: 0 I: 0 | | Unknown: 0 |
| | | Total: 46 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 27 |
| At Driveway Access: | 0 |
| Intersection Related: | 19 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 46 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 41 |
| Wet: | 2 |
| Muddy: | 0 |
| Snowy: | 1 |
| Icy: | 0 |
| 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: | 0 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 46 |

ADT: 40,458 Length: 0.04



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

CDOT Project # 17659 04/09/2019
Exhibit 2

Job #: 20190409201054

Location: 95A Begin: 2.49 End: 2.53 From:01/01/2014 To:12/31/2016

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 21 | 25 | 3 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 8 | 6 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 14 | 13 | 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 | 1 | 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: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 46 | 46 | 4 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 25 | 26 | 1 |
| Slowing: | 2 | 0 | 0 |
| Stopped in Traffic: | 1 | 18 | 2 |
| Making Right Turn: | 1 | 0 | 1 |
| Making Left Turn: | 14 | 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: | 3 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 46 | 46 | 4 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 22 | 42 | 4 |
| Asleep at the Wheel: | 1 | 0 | 0 |
| Illness: | 1 | 0 | 0 |
| Distracted by Passenger: | 1 | 0 | 0 |
| Driver Inexperience: | 7 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 5 | 0 | 0 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 8 | 4 | 0 |
| Total: | 46 | 46 | 4 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 13 | 21 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 5 | 6 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 22 | 12 | 3 |
| Southwest: | 0 | 0 | 0 |
| West: | 6 | 7 | 1 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 46 | 46 | 4 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 43 | 46 | 4 |
| 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: | 46 | 46 | 4 |

ADT: 40,458 Length: 0.04

Project Information

Project Name: SH 225A Westbound Off-Ramp / Tamarac Parkway Signal Upgrade

Project Description: Upgrade signal

CDOT Region: 6 Project Def: 17659 County: Denver

Location: SH 225A Mile Points: 0.79 Length: N/A

Schedule: Work Start Date: 6/1/2011 Completion Date: 12/28/2013

Problem Description: The five-year crash history (2000 – 2004) showed that there was a total of 18 injury crashes and 40 PDO crashes at this intersection. Of the 58 crashes, 23 were broadside type crashes.

Improvement Description: Between June 1, 2011 and December 28, 2013, the signal was replaced. This replaced span wires with 8-8-12 signal heads with mast arms and 12-inch signals heads on each approach. The cost of construction was \$274,119.

The FHEP application anticipated that an 24% reduction in crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 2.63.

Summary and Findings

The analysis of safety before and after the improvements at this intersection shows almost no change in the number of crashes and number of injuries. There were 63 total crashes during the three-year period before the improvements were made (2008 – 2010). In the three years after construction (2014 – 2016), the number of crashes was 64. The ADT increased from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a decrease in the number of broadside and sideswipe same direction crashes after the completion of the project. The number of rear-end crashes was largely unchanged and the number of approach turn crashes increased.

There was an overturning fatality in the before period and no fatalities in the after period. There was almost no change in injury crashes, the number of injuries increased from 18 injuries in the three years before construction to 19 injury in the three years after construction. The number of PDO went from 47 in the before period to 48 in the after period. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 10 years for this project is **19.14** to one. The result is an improvement that was justified from the safety improvement as well as cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records at the westbound ramp terminal at Tamarac Parkway (MP 0.79) shows a slight increase in the number of crashes from 63 during the three-year period (2008 to 2010) before the improvements to 64 during the three-year after period (2014 to 2016) (**Table 1**). The number of serious crashes remained unchanged, however there were no fatalities in the after period:

- Before (2008 – 2010) – 1 fatal crash with 1 killed and 15 injury crashes with 18 injuries
- After (2014 – 2016) – No fatal crashes and 16 injury crashes with 19 injuries

The crash rate at this intersection decreased in the after period:

- Before (2008 – 2010) – 1.95 crashes per million entering vehicles (cpmev)
- After (2014 – 2016) – 1.75 cpmev

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|---|---|---|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) |
| AADT (SH 225A Westbound Ramps/Tamarac Pkwy) | 22,000 vpd / 7,450 vpd | 24,950 vpd / 8,500vpd |
| Filters: | Ramp N At Intersection Intersection Related | Ramp N At Intersection Intersection Related |
| Total Crashes | 63 | 64 |
| Fatal Crashes (Fatalities) | 1 (1) | 0 (0) |
| Injury Crashes (Injuries) | 15 (18) | 16 (19) |
| Property Damage Only | 47 | 48 |
| Crash Types: # (%) [significance] | | |
| Rear-End | 19(30.2%) | 22 (34.4%) |
| Approach Turn | 17 (27.0%) | 29 (45.3%) |
| Broadside | 15 (23.8%) | 10 (15.6%) |
| Sideswipe Same Direction | 6 (9.5%) | 1 (1.6%) |

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 (**Figures 1 and 2**) and for fatal and injury crashes (**Figures 3 and 4**) reflect slight improvement in the crash record for this project. For both the frequency and severity of crashes, the intersection is LOSS IV in both the before and after periods. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes – Before
SH 225A, MP 0.79 WB Ramp Terminal
Before: 2008 to 2010 After: 2014 to 2016

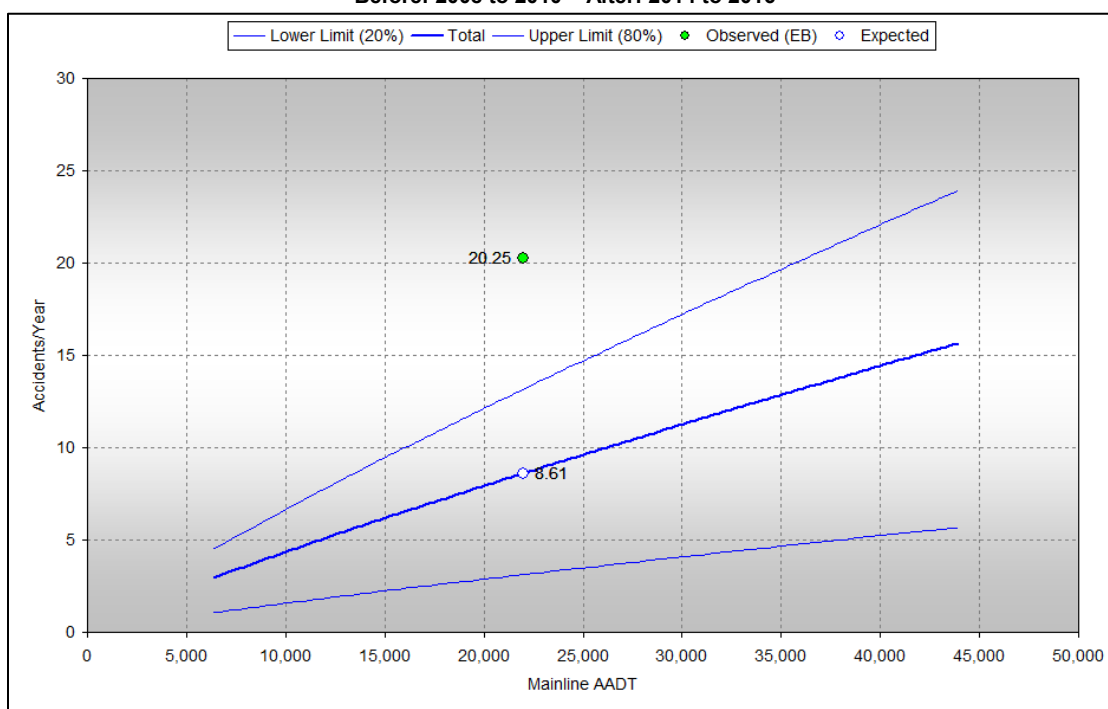


Figure 2 – SPF for Total Crashes – After/No Action After

SH 225A, MP 0.79 WB Ramp Terminal
 Before: 2008 to 2010 After: 2014 to 2016

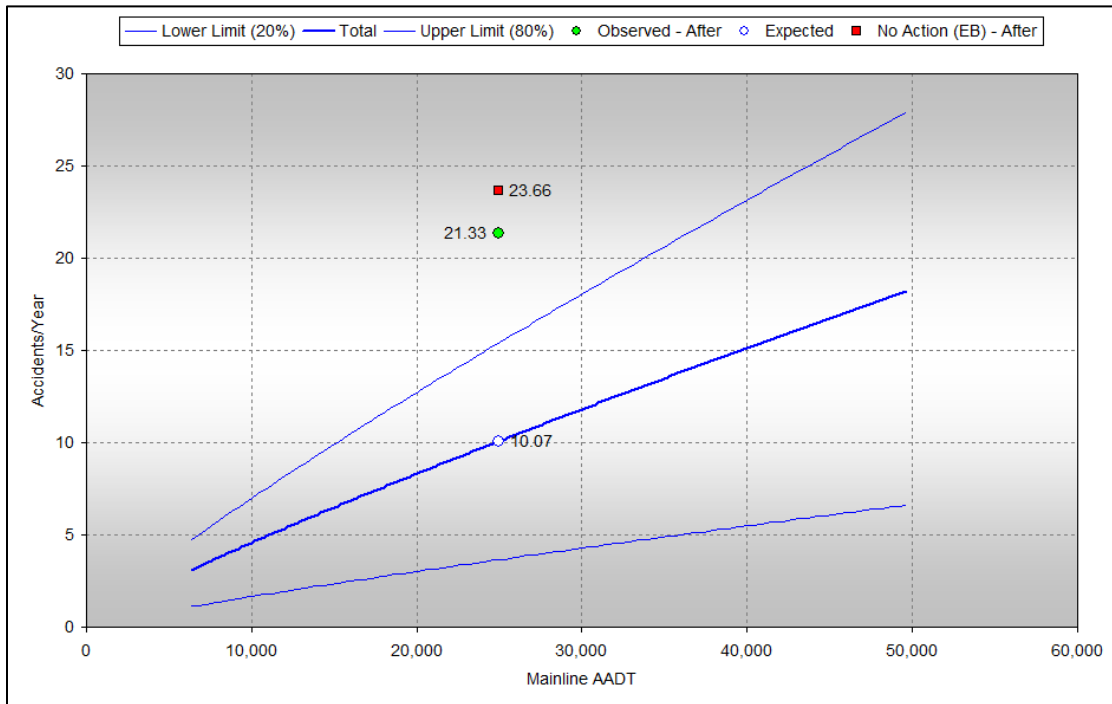


Figure 3 – SPF for Injury and Fatal Crashes – Before

SH 225A, MP 0.79 WB Ramp Terminal
 Before: 2008 to 2010 After: 2014 to 2016

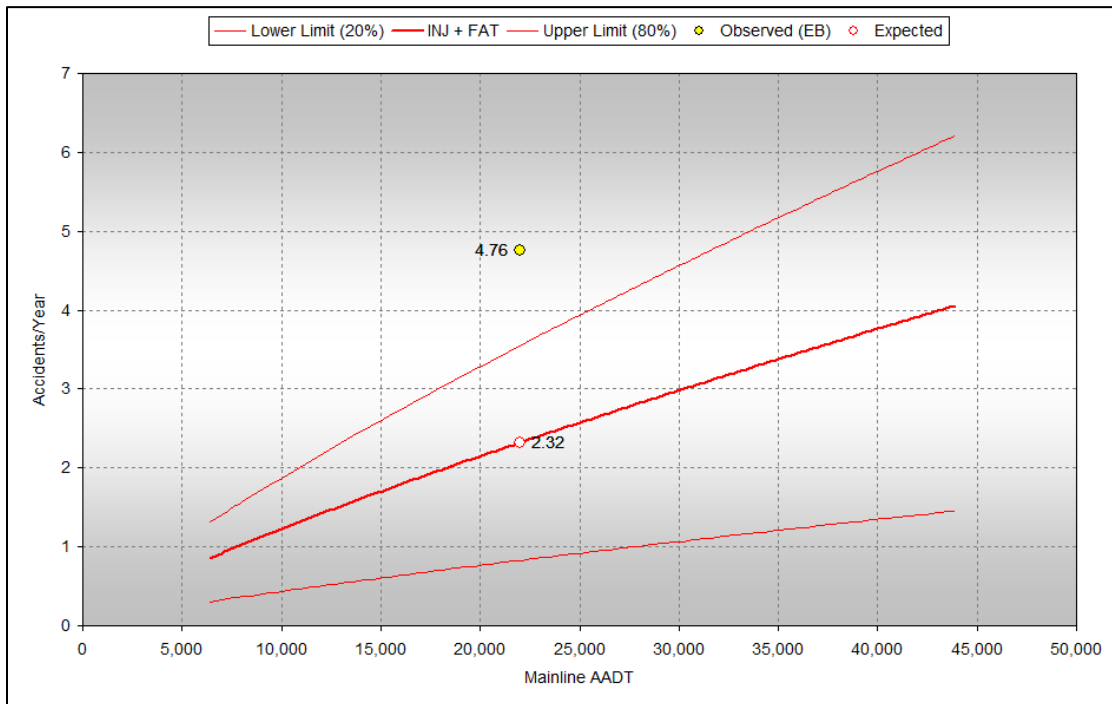


Figure 4 – SPF for Injury and Fatal Crashes – After/No Action After

SH 225A, MP 0.79 WB Ramp Terminal
 Before: 2008 to 2010 After: 2014 to 2016

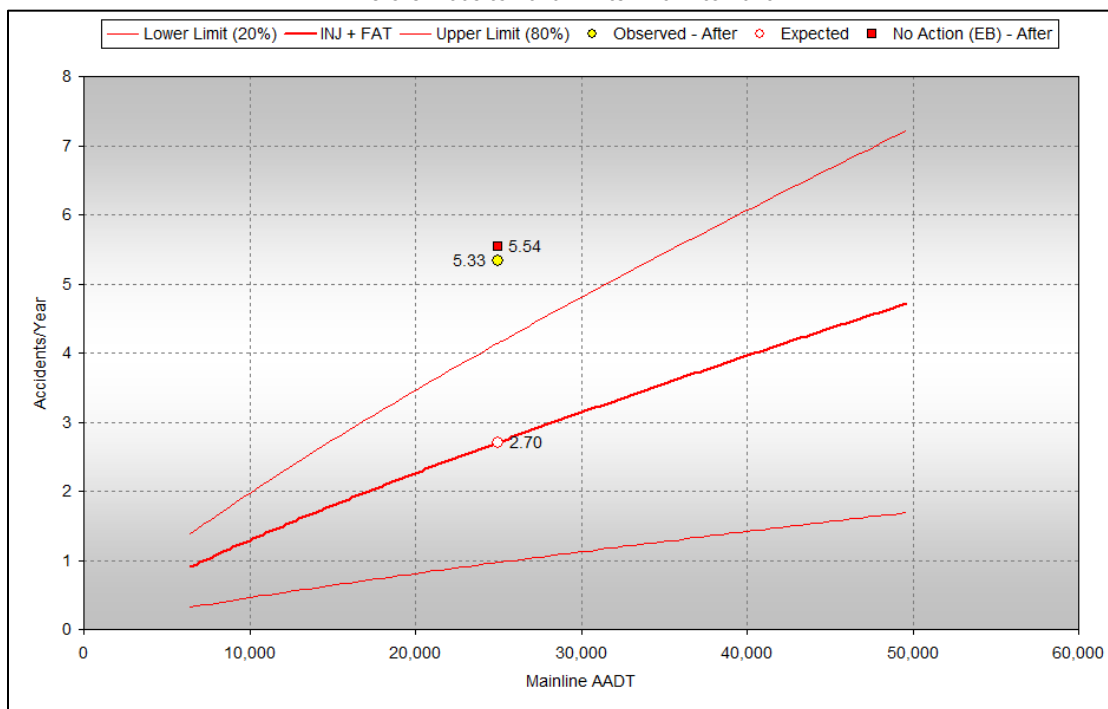


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action After |
|------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| EB Correction: | Yes | No | Yes |
| SPF Graph | Signalized 4-Lane Ramp Intersection | Signalized 4-Lane Ramp Intersection | Signalized 4-Lane Ramp Intersection |
| Total Crashes: | | | |
| LOSS | LOSS IV | LOSS IV | LOSS IV |
| CPY | 20.25 | 21.33 | 23.66 |
| Mean CPY | 8.61 | 10.07 | 10.07 |
| Proportion of Mean | 2.35 | 2.12 | 2.35 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS IV | LOSS IV | LOSS IV |
| CPY | 4.76 | 5.33 | 5.54 |
| Mean CPY | 2.32 | 2.70 | 2.70 |
| Proportion of Mean | 2.05 | 1.97 | 2.05 |


A more detailed review of the before and after crash record shows the crash types that were most affected by the signal upgrade. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: rear-end, broadside, approach turn, and sideswipe same direction. After the signal upgrade, there was a decrease in broadside and sideswipe same direction crashes. There was an increase in approach turn type crashes. The No-Build After crashes were estimated using the change in Tamarac Parkway traffic volumes between the before and after period, as found in **Table 1** (increase is 13% = $|1-(24,950/22,000)|$).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|--|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 63 | 64 | 71 |
| Fatal (fatalities) | 1 (1) | 0 (0) | 1 (1) |
| Injury (injuries) | 15 (18) | 16 (19) | 17 (20) |
| PDO | 47 | 48 | 53 |
| % Reduction in Total (Injuries/PDO) | | 5% / 9% | |
| Rear-End – Total | 19 | 22 | 21 |
| Injury (injuries) | 3 (3) | 3 (3) | 3 (3) |
| PDO | 16 | 19 | 18 |
| % Reduction in Total (Injuries/PDO) | | 0% / -6% | |
| Approach Turn – Total | 17 | 29 | 19 |
| Injury (injuries) | 5 (5) | 9 (10) | 6 (6) |
| PDO | 12 | 20 | 13 |
| % Reduction in Total (Injuries/PDO) | | -50% / -54% | |
| Broadside – Total | 15 | 10 | 17 |
| Injury (injuries) | 5 (8) | 4 (6) | 6 (9) |
| PDO | 10 | 6 | 11 |
| % Reduction in Total (Injuries/PDO) | | 33% / 45% | |
| Sideswipe Same Dir – Total | 6 | 1 | 7 |
| Injury (injuries) | 0 (0) | 0 (0) | 0 (0) |
| PDO | 6 | 1 | 7 |
| % Reduction in Total (Injuries/PDO) | | 0% / 86% | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 19.14 was ultimately realized.** This outcome displays that this safety improvement project was likely justified. However, it should be noted that the primary driver in this large B/C ratio is the fatality that occurred in the before period, when there were no fatalities in the after period. There is some randomness in whether a severe crash becomes an injury or a fatality, especially when looking at a short three-year period. Therefore, it is difficult to say if the B/C is a good measure of the project improvement. Especially in this case a fatality involved a motorcyclist, which suggests that reduction in fatalities was not connected with signal upgrades.

Figure 5 – Benefit Cost Analysis

| | | | | | | | |
|---|---|--|--|--|--------------------------------|--------------|--------------|
|  | Colorado Department of Transportation DiExSys™ Roadway Safety Systems Economic Analysis Report | | | 04/04/2019 | | | |
| | | | | Job #: 20190404124429 | | | |
| Location: 225A | | Begin: 0.79 | End: 0.79 | From: 01/01/2008 To: 12/31/2010 | | | |
| Benefit Cost Ratio Calculations | | | | | | | |
| | <u>Crashes</u> | <u>Projected Crashes and Reduction Factors</u> | | <u>Other Information</u> | | | |
| PDO: | 47 | Weighted PDO: | 17.19 | 9% :CRF for PDO | Cost of PDO: | \$ 10,400 | |
| INJ: | 15 | 18 :Injured | Weighted INJ: | 6.59 | 5% :CRF for INJ | Cost of INJ: | \$ 98,300 |
| FAT: | 1 | 1 :Killed | Weighted FAT: | 0.37 | 100% :CRF for FAT | Cost of FAT: | \$ 1,724,300 |
| | | B/C Weighted Year Factor: | 3.00 | 9% :Weighted CRF | Interest Rate: | 5% | |
| | | | | | AADT Growth Factor: | 2.0% | |
| | | | | | Service Life: | 10 | |
| | | Cost: \$ 274,119 | | | Capital Recovery Factor: | 0.129 | |
| | | From: 01/01/2008 | | | Annual Maintenance/Delay Cost: | \$ 0 | |
| | | To: 12/31/2010 | Days: 1096 | | | | |
| | | | | | | | |
| | | Benefit Cost Ratio: 19.14 | (B/C Based on Injury Numbers : PDO/Injured/Killed) | | | | |
| | Type of Improvement: Signal Upgrade | | | | | | |
| | Special Notes: | | | | | | |

It was noted that far more approach turn crashes occurred per year during the after period (29 crashes) than in the before period (17 crashes). In an effort to see if this was related to the improvement, nine years of approach turn crash data was examined. **Figure 6** shows that the frequency of approach turns increased in late 2014. This was well after the signal upgrade project was completed. It is recommended that the Region be contacted to learn what operational changes may have been made that can explain the increase in approach turn crashes; this information would likely be extremely useful.

With 29 approach turn crashes in a three-year period, the City of Denver should consider changing the signal timing to pre-2015 signal timing or changing the northbound left turn to protected only.

Signal upgrade was initially successful, **see Figure 7**, but its benefits were lost after the City changed left turn phasing in 2015.

Figure 6 – Cumulative Approach Turn Crashes Over 9 Years

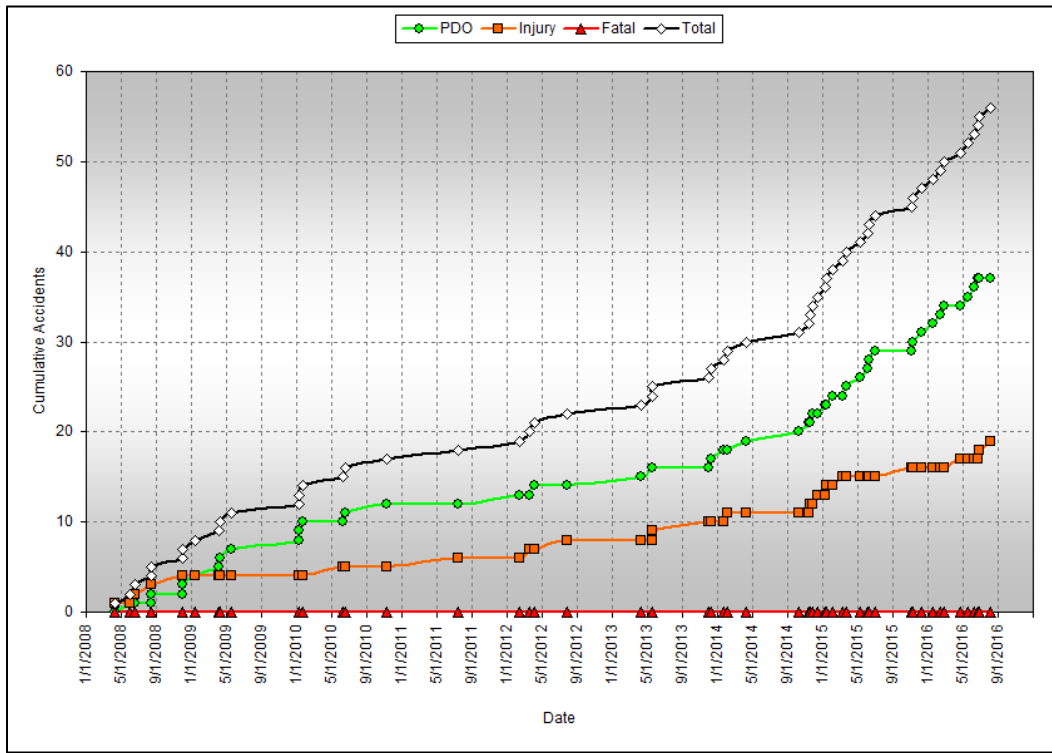
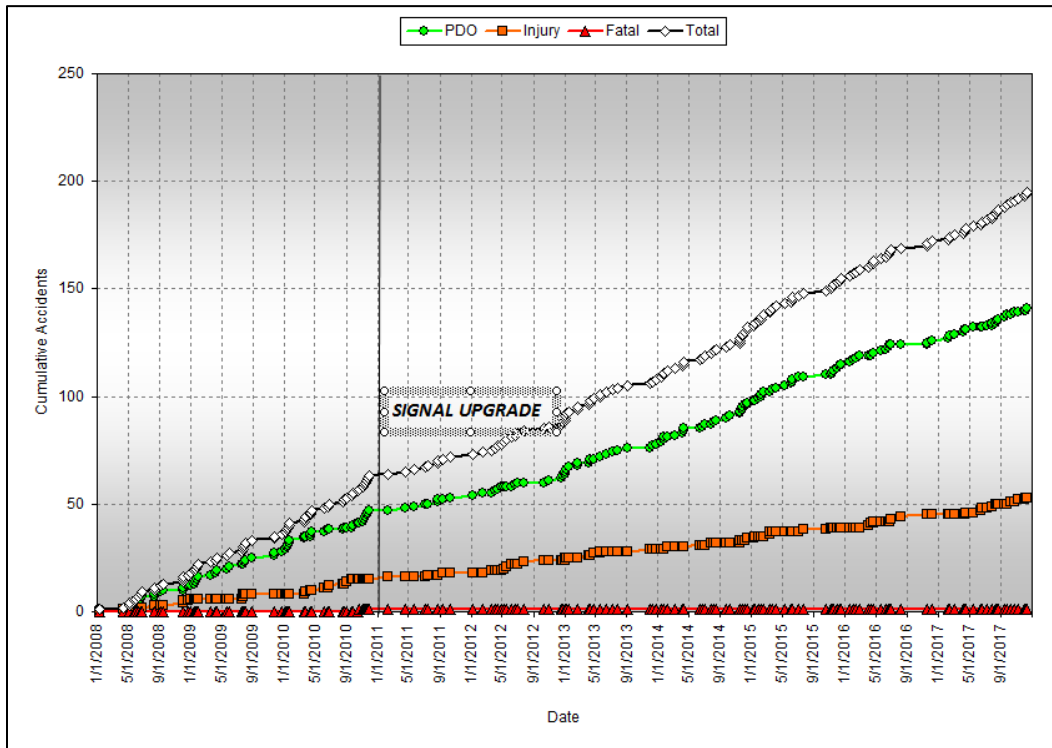


Figure 7 – Cumulative Crashes Over 9 Years





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

CDOT Project # 17659 04/03/2019

Exhibit 1

Job #: 20190403153028

Location: 225A Begin: 0.79 End: 0.79 From:01/01/2008 To:12/31/2010

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 47 | |
| INJ: | 15 | 18 :Injured |
| FAT: | 1 | 1 :Killed |
| Total: | 63 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 3 |
| Two Vehicles: | 55 |
| Three or More: | 5 |
| Unknown: | 0 |
| Total: | 63 |

Location

| | |
|------------------|-----------|
| On Road: | 61 |
| Off Road Left: | 2 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 63 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 45 |
| Dawn or Dusk: | 3 |
| Dark - Lighted: | 13 |
| Dark - Unlighted: | 1 |
| Unknown: | 1 |
| Total: | 63 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 60 |
| Rain: | 2 |
| Snow/Sleet/Hail: | 0 |
| Fog: | 1 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 63 |

Crash Rates

| | | |
|---------------|-----------------|-------------|
| PDO: | 388.67 * | * MVMT |
| INJ: | 124.04 * | ** 100 MVMT |
| FAT: | 826.96 ** | |
| Total: | 520.98 * | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 1 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 1 | Culvert/Headwall: | 0 |
| Broadside: | 15 | Embankment: | 0 |
| Head On: | 0 | Curb: | 2 |
| Rear End: | 19 | Delineator Post: | 0 |
| Sideswipe (Same): | 6 | Fence: | 0 |
| Sideswipe (Opposite): | 0 | Tree: | 0 |
| Approach Turn: | 17 | 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: | 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: | 63 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----------------------|------------------------------------|
| Mainline: | 0 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 63 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | Left Frontage Rd (L): | 0 |
| C: 0 G: 0 K: 0 | Rt Frontage Rd (R): | 0 |
| D: 0 H: 0 T: 0 | HOV Lanes (V): | 0 |
| E: 0 I: 0 | Unknown: | 0 |
| | Total: | 63 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 55 |
| At Driveway Access: | 0 |
| Intersection Related: | 8 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 63 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 60 |
| Wet: | 2 |
| 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: | 63 |

ADT: 110,333 Length: 0.00



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

CDOT Project # 17659 04/03/2019

Exhibit 1

Job #: 20190403153028

Location: 225A **Begin: 0.79** **End: 0.79** **From:01/01/2008** **To:12/31/2010**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 47 | 41 | 5 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 3 | 8 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 1 | 0 |
| SUV: | 11 | 8 | 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 | 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: | 1 | 0 | 0 |
| Other: | 0 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 63 | 60 | 5 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 28 | 32 | 3 |
| Slowing: | 5 | 0 | 0 |
| Stopped in Traffic: | 0 | 17 | 1 |
| Making Right Turn: | 7 | 2 | 0 |
| Making Left Turn: | 22 | 9 | 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: | 1 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 63 | 60 | 5 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 43 | 60 | 5 |
| 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: | 3 | 0 | 0 |
| Driver Unfamiliar with Area: | 6 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 8 | 0 | 0 |
| Total: | 63 | 60 | 5 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 22 | 11 | 2 |
| Northeast: | 0 | 0 | 0 |
| East: | 2 | 1 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 25 | 25 | 1 |
| Southwest: | 0 | 0 | 0 |
| West: | 13 | 22 | 2 |
| Northwest: | 1 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 63 | 60 | 5 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 62 | 60 | 5 |
| 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: | 63 | 60 | 5 |

ADT: 110,333 **Length: 0.00**



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

CDOT Project # 17659 04/08/2019

Exhibit 2

Job #: 20190408102057

Location: 225A **Begin: 0.79** **End: 0.79** **From:01/01/2014** **To:12/31/2016**

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 48 | |
| INJ: | 16 | 19 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 64 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 0 |
| Two Vehicles: | 60 |
| Three or More: | 4 |
| Unknown: | 0 |
| Total: | 64 |

Location

| | |
|------------------|-----------|
| On Road: | 64 |
| Off Road Left: | 0 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 64 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 45 |
| Dawn or Dusk: | 2 |
| Dark - Lighted: | 17 |
| Dark - Unlighted: | 0 |
| Unknown: | 0 |
| Total: | 64 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 59 |
| Rain: | 2 |
| Snow/Sleet/Hail: | 3 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 64 |

Crash Rates

| | | |
|---------------|----------------|-------------|
| PDO: | 330.95* | * MVMT |
| INJ: | 110.32* | ** 100 MVMT |
| FAT: | 0.00** | |
| Total: | 441.27* | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 0 | Bridge Abutment: | 0 |
| Other Non Collision: | 0 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 10 | Embankment: | 0 |
| Head On: | 1 | Curb: | 0 |
| Rear End: | 22 | Delineator Post: | 0 |
| Sideswipe (Same): | 1 | Fence: | 0 |
| Sideswipe (Opposite): | 0 | Tree: | 0 |
| Approach Turn: | 29 | Large Boulders or Rocks: | 0 |
| Overtaking Turn: | 1 | Barricade: | 0 |
| Parked Motor Vehicle: | 0 | Wall/Building: | 0 |
| Railway Vehicle: | 0 | Crash Cushion: | 0 |
| Bicycle: | 0 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 0 |
| Domestic Animal: | 0 | Total Fixed Objects: | 0 |
| Wild Animal: | 0 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 0 | Vehicle Cargo/Debris: | 0 |
| Traffic Signal Pole: | 0 | Road Maintenance Equipment: | 0 |
| Sign: | 0 | Involving Other Object: | 0 |
| Bridge Rail: | 0 | Total Other Objects: | 0 |
| Guard Rail: | 0 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 64 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----------------------|------------------------------------|
| Mainline: | 0 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 64 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | Left Frontage Rd (L): | 0 |
| C: 0 G: 0 K: 0 | Rt Frontage Rd (R): | 0 |
| D: 0 H: 0 T: 0 | HOV Lanes (V): | 0 |
| E: 0 I: 0 | Unknown: | 0 |
| | Total: | 64 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 57 |
| At Driveway Access: | 0 |
| Intersection Related: | 7 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 64 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 55 |
| Wet: | 8 |
| 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: | 64 |

ADT: 132,333 **Length: 0.00**



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

CDOT Project # 17659 04/08/2019

Exhibit 2

Job #: 20190408102057

Location: 225A **Begin: 0.79** **End: 0.79** **From:01/01/2014** **To:12/31/2016**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 46 | 36 | 4 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 3 | 3 | 0 |
| Pickup Truck/Utility Van w/Trl: | 0 | 0 | 0 |
| SUV: | 12 | 23 | 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: | 2 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 64 | 64 | 4 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 23 | 41 | 1 |
| Slowing: | 3 | 1 | 0 |
| Stopped in Traffic: | 2 | 19 | 3 |
| Making Right Turn: | 4 | 0 | 0 |
| Making Left Turn: | 31 | 3 | 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 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 64 | 64 | 4 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 37 | 61 | 4 |
| 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: | 10 | 0 | 0 |
| Driver Unfamiliar with Area: | 6 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 6 | 3 | 0 |
| Total: | 64 | 64 | 4 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 28 | 11 | 1 |
| Northeast: | 0 | 0 | 0 |
| East: | 1 | 0 | 0 |
| Southeast: | 1 | 1 | 0 |
| South: | 24 | 31 | 0 |
| Southwest: | 2 | 2 | 0 |
| West: | 7 | 18 | 3 |
| Northwest: | 1 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 64 | 64 | 4 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 62 | 64 | 4 |
| 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: | 64 | 64 | 4 |

ADT: 132,333 **Length: 0.00**

Project Information

Project Name: SH 2A I-70 Westbound Off-Ramp Signal Upgrade

Project Description: Upgrade signal

CDOT Region: 6 Project Def: 17659 County: Denver

Location: SH 2A Mile Points: 8.82 Length: N/A

Schedule: Work Start Date: 6/1/2011 Completion Date: 12/28/2013

Problem Description: The five-year crash history (2000 – 2004) showed that there was a total of 17 injury crashes and 38 PDO crashes at this intersection. Of the 55 crashes, 23 were broadside type crashes.

Improvement Description: Between June 1, 2011 and December 28, 2013, the signal was replaced. This replaced a diagonal span wire with 8-8-12 signal heads with mast arms and 12-inch signals heads on each approach. The cost of construction was \$274,119.

The FHEP application anticipated that an 24% reduction in crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 2.48.

Summary and Findings

The analysis of safety before and after the improvements at this intersection shows a decrease in the number of crashes and a decrease in the number of injuries. There were 30 total crashes during the three-year period before the improvements were made (2008 – 2010). In the three years after construction (2014 – 2016), the number of crashes decreased to 16. The ADT increased from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a decrease in the number of broadside, sideswipe same direction, and rear-end crashes after the completion of the project.

There was a decrease in injury crashes, the number of injuries decreased from 12 injuries in the three years before construction to 1 injury in the three years after construction. The number of PDO decreased from 23 in the before period to 15 in the after period. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 10 years for this project is **12.40** to one. The result is an improvement that was justified from the safety improvement as well as cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 8.80 to 8.84 shows a decrease in the number of crashes from 30 during the three-year period (2008 to 2010) before the improvements to 16 during the three-year after period (2014 to 2016) (**Table 1**). The number of serious crashes also showed a decrease in the after period:

- Before (2008 – 2010) – No fatal crashes and 7 injury crashes with 12 injuries
- After (2014 – 2016) – No fatal crashes and 1 injury crash with 1 person injured

The crash rate at this intersection decreased in the after period:

- Before (2008 – 2010) – 0.88 crashes per million entering vehicles (cpmev)
- After (2014 – 2016) – 0.43 cpmev

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) |
| AADT (SH 2A/I-70 WB Ramp) | 27,650 vpd / approx. 3,500 vpd | 30,000 vpd / approx. 3,850 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 30 | 16 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 7 (12) | 1 (1) |
| Property Damage Only | 23 | 15 |
| Crash Types: # (%) [significance] | | |
| Sideswipe Same Direction | 12 (40.0%) | 7 (43.8%) |
| Broadside | 10 (33.3%) | 3 (18.8%) |
| Rear-End | 6 (20.0%) | 5 (31.3%) |
| Overtaking Turn | 2 (6.7%) | 1 (6.3%) |

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 (**Figures 1 and 2**) and for fatal and injury crashes (**Figures 3 and 4**) reflect improvement in the crash record for this project. The plotted points are outside of the bounds of the SPF model, so the LOSS category can only be estimated for the scenarios. It is estimated that LOSS went from LOSS II/II in the before period to LOSS II in the after period for the frequency of crashes. For the severity of crashes, the intersection went from LOSS II/III in the before period to LOSS I in the after period. **Table 2** provides a summary of the crashes per year (CPY). Due to the limits of this model, a comparison with the mean (expected) CPY for the before and after periods was not able to be calculated.

Figure 1 – SPF for Total Crashes – Before
SH 2A, MP 8.82
Before: 2008 to 2010 After: 2014 to 2016

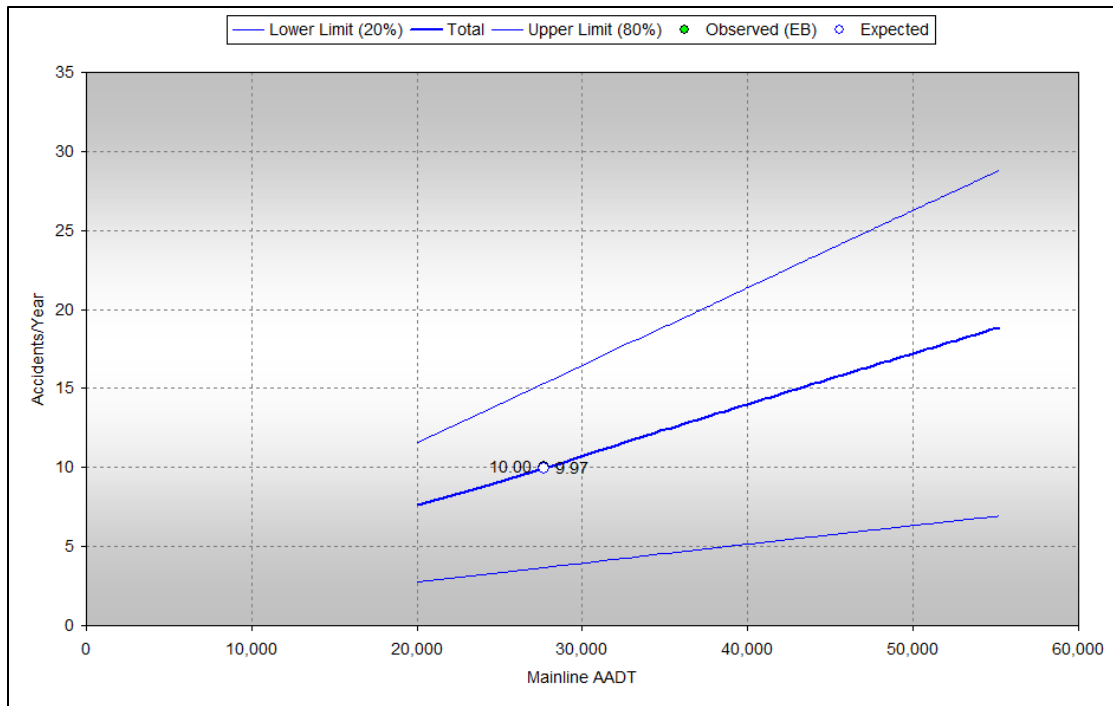


Figure 2 – SPF for Total Crashes – After/No Action After

SH 2A, MP 8.82

Before: 2008 to 2010 After: 2014 to 2016

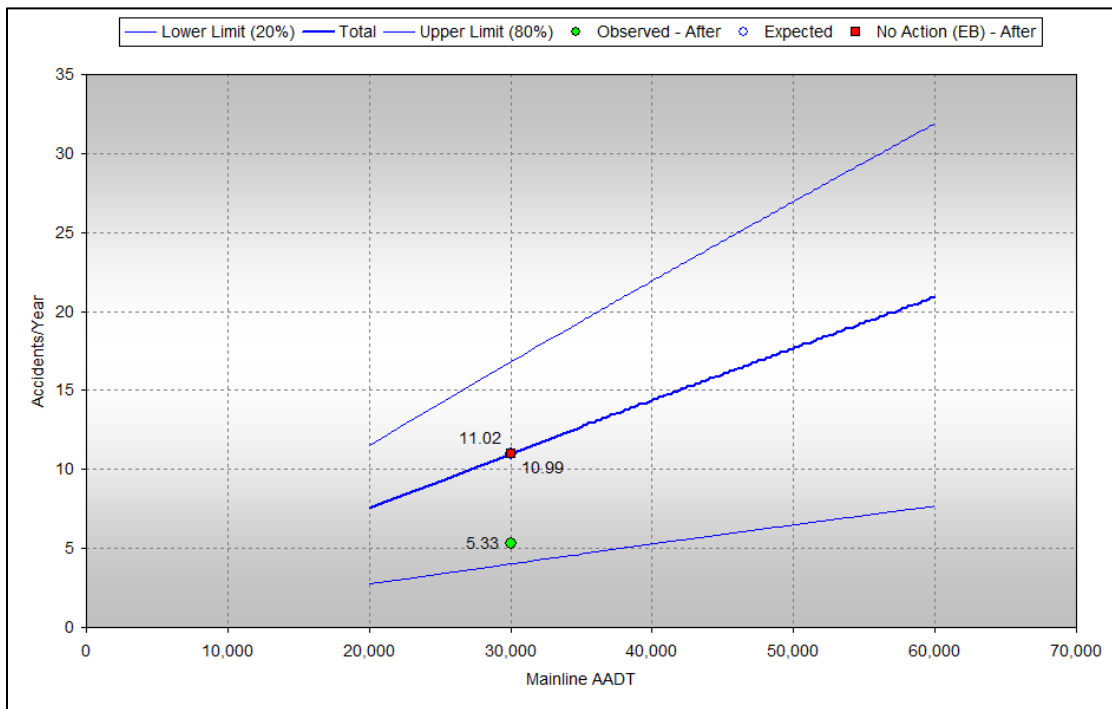


Figure 3 – SPF for Injury and Fatal Crashes – Before

SH 2A, MP 8.82

Before: 2008 to 2010 After: 2014 to 2016

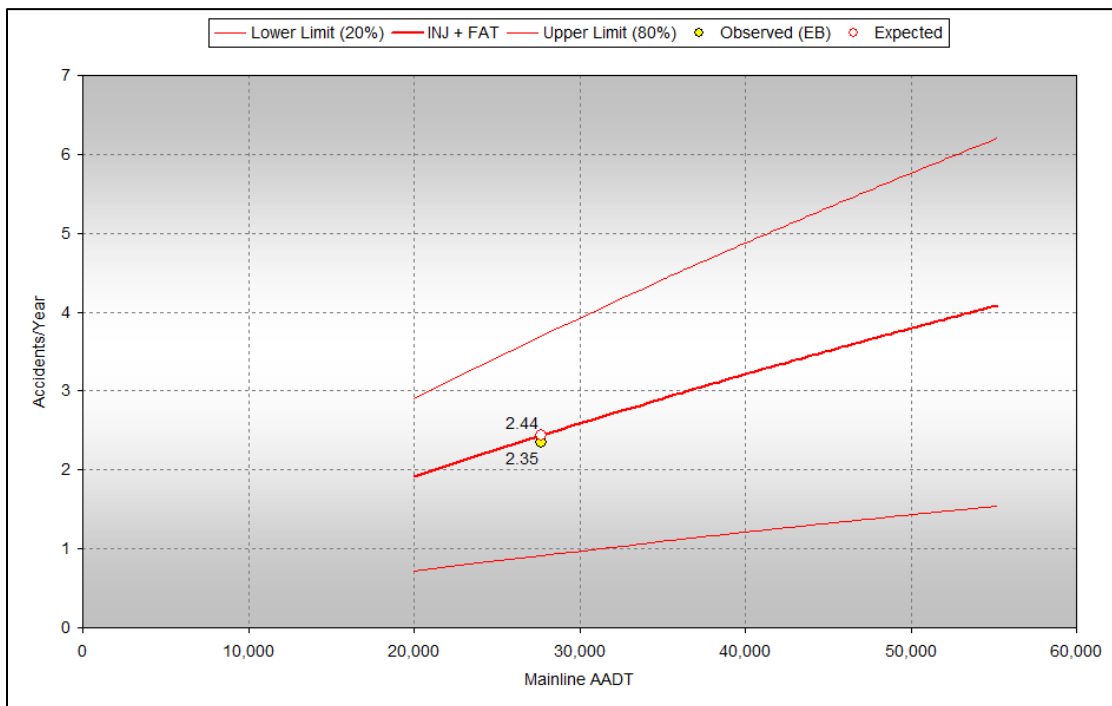


Figure 4 – SPF for Injury and Fatal Crashes – After/No Action After

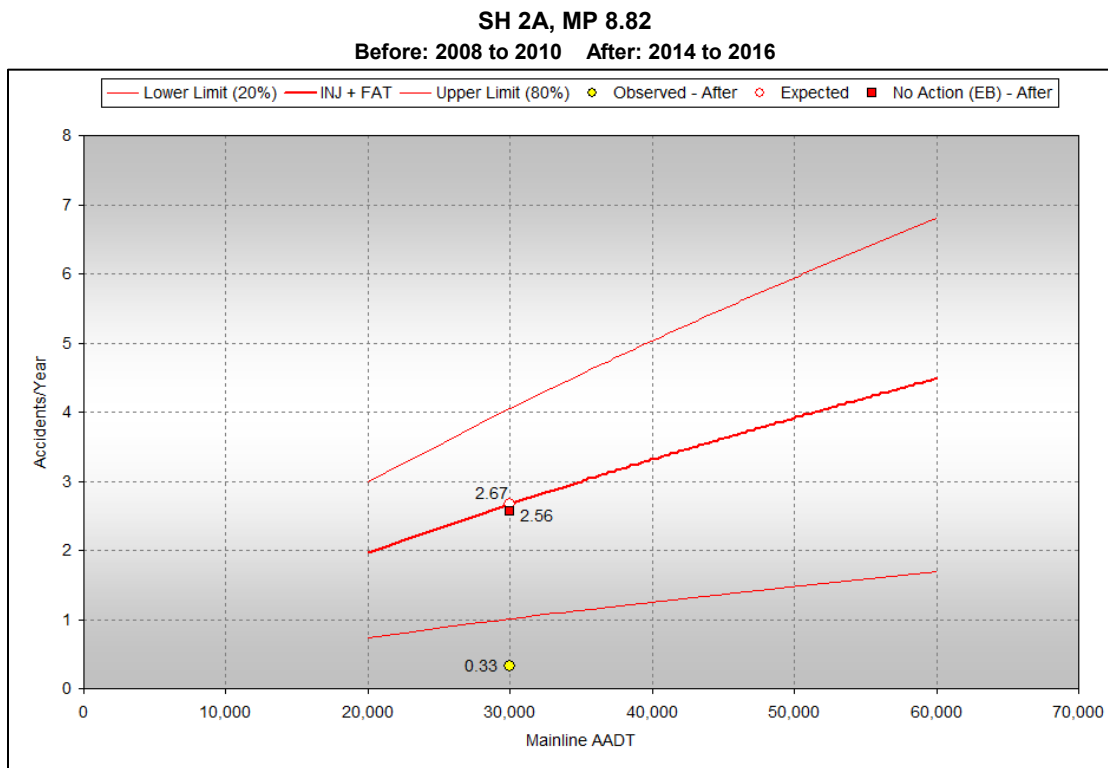


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action After |
|------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| EB Correction: | Yes | No | Yes |
| SPF Graph | Signalized 6-Lane Ramp Intersection | Signalized 6-Lane Ramp Intersection | Signalized 6-Lane Ramp Intersection |
| Total Crashes: | | | |
| LOSS | LOSS II/III | LOSS II | LOSS II/III |
| CPY | 10.00 | 5.33 | 10.99 |
| Mean CPY | 9.97 | 11.02 | 11.02 |
| Proportion of Mean | 1.00 | 0.48 | 1.00 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS II | LOSS I | LOSS II |
| CPY | 2.35 | 0.33 | 2.56 |
| Mean CPY | 2.44 | 2.67 | 2.67 |
| Proportion of Mean | 0.96 | 0.12 | 0.96 |

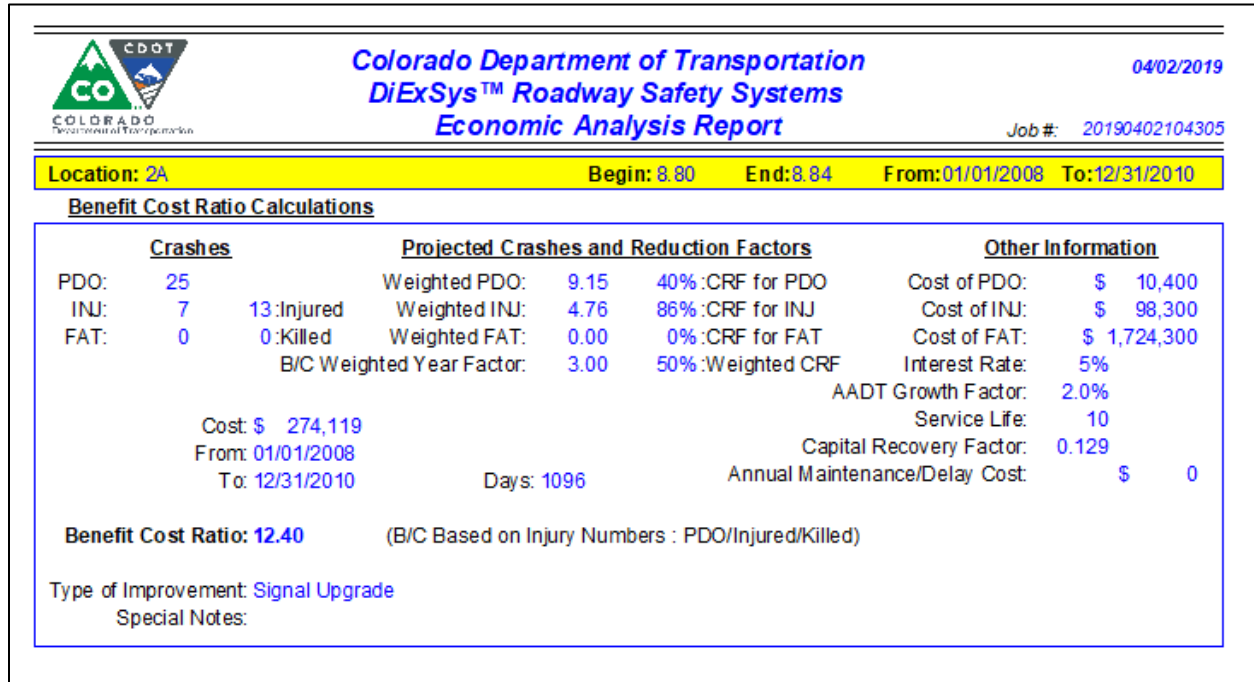
A more detailed review of the before and after crash record shows the crash types that were most affected by the signal upgrade. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: rear-end, broadside, and sideswipe same direction. After the signal upgrade, there was a decrease in all related crash types. Additionally, there was a significant decrease in number of injury crashes. The No-Build After crashes were estimated using the change in SH 2A traffic volumes between the before and after period, as found in **Table 1** (increase is 8% = $|1-(27,650/30,000)|$).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|---|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 30 | 16 | 32 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 7 (12) | 1 (1) | 7 (13) |
| PDO | 23 | 15 | 25 |
| % Reduction in Total (Injuries/PDO) | | 86% / 40% | |
| Sideswipe Same Direction – Total | 12 | 7 | 13 |
| Injury (injuries) | 1 (1) | 1 (1) | 1 (1) |
| PDO | 11 | 6 | 12 |
| % Reduction in Total (Injuries/PDO) | | 0% / 50% | |
| Broadside – Total | 10 | 3 | 11 |
| Injury (injuries) | 3 (8) | 0 (0) | 3 (9) |
| PDO | 7 | 3 | 8 |
| % Reduction in Total (Injuries/PDO) | | 100% / 63% | |
| Rear-End – Total | 6 | 5 | 6 |
| Injury (injuries) | 3 (3) | 0 (0) | 3 (3) |
| PDO | 3 | 5 | 3 |
| % Reduction in Total (Injuries/PDO) | | 100% / -66% | |

Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 12.40 was ultimately realized.** This outcome displays that this safety improvement project was justified.

Figure 5 – Benefit Cost Analysis





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

CDOT Project # 17659 03/30/2019
Exhibit 1

Job #: 20190330225711

Location: 2A Begin: 8.80 End: 8.84 From:01/01/2008 To:12/31/2010

| Severity | |
|---------------|--------------------|
| PDO: | 23 |
| INJ: | 7 12 :Injured |
| FAT: | 0 0 :Killed |
| Total: | 30 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 0 |
| Two Vehicles: | 23 |
| Three or More: | 7 |
| Unknown: | 0 |
| Total: | 30 |

| Location | |
|------------------|-----------|
| On Road: | 30 |
| Off Road Left: | 0 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 30 |

| Lighting Conditions | |
|---------------------|-----------|
| Daylight: | 22 |
| Dawn or Dusk: | 0 |
| Dark - Lighted: | 8 |
| Dark - Unlighted: | 0 |
| Unknown: | 0 |
| Total: | 30 |

| Weather Conditions | |
|--------------------|-----------|
| None: | 27 |
| Rain: | 1 |
| Snow/Sleet/Hail: | 2 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 30 |

| Crash Rates | |
|---------------|-------------------------|
| PDO: | 14.87 * * MVMT |
| INJ: | 4.53 * ** 100 MVMT |
| FAT: | 0.00 ** |
| Total: | 19.40 * |

| Crash Type | |
|-----------------------------|-----------|
| Overtuning: | 0 |
| Other Non Collision: | 0 |
| Pedestrians: | 0 |
| Broadside: | 10 |
| Head On: | 0 |
| Rear End: | 6 |
| Sideswipe (Same): | 12 |
| Sideswipe (Opposite): | 0 |
| Approach Turn: | 0 |
| Overtaking Turn: | 2 |
| Parked Motor Vehicle: | 0 |
| Railway Vehicle: | 0 |
| Bicycle: | 0 |
| Motorized Bicycle: | 0 |
| Domestic Animal: | 0 |
| Wild Animal: | 0 |
| Light/Utility Pole: | 0 |
| Traffic Signal Pole: | 0 |
| Sign: | 0 |
| Bridge Rail: | 0 |
| Guard Rail: | 0 |
| Cable Rail: | 0 |
| Concrete Barrier: | 0 |
| Bridge Abutment: | 0 |
| Column/Pier: | 0 |
| Culvert/Headwall: | 0 |
| Embankment: | 0 |
| Curb: | 0 |
| Delineator Post: | 0 |
| Fence: | 0 |
| Tree: | 0 |
| Large Boulders or Rocks: | 0 |
| Barricade: | 0 |
| Wall/Building: | 0 |
| Crash Cushion: | 0 |
| Mailbox: | 0 |
| Other Fixed Object: | 0 |
| Total Fixed Objects: | 0 |
| Rocks in Roadway: | 0 |
| Vehicle Cargo/Debris: | 0 |
| Road Maintenance Equipment: | 0 |
| Involving Other Object: | 0 |
| Total Other Objects: | 0 |
| Unknown: | 0 |
| Total: | 30 |

| Mainline/Ramps/Frontage Roads | |
|-------------------------------|-----------|
| Mainline: | 30 |
| Crossroad (A): | 0 |
| Ramps | |
| B: | 0 |
| C: | 0 |
| D: | 0 |
| E: | 0 |
| F: | 0 |
| G: | 0 |
| H: | 0 |
| I: | 0 |
| J: | 0 |
| K: | 0 |
| L: | 0 |
| M: | 0 |
| N: | 0 |
| O: | 0 |
| P: | 0 |
| Left Frontage Rd (L): | 0 |
| Rt Frontage Rd (R): | 0 |
| HOV Lanes (V): | 0 |
| Unknown: | 0 |
| Total: | 30 |

| Road Description | |
|-----------------------|-----------|
| At Intersection: | 24 |
| At Driveway Access: | 0 |
| Intersection Related: | 6 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 30 |

| Road Conditions | |
|------------------------------|-----------|
| Dry: | 25 |
| 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: | 1 |
| Slushy w/Icy Road Treatment: | 0 |
| Unknown: | 0 |
| Total: | 30 |

ADT: 27,667 Length: 0.05



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

CDOT Project # 17659 03/30/2019
 Exhibit 1

Job #: 20190330225711

Location: 2A **Begin: 8.80** **End: 8.84** **From:01/01/2008** **To:12/31/2010**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 11 | 20 | 5 |
| Passenger Car/Van w/Trl: | 0 | 0 | 1 |
| Pickup Truck/Utility Van: | 3 | 0 | 0 |
| Pickup Truck/Utility Van w/Trl: | 2 | 2 | 0 |
| SUV: | 5 | 4 | 1 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 7 | 4 | 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: | 30 | 30 | 7 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 15 | 10 | 2 |
| Slowing: | 0 | 1 | 0 |
| Stopped in Traffic: | 0 | 3 | 3 |
| Making Right Turn: | 0 | 0 | 0 |
| Making Left Turn: | 9 | 15 | 2 |
| Making U-Turn: | 2 | 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 | 1 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 1 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 30 | 30 | 7 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 16 | 30 | 7 |
| 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: | 1 | 0 | 0 |
| Driver Unfamiliar with Area: | 1 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 8 | 0 | 0 |
| Total: | 30 | 30 | 7 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 15 | 7 | 2 |
| Northeast: | 0 | 0 | 0 |
| East: | 0 | 0 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 3 | 3 | 2 |
| Southwest: | 0 | 0 | 0 |
| West: | 12 | 20 | 3 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 30 | 30 | 7 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 28 | 30 | 7 |
| 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: | 30 | 30 | 7 |

ADT: 27,667 **Length: 0.05**



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

CDOT Project # 17659 04/02/2019

Exhibit 2

Job #: 20190402104943

Location: 2A **Begin: 8.80** **End: 8.84** **From:01/01/2014** **To:12/31/2016**

Severity

| | | |
|---------------|-----------|------------|
| PDO: | 15 | |
| INJ: | 1 | 1 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 16 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 0 |
| Two Vehicles: | 15 |
| Three or More: | 1 |
| Unknown: | 0 |
| Total: | 16 |

Location

| | |
|------------------|-----------|
| On Road: | 16 |
| Off Road Left: | 0 |
| Off Road Right: | 0 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 16 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 12 |
| Dawn or Dusk: | 0 |
| Dark - Lighted: | 4 |
| Dark - Unlighted: | 0 |
| Unknown: | 0 |
| Total: | 16 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 14 |
| Rain: | 0 |
| Snow/Sleet/Hail: | 2 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 16 |

Crash Rates

| | | |
|---------------|----------------|-------------|
| PDO: | 10.37 * | * MVMT |
| INJ: | 0.69 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 11.06 * | |

Crash Type

| | | | |
|-----------------------|---|-----------------------------|-----------|
| Overtuning: | 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): | 7 | 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: | 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: | 16 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|----|------------------------------------|
| Mainline: | 16 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | | Left Frontage Rd (L): 0 |
| C: 0 G: 0 K: 0 | | Rt Frontage Rd (R): 0 |
| D: 0 H: 0 T: 0 | | HOV Lanes (V): 0 |
| E: 0 I: 0 | | Unknown: 0 |
| | | Total: 16 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 13 |
| At Driveway Access: | 0 |
| Intersection Related: | 3 |
| Non Intersection: | 0 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 16 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 14 |
| Wet: | 1 |
| 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: | 16 |

ADT: 30,000 **Length: 0.04**



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

CDOT Project # 17659 04/02/2019
 Exhibit 2

Job #: 20190402104943

Location: 2A **Begin: 8.80** **End: 8.84** **From:01/01/2014** **To:12/31/2016**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 5 | 8 | 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: | 0 | 4 | 0 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 5 | 1 | 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: | 4 | 0 | 0 |
| Other: | 0 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 16 | 16 | 1 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 6 | 5 | 1 |
| Slowing: | 0 | 0 | 0 |
| Stopped in Traffic: | 0 | 5 | 0 |
| Making Right Turn: | 1 | 0 | 0 |
| Making Left Turn: | 7 | 6 | 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 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 16 | 16 | 1 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 9 | 14 | 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: | 1 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 1 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 1 | 0 |
| Unknown: | 3 | 1 | 0 |
| Total: | 16 | 16 | 1 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 4 | 4 | 1 |
| Northeast: | 0 | 0 | 0 |
| East: | 0 | 0 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 5 | 4 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 7 | 8 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 16 | 16 | 1 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 16 | 16 | 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: | 16 | 16 | 1 |

ADT: 30,000 Length: 0.04

Project Information

Project Name: SH 26B Pecos Street Signal Upgrade

Project Description: Upgrade signal

CDOT Region: 6 Project Def: 17659 County: Denver

Location: SH 26B Mile Points: 13.70 Length: N/A

Schedule: Work Start Date: 6/1/2011 Completion Date: 12/28/2013

Problem Description: The five-year crash history (2000 – 2004) showed that there was a total of 14 injury crashes and 30 PDO crashes at this intersection. Of the 44 crashes, 11 were broadside type crashes.

Improvement Description: Between June 1, 2011 and December 28, 2013, the signal was replaced. This replaced a diagonal span wire with 8-8-12 signal heads with mast arms and 12 inch signals heads on each approach. The cost of construction was \$274,119.

The FHEP application anticipated that an 24% reduction in crashes might be realized due to the improvement. The expected benefit/cost ratio was estimated to be 2.03.

Summary and Findings

The analysis of safety before and after the improvements at this intersection shows a slight increase in the number of crashes, with a decrease in the number of injuries. There were 9 total crashes during the three-year period before the improvements were made (2008 – 2010). In the three years after construction (2014 – 2016), the number of crashes increased to 10. The ADT increased from the before period to the after period.

A comparison of all crash types before and after the improvements were made showed that there was a decrease in the number of broadside crashes after the completion of the project. However, there was an increase in rear-end and approach turn crashes after the completion of the project.

There was an increase in injury crashes, but the number of injuries decrease from 5 injuries in the three years before construction to 3 injuries in the three years after construction. The number of PDO was unchanged with 7 in both the before and after periods. The ratio of benefits of crash reduction to the cost of construction over the life-cycle of 10 years for this project is **3.25** to one. The result is an improvement that was justified from the safety improvement as well as cost effectiveness standpoints.

Results of Safety Analyses

Using Vision Zero Suite, the review of before and after crash records from MP 13.68 to 13.72 shows an increase in the number of crashes from 9 during the three-year period (2008 to 2010) before the improvements to 10 during the three-year after period (2014 to 2016) (**Table 1**). The number of serious crashes also showed a slight increase in the after period, although there was a decrease in the number of injuries:

- Before (2008 – 2010) – No fatal crashes and 2 injury crashes with 5 injuries
- After (2014 – 2016) – No fatal crashes and 3 injury crashes with 3 injuries

The crash rate at this intersection decreased in the after period:

- Before (2008 – 2010) – 0.27 crashes per million entering vehicles (cpmev)
- After (2014 – 2016) – 0.25 cpmev

Table 1 –Results of Overall Crash Analyses

| | Before | After |
|--|---|---|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) |
| AADT (SH 26B/Pecos St) | 28,000 vpd / approx. 2,800 vpd | 33,000 vpd / approx. 3,300 vpd |
| Filters: | At Intersection Intersection Related | At Intersection Intersection Related |
| Total Crashes | 9 | 10 |
| Fatal Crashes (Fatalities) | 0 (0) | 0 (0) |
| Injury Crashes (Injuries) | 2 (5) | 3 (3) |
| Property Damage Only | 7 | 7 |
| Crash Types: # (%) [significance] | | |
| Rear-End | 3 (33.3%) | 6 (60.0%) |
| Broadside | 3 (33.3%) | 0 |
| Sideswipe Same Direction | 2 (22.2%) | 0 |
| Approach Turn | 1 (11.1%) | 3 (30.0%) |
| Fixed Object | 0 | 1 (10.0%) |

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 of safety uses quantitative and qualitative measures that characterize safety of a roadway segment in reference to its expected performance and severity. If the level of service 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 (**Figures 1 and 2**) and for fatal and injury crashes (**Figures 3 and 4**) reflect slight improvement in the crash record for this project. LOSS went from LOSS II in the before period to LOSS I in the after period for both the frequency and severity of crashes. **Table 2** provides a summary of the crashes per year (CPY) and a comparison with the mean (expected) CPY for the before and after periods.

Figure 1 – SPF for Total Crashes – Before
SH 26B, MP 13.70
Before: 2008 to 2010 After: 2014 to 2016

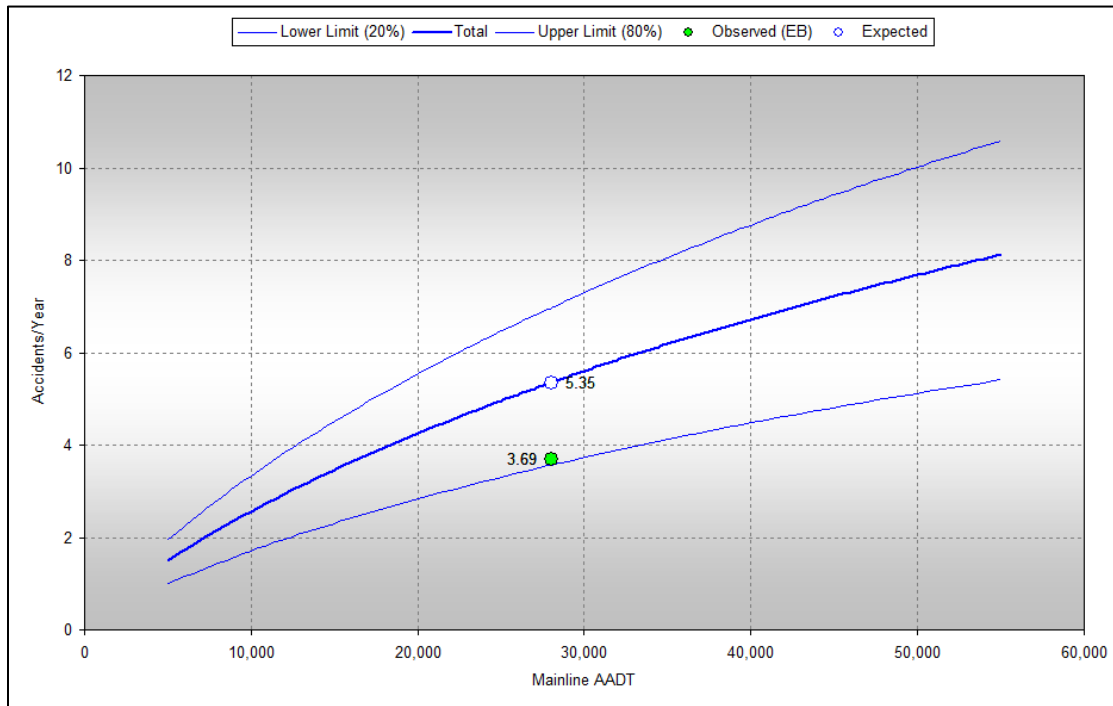


Figure 2 – SPF for Total Crashes – After/No Action After

SH 26B, MP 13.70

Before: 2008 to 2010 After: 2014 to 2016

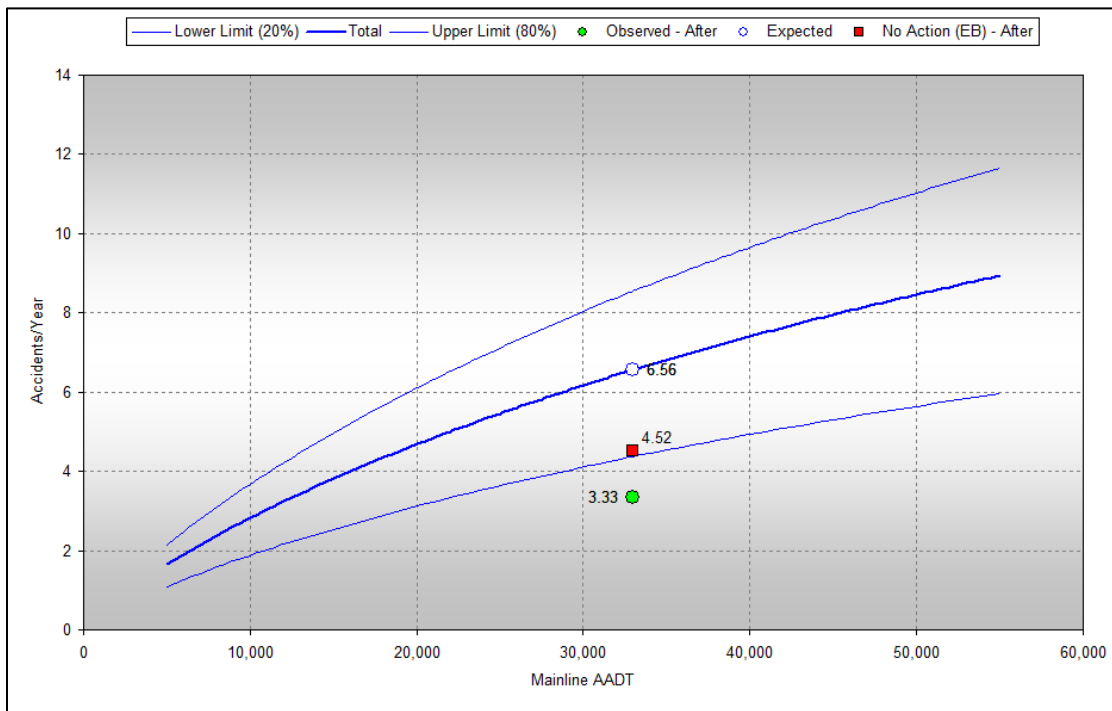


Figure 3 – SPF for Injury and Fatal Crashes – Before

SH 26B, MP 13.70

Before: 2008 to 2010 After: 2014 to 2016

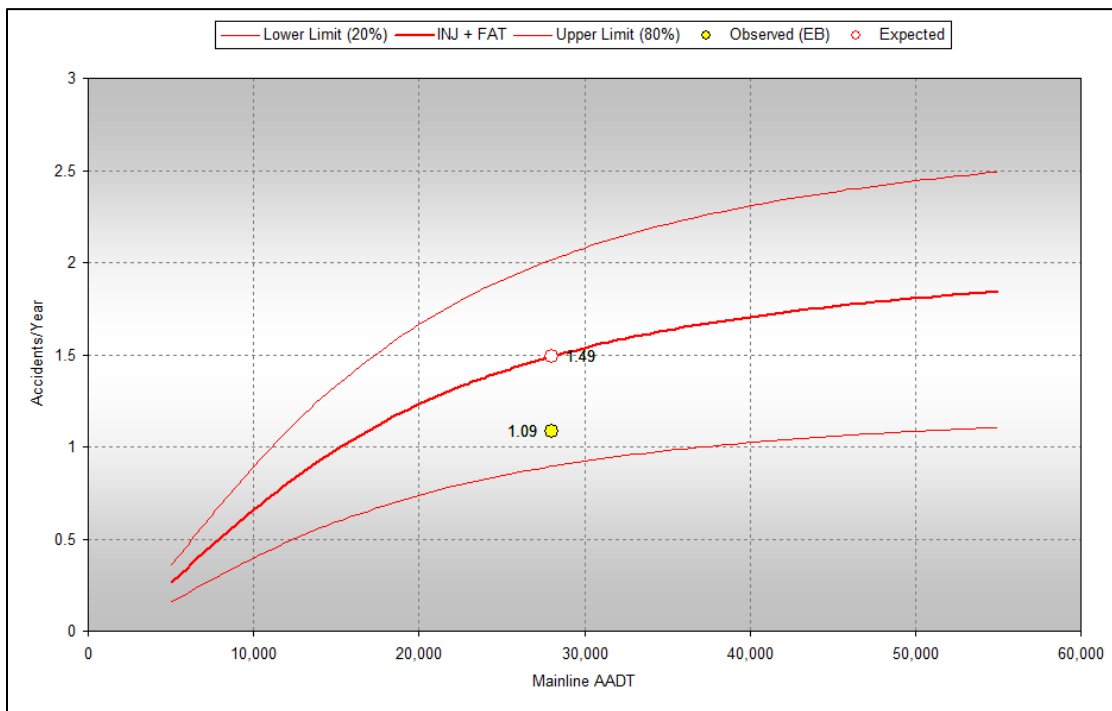


Figure 4 – SPF for Injury and Fatal Crashes – After/No Action After

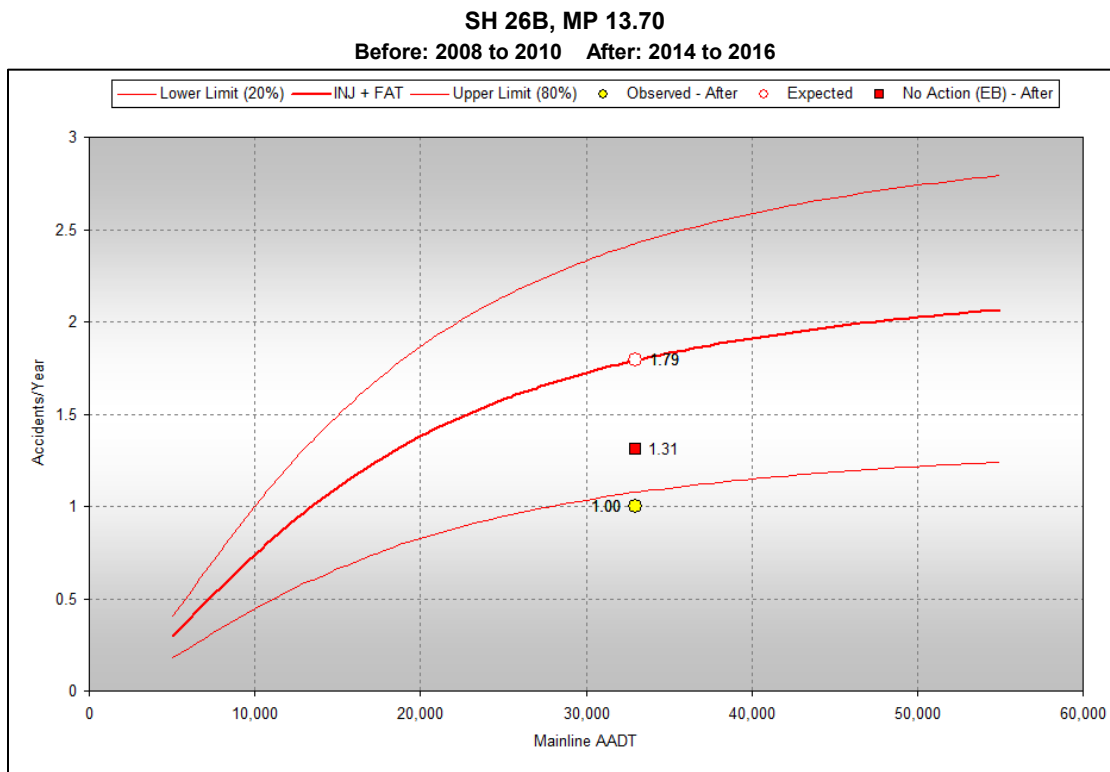


Table 2 –Safety Performance Function (SPF)

| | Before | After | No Action 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 I | LOSS II |
| CPY | 3.69 | 3.33 | 4.52 |
| Mean CPY | 5.35 | 6.56 | 6.56 |
| Proportion of Mean | 0.69 | 0.51 | 0.69 |
| Fatal & Injury Crashes: | | | |
| LOSS | LOSS II | LOSS I | LOSS II |
| CPY | 1.09 | 1.00 | 1.31 |
| Mean CPY | 1.49 | 1.79 | 1.79 |
| Proportion of Mean | 0.73 | 0.59 | 0.73 |

A more detailed review of the before and after crash record shows the crash types that were most affected by the signal upgrade. **Table 3** shows a comparison of the total crashes as well as the primary types of crashes that were most directly affected by the improvement: rear-end, broadside, and approach turn. After the signal upgrade, there was a decrease in broadside crashes. However, there was an increase in the number of rear-end and approach turn crashes after the improvement. The No-Build After crashes were estimated using the change in SH 26B


traffic volumes between the before and after period, as found in **Table 1** (increase is 18% = |1-(28,000/33,000)|).

Table 3 – Results of Crash Analyses

| | Before | After | No-Build After |
|--|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2008 to 12/31/2010 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) | 1/1/2014 to 12/31/2016 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 9 | 10 | 11 |
| Fatal (fatalities) | 0 (0) | 0 (0) | 0 (0) |
| Injury (injuries) | 2 (5) | 3 (3) | 2 (6) |
| PDO | 7 | 7 | 9 |
| % Reduction in Total (Injuries/PDO) | | 50% / 22% | |
| Rear-End – Total | 3 | 6 | 4 |
| Injury (injuries) | 0 (0) | 3 (3) | 0 (0) |
| PDO | 3 | 3 | 4 |
| % Reduction in Total (Injuries/PDO) | | NA / 25% | |
| Broadside – Total | 3 | 0 | 4 |
| Injury (injuries) | 0 (0) | 0 (0) | 0 (0) |
| PDO | 3 | 0 | 4 |
| % Reduction in Total (Injuries/PDO) | | NA / 100% | |
| Approach Turn – Total | 1 | 3 | 1 |
| Injury (injuries) | 0 (0) | 0 (0) | 0 (0) |
| PDO | 1 | 3 | 1 |
| % Reduction in Total (Injuries/PDO) | | NA / -200% | |

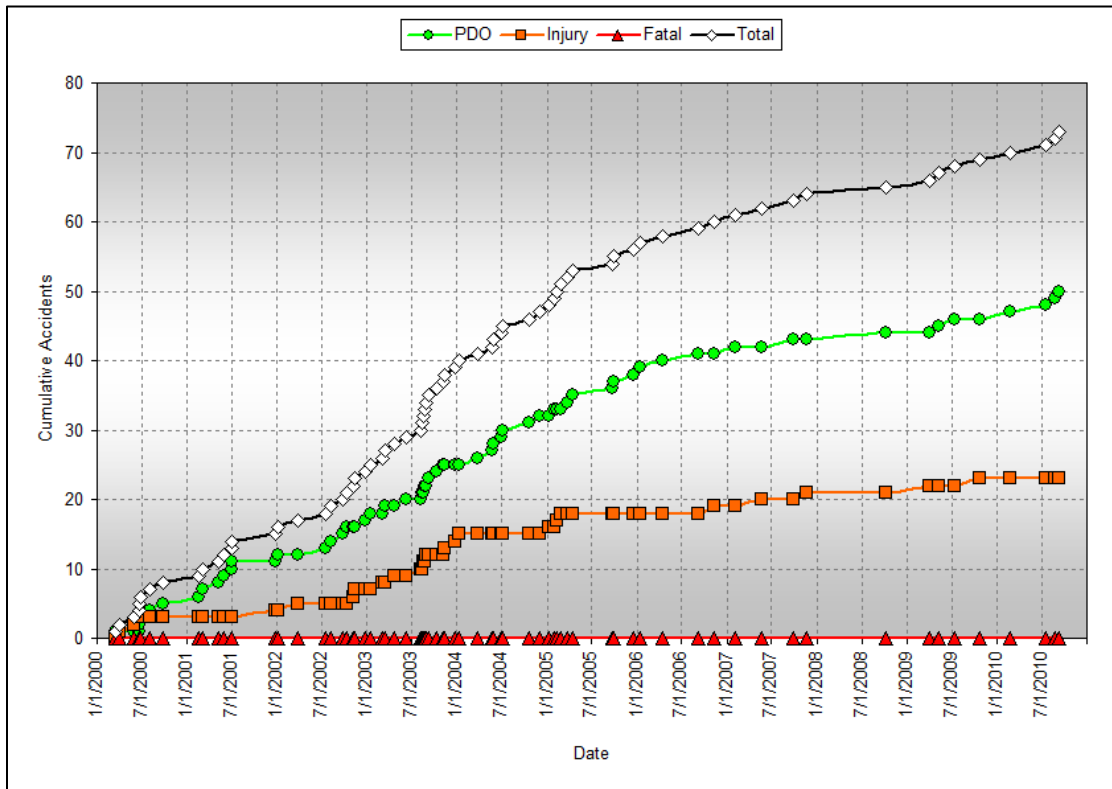
Vision Zero Suite includes benefit/cost (B/C) analyses within its procedures. The results of the B/C analysis are shown in **Figure 5** for all crashes at the intersection. **A calculated B/C ratio of 3.25 was ultimately realized.** This outcome displays that this safety improvement project was justified.

Figure 5 – Benefit Cost Analysis

|  | | Colorado Department of Transportation DiExSys™ Roadway Safety Systems Economic Analysis Report | | 03/30/2019 Job #: 20190330173439 |
|---|--|---|-------------------------------------|---|
| Location: 26B | | Begin: 13.68 | End: 13.72 | From: 01/01/2008 To: 12/31/2010 |
| <u>Benefit Cost Ratio Calculations</u> | | | | |
| <u>Crashes</u> | <u>Projected Crashes and Reduction Factors</u> | | | <u>Other Information</u> |
| PDO: 9 | Weighted PDO: 3.29 | 22% :CRF for PDO | Cost of PDO: \$ 10,400 | |
| INJ: 2 | Weighted INJ: 2.20 | 50% :CRF for INJ | Cost of INJ: \$ 98,300 | |
| FAT: 0 | Weighted FAT: 0.00 | 0% :CRF for FAT | Cost of FAT: \$ 1,724,300 | |
| | 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 | |
| Cost: \$ 274,119 | | | Annual Maintenance/Delay Cost: \$ 0 | |
| From: 01/01/2008 | Days: 1096 | | | |
| To: 12/31/2010 | | | | |
| Benefit Cost Ratio: 3.25 | | (B/C Based on Injury Numbers : PDO/Injured/Killed) | | |
| Type of Improvement: Upgrade Signal | | | | |
| Special Notes: | | | | |

It was noted that significantly fewer total crashes and broadside crashes occurred per year during the before period (2008 – 2010) than the period used in the FHEP application (2000 – 2004). Examining safety performance at this intersection over a 11-year period (2000-2010), there is an observed significant improvement in safety performance beginning in mid-2005 (**Figures 6**). It is recommended that the Region be contacted to learn what operational changes may have been made that can explain the improvement; this information would likely be extremely useful.

Figure 6 – Cumulative Crashes Over 10 Years





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

CDOT Project # 17659 03/30/2019

Exhibit 1

Job #: 20190330155603

Location: 26B **Begin: 13.68** **End: 13.72** **From:01/01/2008** **To:12/31/2010**

Severity

| | | |
|---------------|----------|------------|
| PDO: | 7 | |
| INJ: | 2 | 5 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 9 | |

Number of Vehicles

| | |
|----------------|----------|
| One Vehicle: | 0 |
| Two Vehicles: | 7 |
| Three or More: | 2 |
| 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: | 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: | 3.85 * | * MVMT |
| INJ: | 1.10 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 4.95 * | |

Crash Type

| | | | |
|-----------------------|---|-----------------------------|----------|
| Overtuning: | 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): | 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: | 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: | 9 |
| Concrete Barrier: | 0 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|---|------------------------------------|
| Mainline: | 9 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | | Left Frontage Rd (L): 0 |
| C: 0 G: 0 K: 0 | | Rt Frontage Rd (R): 0 |
| D: 0 H: 0 T: 0 | | HOV Lanes (V): 0 |
| E: 0 I: 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: 41,467 **Length: 0.04**



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

CDOT Project # 17659 03/30/2019

Exhibit 1

Job #: 20190330155603

Location: 26B **Begin: 13.68** **End: 13.72** **From:01/01/2008** **To:12/31/2010**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|----------|----------|----------|
| Passenger Car/Van: | 4 | 6 | 1 |
| 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: | 2 | 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 | 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 | 9 | 2 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|----------|----------|----------|
| Going Straight: | 7 | 5 | 2 |
| Slowing: | 0 | 0 | 0 |
| Stopped in Traffic: | 0 | 2 | 0 |
| Making Right Turn: | 0 | 1 | 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: | 1 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 9 | 9 | 2 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|----------|----------|----------|
| No Apparent Contributing Factor: | 7 | 8 | 2 |
| Asleep at the Wheel: | 0 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 1 | 1 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 1 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 9 | 9 | 2 |

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

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|----------|----------|----------|
| No Impairment Suspected: | 9 | 9 | 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: | 9 | 9 | 2 |

ADT: 41,467 **Length: 0.04**



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

CDOT Project # 17659 03/30/2019

Exhibit 2

Job #: 20190330164612

Location: 26B **Begin: 13.68** **End: 13.72** **From:01/01/2014** **To:12/31/2016**

| Severity | |
|---------------|------------|
| PDO: | 7 |
| INJ: | 3 :Injured |
| FAT: | 0 :Killed |
| Total: | 10 |

| Number of Vehicles | |
|--------------------|-----------|
| One Vehicle: | 1 |
| Two Vehicles: | 6 |
| Three or More: | 3 |
| 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: | 7 |
| Dawn or Dusk: | 1 |
| Dark - Lighted: | 2 |
| Dark - Unlighted: | 0 |
| 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: | 4.99* * MVMT |
| INJ: | 2.14* ** 100 MVMT |
| FAT: | 0.00** |
| Total: | 7.13* |

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

| Mainline/Ramps/Frontage Roads | |
|-------------------------------|-----------|
| Mainline: | 10 |
| Crossroad (A): | 0 |
| Total: | 10 |
| Frontage/Ramp Intersections | |
| M: | 0 |
| N: | 0 |
| O: | 0 |
| P: | 0 |
| Total: | 10 |
| Ramps | |
| B: | 0 |
| C: | 0 |
| D: | 0 |
| E: | 0 |
| F: | 0 |
| G: | 0 |
| H: | 0 |
| I: | 0 |
| J: | 0 |
| K: | 0 |
| L: | 0 |
| T: | 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: | 9 |
| 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: | 10 |

ADT: 32,000 **Length: 0.04**



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

CDOT Project # 17659 03/30/2019

Exhibit 2

Job #: 20190330164612

Location: 26B **Begin: 13.68** **End: 13.72** **From:01/01/2014** **To:12/31/2016**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|----------|----------|
| Passenger Car/Van: | 4 | 6 | 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: | 4 | 2 | 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: | 10 | 9 | 3 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|----------|----------|
| Going Straight: | 5 | 5 | 1 |
| Slowing: | 1 | 0 | 0 |
| Stopped in Traffic: | 1 | 4 | 2 |
| Making Right Turn: | 0 | 0 | 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: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 10 | 9 | 3 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|----------|----------|
| No Apparent Contributing Factor: | 3 | 9 | 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: | 2 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 5 | 0 | 0 |
| Total: | 10 | 9 | 3 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|----------|----------|
| North: | 0 | 0 | 0 |
| Northeast: | 0 | 0 | 0 |
| East: | 6 | 6 | 2 |
| Southeast: | 0 | 0 | 0 |
| South: | 1 | 1 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 3 | 2 | 1 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 10 | 9 | 3 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|----------|----------|
| No Impairment Suspected: | 9 | 9 | 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: | 10 | 9 | 3 |

ADT: 32,000 **Length: 0.04**

Project Information

| | | |
|-----------------------------|---|------------------------------------|
| Project Name: | I 25 Through Pueblo | |
| Project Description: | Surface Treatment and Safety Improvements | |
| CDOT Region: 2 | <u>Project Def:</u> 17746 | <u>County:</u> Pueblo |
| Location: I 25 | <u>Mile Points:</u> 96.36 to 97.25 | <u>Length:</u> 0.89 Mile |
| Schedule: | <u>Work Start Date:</u> 6/28/2010 | <u>Completion Date:</u> 11/10/2011 |

Problem Description: The crash history from VZS for the evaluation period of 1999 to 2005 showed 9 northbound off-road to the right crashes within three sub-sections of this stretch of I-25 in Pueblo. Those crashes included 5 injury crashes with 6 people injured. Specifically, these sections are:

- MP 96.36 to 96.47
- MP 96.80 to 96.94
- MP 97.18 to 97.25

Improvement Description: Between June 28, 2010 and November 10, 2011 guardrail was installed on northbound I-25 in proximity to those sections identified in the study. However, the exact locations differed. The observed installations locations are:

- MP 96.35 to 96.38
- MP 96.80 to 96.99
- MP 97.05 to 97.19

The cost of the guardrail construction was \$230,000.

The FHEP application anticipated that off-road to the right crashes would be impacted by this improvement within the guardrail extents. It was anticipated that there would be a 40% reduction in injury crashes of this type. No reduction was expected for property damage only crashes, and although a 60% reduction factor was shown for fatal crashes, there were no such crashes in the evaluation period.

Summary and Findings

We examined the relevant crash history for the 5-year period prior to construction (2005-2009) and for the 5-year period immediately following the construction (2012-2016) to assess the effectiveness of the improvement. We filtered for northbound, off-right only crashes to capture the effect of guardrail deployment.

Since the presence of guardrail can modify driving behavior it is meaningful to evaluate the crash history not only within the precise guardrail limits, but for a short distance before and beyond the rail placement. Additionally, the precision with which crashes locations are reported may only be accurate to within a few hundred feet. Accordingly, the limits we have chosen for the crash evaluation will be 0.05 miles before and after the actual limits of the guardrail installation. Since the gap between the last two sections of guardrail is only 0.06 mile, the three sections of guardrail are contained within two sets of limits. Those limits are:

- MP 96.30 to 96.43
- MP 96.75 to 97.24

The analysis of safety performance before and after the installation of the three sections of guardrail showed no change in the total number of crashes in the affected crash type, with 5 crashes in both periods. However the number of injury related crashes decreased from 3 to 1 from the before period to the after period. Of the 5 crashes in the after period, 3 of them were guardrail crashes. All crashes in both time frames were fixed object or other object crashes. The upgrades have likely contributed to the reduction in the severity of crashes in the stretch. The \$230,000 construction project appears to have been cost effective from the safety standpoint with resulting benefit to cost ratio of **2.63**.

Results of Safety Analyses

Using VZS, the review of before and after crash records showed the number of crashes was unchanged between the two study periods. The total number of crashes was 5 during the five-year period (2005 to 2009) before the guardrail upgrades and 5 during the five-year after period (2012 to 2016) (see **Table 1**). The number of severe crashes decreased in the five-year period after the improvements from 3 to 1. There were no fatal crashes in either period.

- Before (2005 – 2009) – 3 injury crashes with 3 people injured and 0 fatalities
- After (2012 – 2016) – 1 injury crash with 1 person injured and 0 fatalities

With an 8% decrease in traffic volumes recorded for the segment, the total crash rate for the relevant crash type shows a slight increase. To estimate crash rates, we divided the number crashes by the average AADT for the period by 0.5 to account for the directional selectivity, multiplied by the total distance of 0.62 miles that we are examining, and the number of days in the period.

- Before (2005 – 2009): 0.198 crashes per million vehicles miles travelled (Mvmt)
- After (2012 – 2016): 0.215 per Mvmt

Table 1 - 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 (I-25) | 44,669 | 41,089 |
| Filters: | Northbound Mainline Off Right | Northbound Mainline Off Right |
| Total Crashes | 5 | 5 |
| Fatal Crashes (Fatalities) | 0 | 0 |
| Injury Crashes (Injuries) | 3 (3) | 1 (1) |
| Property Damage Only | 2 | 4 |
| Crash Types: # (%) | | |
| Fixed Object | 5 (100%) | 4 (80%) |

The magnitude of safety problems on select highway sections and intersections can often be assessed through the use of Safety Performance Function (SPF) methodology. However, it is not as feasible to derive meaningful SPF relationships for cases like this one where we are observing only a small subset of crashes that occurred in a single direction, because the predictive functions were developed using the entire traffic volumes and all crashes for the locations under consideration. Therefore we will dispense with SPF analyses for this report and focus on crash numbers, crash rates and benefit to cost analysis.

A more detailed review of the before and after crash record shows the crash types that were most affected by the guardrail upgrade for northbound I-25. **Table 2** shows a comparison of the total crashes, which all involved striking objects, as well as a breakdown of guardrail and non-guardrail objects. The guardrail upgrade appears to have reduced the number of crashes with objects other than guardrail, and in so doing, also reduced the percentage of crashes involving injury from 60% to 20% of all crashes. The No Build After crashes were estimated using the change in I-25 traffic volumes between the before and after period, as found in **Table 1** (decrease is $0.919 = 41,089/44,669$). Because the total number of crashes is small and the multiplication factor for the traffic volume change is close to 1, the projected numbers did not change from the before period numbers.

Table 2 – Results of Crash Analyses

| | Before | After | No Build After |
|--|-----------------------------------|-----------------------------------|-----------------------------------|
| Time Period: | 1/1/2003 to 12/31/2007 (3 yr.) | 1/1/2010 to 12/31/2014 (3 yr.) | 1/1/2010 to 12/31/2014 (3 yr.) |
| Crash Types: | | | |
| Total Crashes | 5 | 5 | 5 |
| Fatal (fatalities) | 0 | 0 | 0 |
| Injury (injuries) | 3 (3) | 1 (1) | 3 (3) |
| PDO | 2 | 4 | 2 |
| % Reduction in Total (Injuries/PDO) | | 0% (67% / -100%) | |
| Non Guardrail Objects – Total | 4 | 2 | 4 |
| Injury (injuries) | 2 (2) | 0 (0) | 2 (2) |
| PDO | 2 | 2 | 2 |
| % Reduction in Total (Injuries/PDO) | | 50% (50%/100%) | |
| Guardrail - Total | 1 | 3 | 1 |
| Injury (injuries) | 1 (1) | 1 (1) | 1 (1) |
| PDO | 0 | 2 | 0 |
| % Reduction in Total (Injuries/PDO) | | 40% (100%/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 stretches of I-25 within 0.05 mile of the guardrail upgrades. The analysis is based on the reduction of the number of people injured in personal injury crashes. As shown, using the \$230,000 project cost as the cost basis, the safety

related B/C ratio for the improvement is 2.63, showing that the improvement appears to have been cost effective from the safety standpoint.

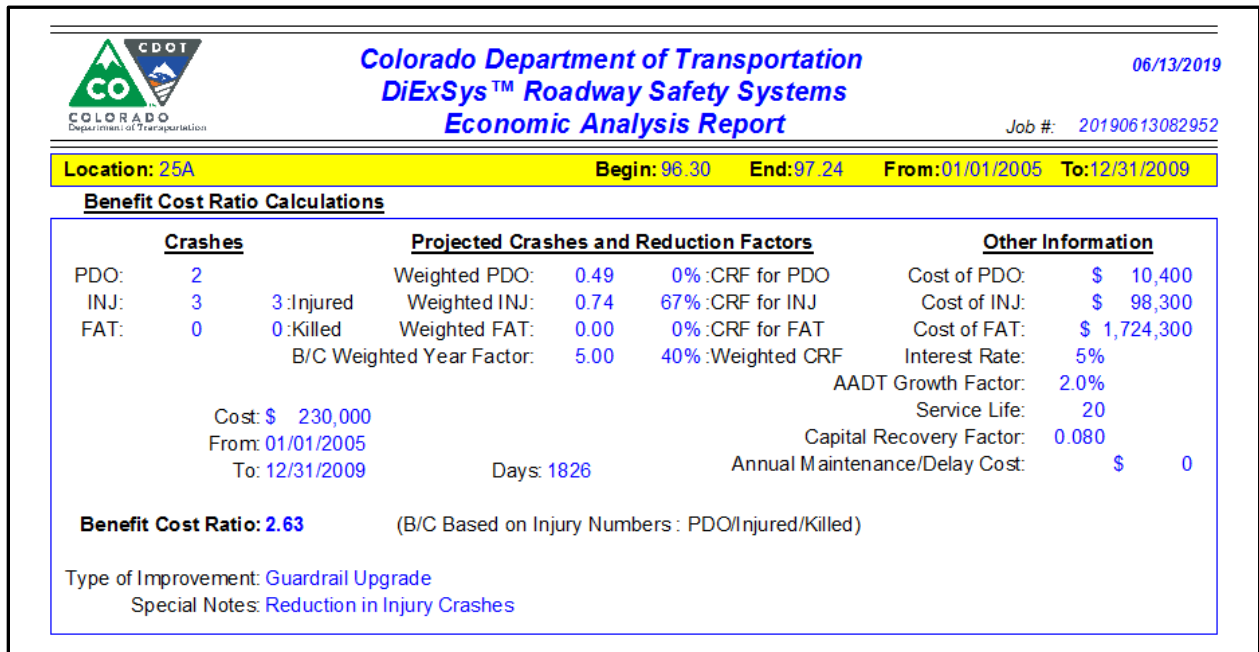


Figure 3 – Benefit Cost Analysis – Reduction in Injury Crashes Only

Figures 4 and 5 show the location of the relevant northbound crashes in the before and after periods respectively.

Figure 4 – Northbound Crashes in Before Period (2005-2009)

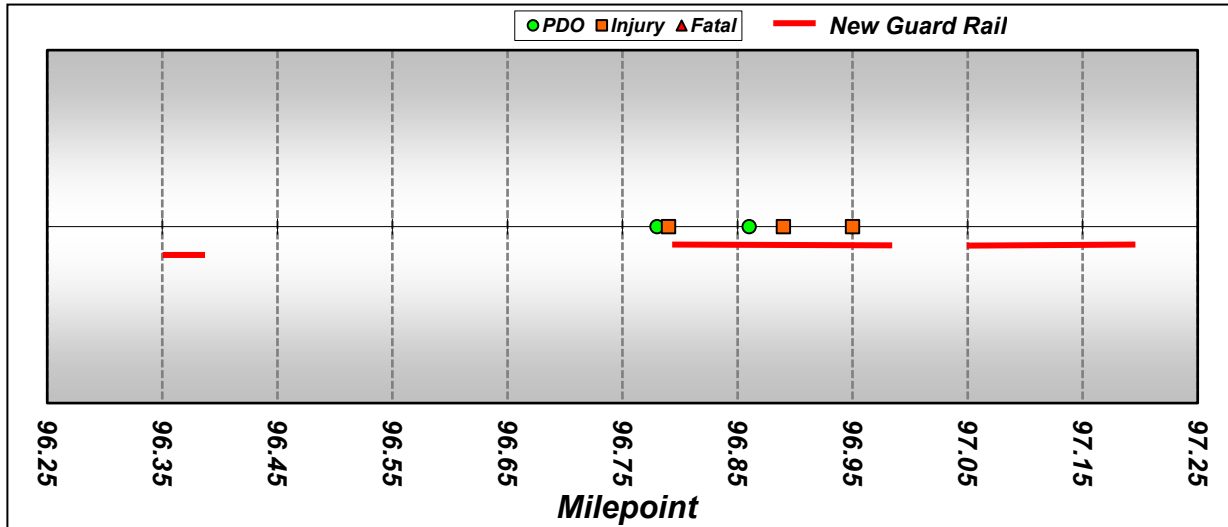
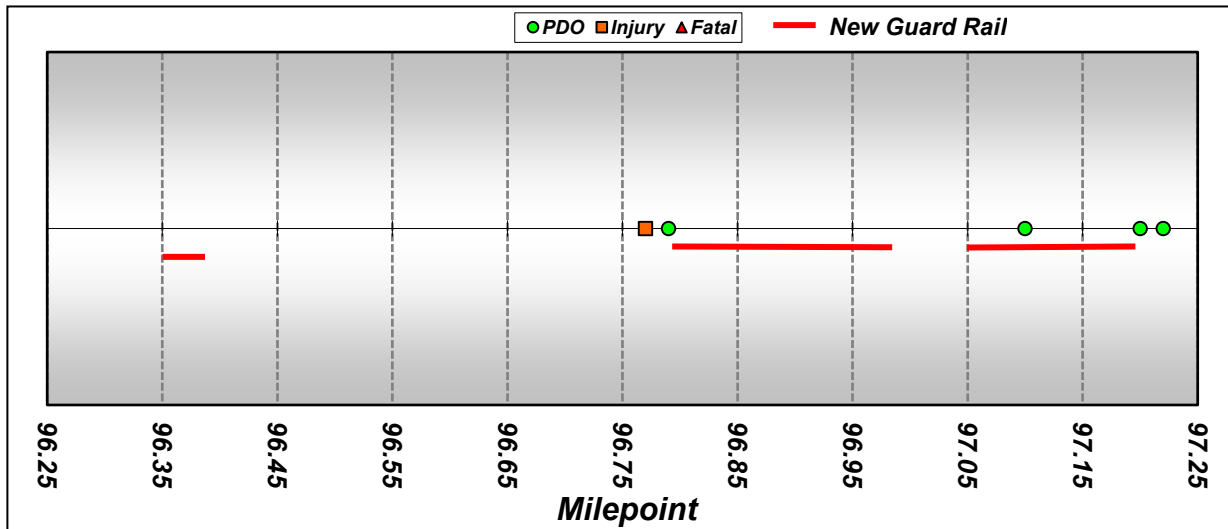


Figure 5 – Northbound Crashes in Before Period (2005-2009)





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

CDOT Project #17746 06/17/2019
Exhibit 1

Job #: 20190617121532

Location: 25A **Begin: 96.36** **End: 97.25** **From:01/01/2005** **To:12/31/2009**

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 45 | |
| INJ: | 22 | 27 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 67 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 42 |
| Two Vehicles: | 23 |
| Three or More: | 2 |
| Unknown: | 0 |
| Total: | 67 |

Location

| | |
|------------------|-----------|
| On Road: | 29 |
| Off Road Left: | 25 |
| Off Road Right: | 13 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 67 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 42 |
| Dawn or Dusk: | 2 |
| Dark - Lighted: | 21 |
| Dark - Unlighted: | 1 |
| Unknown: | 1 |
| Total: | 67 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 55 |
| Rain: | 5 |
| Snow/Sleet/Hail: | 7 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 0 |
| Unknown: | 0 |
| Total: | 67 |

Crash Rates

| | | |
|---------------|---------------|-------------|
| PDO: | 0.67 * | * MVMT |
| INJ: | 0.33 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 1.00 * | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 1 | Bridge Abutment: | 0 |
| Other Non Collision: | 3 | Column/Pier: | 0 |
| Pedestrians: | 0 | Culvert/Headwall: | 0 |
| Broadside: | 0 | Embankment: | 0 |
| Head On: | 0 | Curb: | 1 |
| Rear End: | 15 | Delineator Post: | 0 |
| Sideswipe (Same): | 6 | Fence: | 3 |
| 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: | 38 |
| Wild Animal: | 1 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 3 | Vehicle Cargo/Debris: | 0 |
| Traffic Signal Pole: | 0 | Road Maintenance Equipment: | 0 |
| Sign: | 4 | Involving Other Object: | 3 |
| Bridge Rail: | 0 | Total Other Objects: | 3 |
| Guard Rail: | 3 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 67 |
| Concrete Barrier: | 24 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|-----------------------|------------------------------------|
| Mainline: | 67 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | Left Frontage Rd (L): | 0 |
| C: 0 G: 0 K: 0 | Rt Frontage Rd (R): | 0 |
| D: 0 H: 0 T: 0 | HOV Lanes (V): | 0 |
| E: 0 I: 0 | Unknown: | 0 |
| | Total: | 67 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 67 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 67 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 53 |
| Wet: | 7 |
| 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: | 1 |
| Total: | 67 |

ADT: 44,911 **Length: 0.81**



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

CDOT Project #17746 06/17/2019
Exhibit 1

Job #: 20190617121532

Location: 25A **Begin: 96.36** **End: 97.25** **From:01/01/2005** **To:12/31/2009**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 47 | 11 | 1 |
| Passenger Car/Van w/Trl: | 1 | 0 | 0 |
| Pickup Truck/Utility Van: | 9 | 7 | 0 |
| Pickup Truck/Utility Van w/Trl: | 3 | 0 | 0 |
| SUV: | 4 | 5 | 0 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 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: | 0 | 0 | 0 |
| Other: | 0 | 1 | 0 |
| Unknown: | 0 | 0 | 1 |
| Total: | 67 | 25 | 2 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 43 | 10 | 1 |
| Slowing: | 0 | 9 | 0 |
| Stopped in Traffic: | 0 | 4 | 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: | 1 | 0 | 0 |
| Starting in Traffic: | 0 | 0 | 0 |
| Parked: | 0 | 0 | 0 |
| Changing Lanes: | 4 | 0 | 0 |
| Avoiding Object/Veh in Road: | 3 | 0 | 0 |
| Weaving: | 1 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 15 | 2 | 0 |
| Unknown: | 0 | 0 | 1 |
| Total: | 67 | 25 | 2 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 38 | 23 | 1 |
| Asleep at the Wheel: | 1 | 0 | 0 |
| Illness: | 1 | 0 | 0 |
| Distracted by Passenger: | 1 | 0 | 0 |
| Driver Inexperience: | 8 | 0 | 0 |
| Driver Fatigue: | 0 | 0 | 0 |
| Driver Preoccupied: | 4 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 14 | 2 | 1 |
| Total: | 67 | 25 | 2 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 67 | 24 | 1 |
| Northeast: | 0 | 0 | 0 |
| East: | 0 | 0 | 0 |
| Southeast: | 0 | 0 | 0 |
| South: | 0 | 1 | 0 |
| Southwest: | 0 | 0 | 0 |
| West: | 0 | 0 | 0 |
| Northwest: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 1 |
| Total: | 67 | 25 | 2 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 60 | 25 | 2 |
| 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: | 67 | 25 | 2 |

ADT: 44,911 **Length: 0.81**



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

CDOT Project #17746 06/17/2019
Exhibit 2

Job #: 20190617121358

Location: 25A **Begin: 96.36** **End: 97.25** **From:01/01/2012** **To:12/31/2016**

Severity

| | | |
|---------------|-----------|-------------|
| PDO: | 46 | |
| INJ: | 19 | 28 :Injured |
| FAT: | 0 | 0 :Killed |
| Total: | 65 | |

Number of Vehicles

| | |
|----------------|-----------|
| One Vehicle: | 40 |
| Two Vehicles: | 24 |
| Three or More: | 1 |
| Unknown: | 0 |
| Total: | 65 |

Location

| | |
|------------------|-----------|
| On Road: | 25 |
| Off Road Left: | 26 |
| Off Road Right: | 14 |
| Off Road at Tee: | 0 |
| Off in Median: | 0 |
| Unknown: | 0 |
| Total: | 65 |

Lighting Conditions

| | |
|-------------------|-----------|
| Daylight: | 45 |
| Dawn or Dusk: | 3 |
| Dark - Lighted: | 16 |
| Dark - Unlighted: | 1 |
| Unknown: | 0 |
| Total: | 65 |

Weather Conditions

| | |
|------------------|-----------|
| None: | 50 |
| Rain: | 6 |
| Snow/Sleet/Hail: | 8 |
| Fog: | 0 |
| Dust: | 0 |
| Wind: | 1 |
| Unknown: | 0 |
| Total: | 65 |

Crash Rates

| | | |
|---------------|---------------|-------------|
| PDO: | 0.61 * | * MVMT |
| INJ: | 0.25 * | ** 100 MVMT |
| FAT: | 0.00 ** | |
| Total: | 0.87 * | |

Crash Type

| | | | |
|-----------------------|----|-----------------------------|-----------|
| Overtuning: | 4 | 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: | 12 | Delineator Post: | 0 |
| Sideswipe (Same): | 10 | Fence: | 0 |
| Sideswipe (Opposite): | 0 | Tree: | 0 |
| Approach Turn: | 0 | Large Boulders or Rocks: | 0 |
| Overtaking Turn: | 0 | Barricade: | 1 |
| Parked Motor Vehicle: | 0 | Wall/Building: | 0 |
| Railway Vehicle: | 0 | Crash Cushion: | 0 |
| Bicycle: | 0 | Mailbox: | 0 |
| Motorized Bicycle: | 0 | Other Fixed Object: | 0 |
| Domestic Animal: | 0 | Total Fixed Objects: | 38 |
| Wild Animal: | 0 | Rocks in Roadway: | 0 |
| Light/Utility Pole: | 1 | Vehicle Cargo/Debris: | 0 |
| Traffic Signal Pole: | 0 | Road Maintenance Equipment: | 0 |
| Sign: | 1 | Involving Other Object: | 1 |
| Bridge Rail: | 0 | Total Other Objects: | 1 |
| Guard Rail: | 9 | Unknown: | 0 |
| Cable Rail: | 0 | Total: | 65 |
| Concrete Barrier: | 26 | | |

Mainline/Ramps/Frontage Roads

| | | |
|----------------|----|------------------------------------|
| Mainline: | 65 | Frontage/Ramp Intersections |
| Crossroad (A): | 0 | M: 0 N: 0 O: 0 P: 0 |
| Ramps | | |
| B: 0 F: 0 J: 0 | | Left Frontage Rd (L): 0 |
| C: 0 G: 0 K: 0 | | Rt Frontage Rd (R): 0 |
| D: 0 H: 0 T: 0 | | HOV Lanes (V): 0 |
| E: 0 I: 0 | | Unknown: 0 |
| | | Total: 65 |

Road Description

| | |
|-----------------------|-----------|
| At Intersection: | 0 |
| At Driveway Access: | 0 |
| Intersection Related: | 0 |
| Non Intersection: | 65 |
| In Alley: | 0 |
| Roundabout: | 0 |
| Ramp: | 0 |
| Parking Lot: | 0 |
| Unknown: | 0 |
| Total: | 65 |

Road Conditions

| | |
|------------------------------|-----------|
| Dry: | 43 |
| Wet: | 9 |
| Muddy: | 0 |
| Snowy: | 0 |
| 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: | 0 |
| Icy w/Icy Road Treatment: | 1 |
| Slushy w/Icy Road Treatment: | 1 |
| Unknown: | 0 |
| Total: | 65 |

ADT: 41,177 **Length: 0.99**



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

CDOT Project #17746 06/17/2019
 Exhibit 2

Job #: 20190617121358

Location: 25A **Begin: 96.36** **End: 97.25** **From:01/01/2012** **To:12/31/2016**

| Vehicle Type | Veh 1 | Veh 2 | Veh 3 |
|-----------------------------------|-----------|-----------|----------|
| Passenger Car/Van: | 43 | 13 | 0 |
| Passenger Car/Van w/Trl: | 0 | 0 | 0 |
| Pickup Truck/Utility Van: | 4 | 4 | 0 |
| Pickup Truck/Utility Van w/Trl: | 1 | 0 | 0 |
| SUV: | 5 | 4 | 1 |
| SUV w/Trl: | 0 | 0 | 0 |
| Truck 10k lbs or Less: | 0 | 0 | 0 |
| Trucks > 10k lbs/Bus > 15 People: | 6 | 2 | 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: | 5 | 0 | 0 |
| Other: | 0 | 1 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 65 | 25 | 1 |

| Vehicle Movement | Veh 1 | Veh 2 | Veh 3 |
|------------------------------|-----------|-----------|----------|
| Going Straight: | 29 | 16 | 1 |
| Slowing: | 0 | 4 | 0 |
| Stopped in Traffic: | 0 | 5 | 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: | 14 | 0 | 0 |
| Avoiding Object/Veh in Road: | 0 | 0 | 0 |
| Weaving: | 0 | 0 | 0 |
| Wrong Way: | 0 | 0 | 0 |
| Other: | 22 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 65 | 25 | 1 |

| Contributing Factor | Veh 1 | Veh 2 | Veh 3 |
|----------------------------------|-----------|-----------|----------|
| No Apparent Contributing Factor: | 40 | 22 | 0 |
| Asleep at the Wheel: | 1 | 0 | 0 |
| Illness: | 0 | 0 | 0 |
| Distracted by Passenger: | 0 | 0 | 0 |
| Driver Inexperience: | 10 | 0 | 0 |
| Driver Fatigue: | 1 | 0 | 0 |
| Driver Preoccupied: | 2 | 0 | 0 |
| Driver Unfamiliar with Area: | 0 | 0 | 0 |
| Driver Emotionally Upset: | 0 | 0 | 0 |
| Evading Law Enforcement Officer: | 0 | 0 | 0 |
| Physical Disability: | 0 | 0 | 0 |
| Unknown: | 11 | 3 | 1 |
| Total: | 65 | 25 | 1 |

| Direction | Veh 1 | Veh 2 | Veh 3 |
|---------------|-----------|-----------|----------|
| North: | 64 | 25 | 1 |
| 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: | 1 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 65 | 25 | 1 |

| Condition of Driver | Veh 1 | Veh 2 | Veh 3 |
|------------------------------------|-----------|-----------|----------|
| No Impairment Suspected: | 61 | 25 | 1 |
| Alcohol Involved: | 4 | 0 | 0 |
| RX, Medication, or Drugs Involved: | 0 | 0 | 0 |
| Illegal Drugs Involved: | 0 | 0 | 0 |
| Alcohol and Drugs Involved: | 0 | 0 | 0 |
| Driver/Pedestrian not Observed: | 0 | 0 | 0 |
| Unknown: | 0 | 0 | 0 |
| Total: | 65 | 25 | 1 |

ADT: 41,177 **Length: 0.99**

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) method¹. 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 Hauer², 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.

Plotting Criteria

Plot Multiple Points # Points:

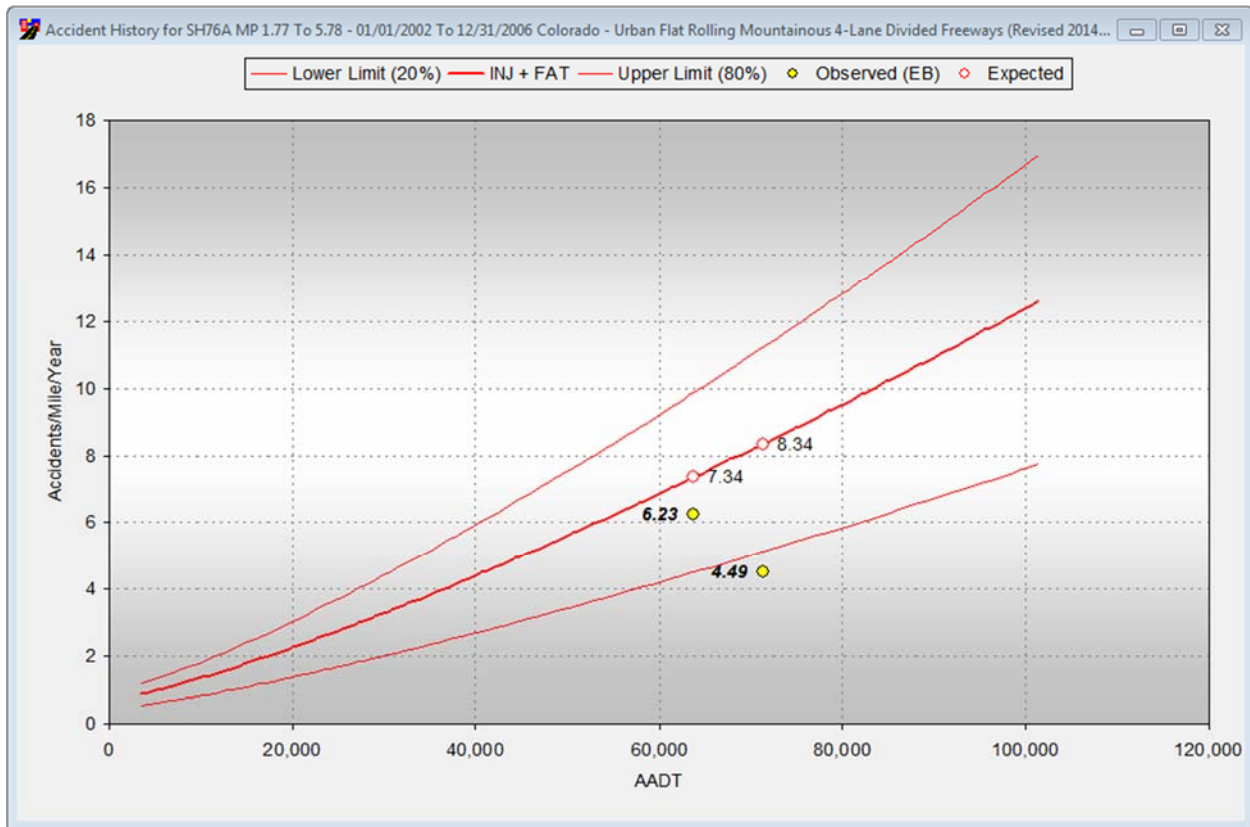
Reset Plot Multiple Points to Zero

Gamma Dist/EB Correction/Dispersion

Upper Limit: EB Correction

Lower Limit: Dispersion = 0.2060

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

$\mu = 7.33 \frac{\text{crash}}{\text{mi}}$ 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 $1/\alpha = 1/0.205 = 4.88$) and Beta = μ/b (here $7.33/4.88 = 1.502$)

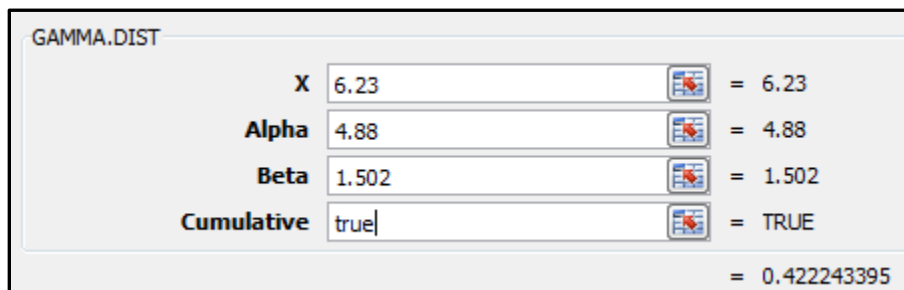


Figure 4 Cumulative Probability of Gamma Function in Excel

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 $\mu = 8.34 \frac{\text{crash}}{\text{mi}}$ 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 $7.09 \frac{\text{crash}}{\text{mi}}$ per year.

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

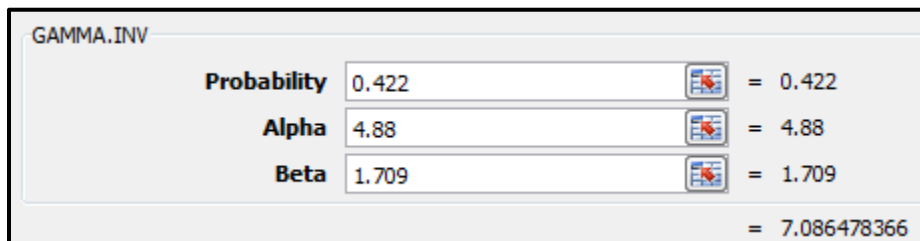
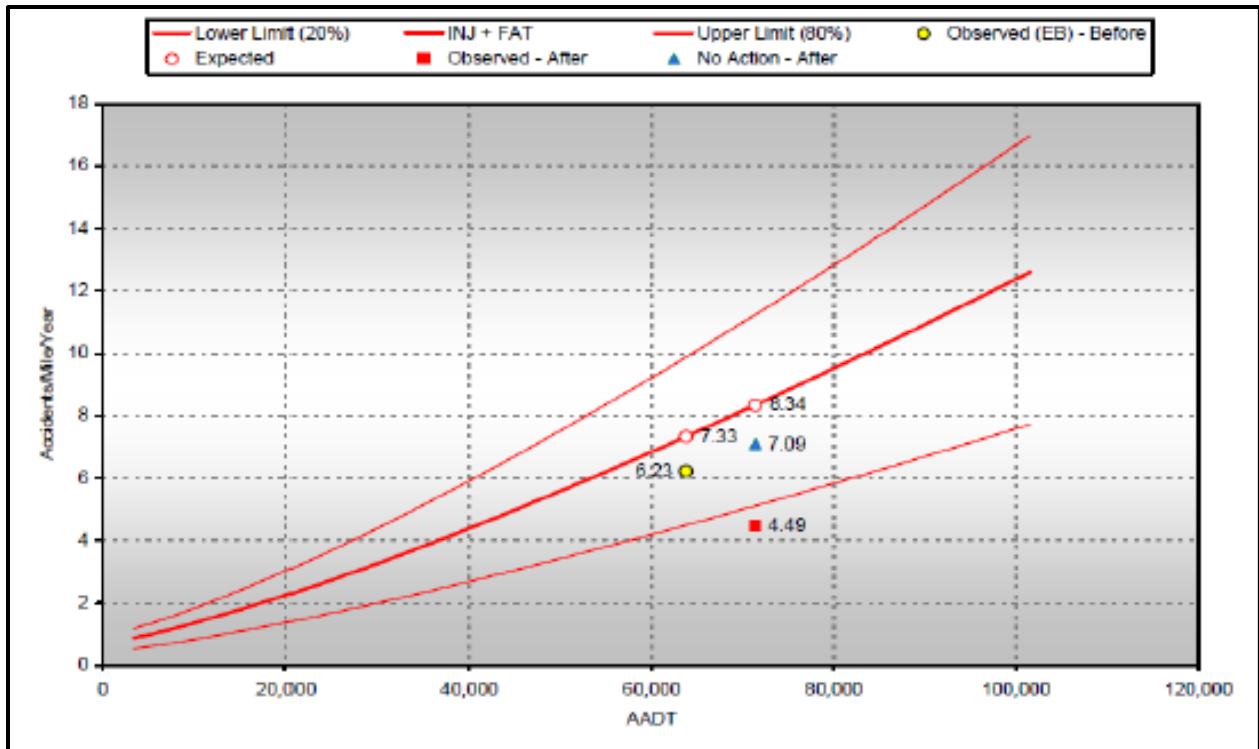


Figure 5 Inverse Gamma Function for a Specified Percentile in Excel

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 Factors³. 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) = $N_{\text{obs.C.A}} / N_{\text{obs.C.B}}$. It indicates how crash counts are expected to change in the absence of treatment. In this case $CR = 80/84 = 0.9524$

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

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

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

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

CMF = Crash Modification Factor

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

$\text{Var}(CMF)$ = variance of the CMF

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

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

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 $N_{\text{exp. TA}}$ 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) method⁴. 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 $N_{\text{pred,B}} = N_{\text{pred,A}}$ (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, $N_{\text{exp}, T, B}$, is computed as:

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

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

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

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

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

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

$$\text{Var}(\text{CMF}) = \frac{\text{CMF}^2 [(1/N_{\text{obs}, T, A}) + (\text{Var}(N_{\text{exp}, T, A}) / N_{\text{exp}, T, A}^2)]}{[1 + \text{Var}(N_{\text{exp}, T, A}) / N_{\text{exp}, T, A}^2]^2} = \frac{0.677^2 [(1/65) + (71.45) / (95.27^2)]}{[1 + (71.45) / (95.27^2)]^2} = 0.0104$$

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

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.